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STATE OF AQUACULTURE REPORT IN KENYA 2021

TOWARDS NUTRITION SENSITIVE FISH FOOD PRODUCTION SYSTEMS

EDITORS :

JONATHAN MUNGUTI, KEVIN OBIERO, PAUL ORINA, DAVID MIRERA, JAMES MWALUMA, DOMITILA KYULE, SAFINA MUSA, MARY OPIYO, JACOB OCHIEWO, ERICK OGELLO, JAMES NJIRU, ATSUSHI HAGIWARA


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EDITORS

Jonathan Munguti, Kevin Obiero, Paul Orina, David Mirera, James Mwaluma, Domitila Kyule, Safina Musa,Mary Opiyo, Jacob Ochiewo, Erick Ogello, James Njiru, Atsushi Hagiwara

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The Director General
Kenya Marine and Fisheries Research Institute
P.O. Box 81651–80100
MOMBASA, KENYA
Telephone: +254 41 475151/2/3/4/5
FAX: 254 41 475157
E-mail: director@kmfri.co.ke
Website: http://www.kmfri.co.keMOMBASA, KENYA
Telephone: +254 41 475151/2/3/4/5
FAX: 254 41 475157
E-mail: director@kmfri.co.ke

Website: http://www.kmfri.co.ke

FOREWORD

Blue foods – fish, invertebrates, algae and aquatic plants captured or cultured in freshwater and marine ecosystems – play a central role in food and nutrition security for billions of people and are a cornerstone of the livelihoods, economies, and cultures of many rural communities. Given its health benefits, prospects for substantial expansion, and potential for a relatively small environmental footprint, aquaculture is promising source of protein in the future. However, the COVID-19 pandemic has upended food systems in Kenya and beyond, leading to lost livelihoods, food insecurity, and rising poverty. The COVID-19 pandemic and subsequent lock-downs are creating health and economic crises, leading to increasing incidence of poverty and a looming food crisis. The food system has been seriously disrupted with impacts occurring at multiple levels and across supply chains.

To capitalize on the potential of blue foods, decision makers must address significant challenges. Although aquaculture is becoming increasingly sustainable, the availability of aquaculture inputs—land, freshwater, feed, energy— is limited, and will likely become even more so in the future. Given the increasing scarcity of water, land and other aquaculture resources, adoption and upscaling of climate smart aquaculture technologies, innovations and management practices will be the key to maintaining the required growth of aquaculture to meet the increasing demand for fish in Kenya and beyond.

Kenya has made remarkable progress in promoting aquaculture. In the past 20 years, fish farming in Kenya has evolved from playing a relatively minor role to become more integrated into the national fish food system. Three main patterns of aquaculture development have characterized the sector as it grows: continued growth in the volume and value chains of fresh water aquaculture; advances in feed processing technology and formulations; and, fish breeding and genetics, particularly for freshwater species such as Nile tilapia and African catfish. In rural populations, aquaculture, is often undertaken as a secondary source of income. Thus, the role of fish farming has increased exponentially, with many agricultural farmers integrating fish into their production systems leading to increased land and yield productivity.

KMFRI's aquaculture research focuses on generating and disseminating scientific information to progressively enhance sustainable production through innovative technologies and best management practices in key thematic areas: (a) innovative culture systems, (b) breeding of fast-growing culture species, (c) fish feed processing and formulation, (d) fish health management and biosecurity, and (e) post-harvest loss reduction, value addition and marketing. Furthermore, in an effort to exploit the vast blue economy space for socio-economic development, KMFRI is spearheading research in marine organisms including; seaweed, finfish (milkfish, mullets, marine tilapia, rabbit fish, ornamental fish) and crustaceans (mud crabs, Artemia and prawns).

This State of Aquaculture Book is a timely and useful review of a critical sector for the food security and livelihoods of millions of people in Kenya. The book comprehensively describes the main aquaculture practices, feed formulation and feeding techniques, fish seed industry, disease pathology and related control techniques, and proposes development strategies for sustainable development of the sector.

I am happy to note these research efforts are already improving food security and nutrition outcomes of rural communities through viable commercial ventures. I would like to congratulate the editorial team and contributing authors their great work and hard effort, and to extend my lofty respect to them. I would also like to express my heartfelt congratulations to the team for the publication of the book.

Hon John Safari Mumba
Chairman, Board of Management

PREFACE

This book reviews the current state of knowledge of inland aquaculture and mariculture in Kenya. The book aims to highlight challenges and opportunities in Kenya's aquaculture sector, and contributes to information sharing and capacity building for better management and sustainable use of the country's aquatic resources.

Building on a unique set of information sources, this book presents a broad view of the current state of knowledge on governance, livelihoods, production and supply chains across two of aquaculture sub-sectors i.e., freshwater aquaculture and mariculture. For the aquaculture industry to be transformed and upgraded, there is need to upscale modern technologies, innovations and management practices (TIMPs) to realize sustainable development envisaged in the SDGs. The innovations include development of model aquaparks, intensive recirculating aquaculture systems (RAS), tank-based systems, hydroponics and aquaponics, as well as high-density intensive production cages in lakes and reservoirs. For instance, cage culture has emerged to become a significant supply system for Nile tilapia over the past decade. Currently, there are close to 3,000 active cages in Lake Victoria producing an estimated 10,000 metric tons of fish annually.

As the world battle the COVID-19 pandemic and the economy and livelihoods of Kenyans are disrupted, the poor and vulnerable are likely to suffer the most. For long term resilience, we must build inclusive food systems. This book draws lessons from ongoing transformations in the fish food system at the national level provide policymakers and practitioners with recommendations to ensure that food systems transform in a healthy, sustainable, and equitable way.

We hope this year's report encourages policymakers, business leaders, development practitioners, researchers, and the media to take action to build more nutrition-sensitive farmed fish food production systems.

Prof James Njiru, PhD
Director General/CEO,KMFRI

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NAME OF RESEARCHER	SPECIALIZATION	STATION/CENTRE
1. Prof James M. Njiru	Fish Ecology	Mombasa
2. Dr. Jonathan M. Munguti	Fish Feed Formulation and Nutrition	Sagana
3. Dr Kevin O. Obiero	Socioeconomics	Sangoro
4. Dr Paul S. Orina	Fish Breeding and Culture Systems	Kegati
5. Ms Safina Musa	Water Quality	Kegati
6. Dr James Mwaluma	Mariculture	Mombasa
7. Dr David O. Mirera	Mariculture	Mombasa
8. Dr. Eric Ogello	Aquaculture / Blue Economy	Maseno University
9. Dr Jacob Ochiewo	Socioeconomics	Mombasa
10 Dr Domitila M. Kyule	Value Addition and Post-harvest	Sagana
11. Dr Mary A. Opiyo	Fish Breeding and Seed production	Sagana
12. Mr Masai Mutune	Aquaculture	Nairobi
13 Dr Betty M. Nyonje	Aquaculture / Blue Economy	Nairobi
14. Mr Jacob Abwao	Fish Breeding and Nutrition	Sagana
15. Ms Cecilia M. Githukia	Fish Feeds and Nutrition	Kegati
16. Mr Elijah Kembenya	Fish Breeding and Seed Production	Sangoro
17. Mr John Okechi	Socioeconomics/ Enterprise Budgets	Kisumu
18. Ms Veronica Ombwa	Water Quality/Cage Culture systems	Kisumu
19. Ms Morine Mukami	Artemia Production, Mariculture	Mombasa
20. Ms Miriam Wainaina	Mariculture systems	Mombasa
21. Ms Caroline Wanjiru	Fish Ecology, Mariculture	Mombasa
22. Ms. Esther Wairimu	Fish Feed Formulation, Mariculture	Mombasa
23. Ms Fonda Jane Awuor	Socioeconomics	Sagana
24. Mr Sheban Hinzano	Fish Breeding	Kegati
25. Ms Venny Mziri	Fish Diseases	Kisumu
26. Mr Robert Ondiba	Fish Nutrition	Sangoro
27. Ms Glady M. Holeh	Mariculture	Gazi
28. Mr Alex Kimathi	Mariculture	Mombasa
29. Jared Nyabeta	Mariculture	Mombasa
30. Ms Josyline Kendi,	Aquaculture Engineering	Sagana
31. Atsushi Hagiwara	Aquaculture	Nagasaki Japan

ABBREVIATIONS AND ACRONYMS

AAK	Aquaculture Association of Kenya
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CBOs	Community Based Organizations
EAC	East African community
EMCA	Environmental Management and Coordination Act
ESP	Economic Stimulus Project
EU	European Union
FAO	Food and Agriculture Organization
FCR	Food Conversion Ration
FFEPP	Fish Farming Enterprise Productivity Programme
FNSP	Food and Nutrition Security Policy
G.O.K	Government of Kenya
GDP	Gross Domestic Product
GHG	Green House Gases
GIS	Geographical Information Systems
KAPAP	Kenya productivity and Agribusiness Project
KEBS	Kenya Bureau of Standards
KFS	Kenya Fisheries Service
KFAC	Kenya Fisheries Advisory Council
KFMA	Kenya Fish Marketing Authority
KMAP	Kenya Market-Led Aquaculture Program
KMFRI	Kenya Marine and Fisheries Research Institute
KNBS	Kenya National Bureau of Statistics
LAVICORD	Lake Victoria Comprehensive and Aquatic Environment Research for Development
LTD	Limited
LVBC	Lake Victoria Basin Commission
LVFO	Lake Victoria Fisheries Organization
LVHD	Large Volume High Density
MOFD	Ministry of Fisheries Development
MT	Metric Tonnes
MTP	Medium Term Plan
NACOSTI	National Council for Science and Technology
NARDTC	National Aquaculture Research and Development Training Centre

NEMA	National Environmental Authority
NGO	Non-Governmental Organizations
OCGs	Organized Community Groups
OECD	Organization for Economic Cooperation and Development
PUFAs	Polyunsaturated Fatty Acids
RAS	Re-circulative Aquaculture Systems
RIAT	Ramogi Institute of Advanced Technology
SARNISSA	Sustainable Aquaculture Research Networks in Sub-Saharan Africa
SDF&BE	State Department of Fisheries and the Blue economy
SDG	sustainable Development Goal
UN	United Nations
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
USD	United States Dollar
USDA	United States Department of Agriculture
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association
WWF	World Wildlife Fund

UNITS

cm	centimetre
ha	hectare
kg	kilogram
km	kilometre
km^2	square kilometre
m	metre
$m^{3/s}$	cubic metre per second
mm	millimetre
t	tonne

CHAPTER 1

AQUACULTURE IN KENYA: EMERGING TRENDS, SOCIOECONOMIC STATUS AND DEVELOPMENT PROSPECTS.

KEVIN OBIERO, JONATHAN MUNGUTI, ERICK OGELLO, JAMES NJIRU, ATSUSHI HAGIWARA

Key Messages	Policy Recommendations
• The fisheries potential of Kenya's inland waters, mainly from commercial fishing is estimated between 150,000 to 300,000 metric tonnes (MT). In 2019, total fisheries production was 147,000 MT valued at $237 million (KNBS, 2020).	• To achieve a rapid transformation of the aquaculture industry, there is need to upscale modern technologies, innovations and management practices (TIMPs) to realize sustainable development envisaged in the SDGs.
• Over the past 20 years, the aquaculture sector in Kenya has evolved from having a relatively minor role to playing a mainstream part in the national fish food system.	• More research and extension service providers should improve technical skills and practical knowledge of fish farmers by giving assistance to women and youth to initiate climate-smart culture technologies in small farms.
• Aquaculture has thus become more integrated into the national food system, with rapid growth in production and major transformations in feed ingredients, production technologies, farm management, and value chains.	• Considering the increasing recognition of the benefits of fish as a vital source of essential macro- and micronutrients, nutrition education programmes in Kenya, such as the Eat More Fish Campaign, are devoted to teaching non-fish-eating tribes the benefits of eating fish.
• Three main patterns of aquaculture development have characterized the sector as it matured: continued growth in the volume and value chains of fresh water aquaculture; advances in feed technology and formulations; and, fish breeding and genetics, particularly for Nile tilapia and African catfish	• The implementation of the "National Guidelines for Healthy Diets and Physical Activity" will foster dietary shifts and behavioural changes towards inclusion and consumption of an adequate quantity of fish in diets for better nutrition and health outcomes across the population.
• Farmed fish production in Kenya would need to reach 150 000 tonnes in 2030 in order to generate enough fish to maintain its already low per capita fish consumption for the growing population.	• There is a need to improve food security among fish farming communities and enhance diet quality through nutrition education and social behaviour change communication.
• Aquaculture has greater potential to continue to supply most of the nation's farmed aquatic food and contribute to food and nutrition security by complimenting fish supplies from inland and marine capture fisheries	• Policies and investments that seek to increase the availability and accessibility of affordable and sustainable farmed aquatic foods should focus on aquaculture development.

Obiero, K., Munguti, J., Ogello, E., Njiru, J., & Hagiwara, A. (2021). Aquaculture in Kenya: Emerging Trends, Socioeconomic Status and Development Prospects. In, Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition-Sensitive Fish Food Production Systems; Chapter 1: pp 1–19.

Intesive Fishing farming

1.1 FISH PRODUCTION IN KENYA

Kenya's fisheries sector plays an important role in the country's economic and social development, albeit below its potential *(Republic of Kenya, 2019).* The main fish sources include aquaculture (farmed fish) and the capture fisheries, with the latter playing a much larger role to date in Kenyan fish production systems, although aquaculture has been recently making a substantial contribution (Table 1.1). The fisheries potential of Kenya's inland waters, mainly from commercial fishing is estimated between 150,000 to 300,000 metric tonnes (MT). Production from capture fisheries has stagnated and declined over the past decade *(SDF&BE, 2016).* Despite a huge potential, the current production level from marine waters is only about 25,000 MT per annum, indicating under-exploitation of the resource *(Munene and Wanjiku, 2020; KNBS, 2020).*

In 2019, total fisheries production was 147,000 MT valued at $237 million *(KNBS, 2020)*.

Current production is mainly from inland freshwater sources that accounted for 121,000 MT, while aquaculture remained relatively stable over the past 5 years and accounted for 12.8% of the country's fish output in 2019 (Table 1). Although capture fisheries presently remain the dominant supplier of fish in Kenya, the maximum sustainable yields (MSY) for most rivers and lakes in Kenya have been exceeded and fish output from these sources plateaued over the past 5 years. Aquaculture is viewed as an alternative to bridging the widening gap between fish demand and its supply in Kenya *(Obiero et al., 2019a).*

Table 1.1: Quantity (in metric tonnes) of fish production in Kenya from 2015 to 2019. Source: KNBS, 2020

Year	2015	2016	2017	2018	2019
Freshwater					
Lake Victoria	109,902	98,666	92,727	98,150	90,743
Lake Turkana	10,605	7,926	4,021	5,430	7,031
Lake Naivasha	1,072	1,064	1,689	2,287	3,087
Lake Baringo	176	141	155	180	203
Lake Jipe/Dams	123	106	112	120	157
Tana River Dams	852	444	422	630	750
Other areas	312	214	332	350	360
Fish Farming	**18,656**	**14,952**	**12,356**	**15,320**	**18,542**
Total Freshwater	141,698	123,513	111,814	122,467	120,873
Marine Sources	22,126	24,165	111,814	24,220	25,670
Grand Total	**163,824**	**147,678**	**135,100**	**146,687**	**146,543**

Source of Data: Kenya National Bureau of Statistics, Economic Survey, KNBS, 2020

1.2 EVOLUTION OF AQUACULTURE IN KENYA

Aquaculture was first introduced in Kenya by the Colonial Government in 1920s ***(Vernon and Someren, 1960)***. From 1920s, static water pond culture was introduced, beginning with native tilapiines followed by Common carp and African catfish. Between 1940s and 1960s, aquaculture was promoted as a means of sustainable food production with the objective of improving nutrition in rural areas, supplementary income generation, diversification to reduce crop failure risks and employment creation in rural areas ***(Adeleke et al., 2020).*** Early efforts focused on basic research and development to provide practical technologies for culture of indigenous species ***(Brummett et al., 2008).*** In 1948, the colonial government established the Sagana and Kiganjo fish culture farms for the production of warm water (tilapia) and cold water (trout) species ***(MoFD, 2010)***.

After independence, the newly formed government created the Fisheries Department domiciled in the Ministry of Agriculture to spearhead fisheries development in Kenya. The Fisheries Department promoted the nascent industry through *"Eat More Fish Campaigns"* in the 1960s that led to the rapid spread of rural pond fish farming in the country. As a result, by early 1970s, Nyanza and Western Provinces alone had over 30,000 fish ponds ***(Zonneveld, 1983)***. However, most of the ponds were later abandoned ***(Charo-Karisa, 2007).*** Between 1970 and 2006, aquaculture production oscillated between 1,000–4,000 MT. In 2007, about 4,250 MT of fish was produced by 4,742 farmers countrywide from 7,477 ponds covering 217 hectares (Ha), 301 dams and reservoirs (497 Ha) and 248 tanks and raceways ***(Nyandat and Owiti, 2013).***

Aquaculture currently plays an important role in the Kenyan economy, contributing to food production, alternative livelihood opportunities, income generation, poverty alleviation and social development *(Ngugi and Manyala, 2009; Rothius et al., 2011; Ogello and Munguti 2016).* From 2009–2013, the Government of Kenya in its commitment to revitalize the economy introduced and implemented the large-scale subsidy program called the Economic Stimulus Programme (ESP) under which aquaculture was identified as a key pillar in the agriculture production sector *(Ole-Moiyoi 2017; Munguti et al., 2017).* The country experienced a rapid expansion of fish farming providing high-protein food, income and employment opportunities. The ESP focused on pond construction, fish feeds and fingerlings supply, post-harvest management, and human resource capacity building of fish farmers and associated institutions *(Musa et al., 2012).* Kenya is now ranked fourth largest producer of farmed fish in Africa *(Satia, 2017).* The number of farmers increased tremendously to 49,050, with an estimated 69,998 ponds occupying 2,063 Ha at the peak of the subsidy program in 2012 *(Nyandat and Owiti, 2013).*

Kenya has made remarkable progress in promoting aquaculture. Kenya's Vision 2030, together with other legal, policy and institutional frameworks also recognize aquaculture as a source of food security, poverty reduction, and employment creation. Through the supportive government policies and substantial public investments, aquaculture production in Kenya increased rapidly from less than 1000 tonnes in 2006 to 24,000 tonnes in the mid-2010s *(Obiero et al. 2019b)* including in regions of the country with little history of fish production or consumption *(Ole-Moiyoi, 2017).* The implementation of the government stimulus program triggered an immediate and short-term demand for about 28 million certified tilapia and catfish fingerlings and over 14,000 MT of formulated fish feeds *(Charo-Karisa and Gichuri, 2010).* The ripple effect of these programs led farmers to construct their ponds, further increasing the demand for seed fish and feed to over 100 million and 100,000 MT, respectively *(Munguti et al., 2014, 2017).* The total area under fish ponds was 2,105 Ha in 2013, but the area reduced to ~ 1,808 ha in the year 2015 because of decline in number of ponds from 69,194 to 60,277 in 2 years (Macharia and Kimani, 2015). As illustrated in Figure 1, pond-based aquaculture production registered depressed performance for the third consecutive year, with total fish output dropping from 24,096 MT in 2014 to 18,542 MT in 2019 *(KNBS, 2020).*

> **BETWEEN 1970 AND 2006, AQUACULTURE PRODUCTION OSCILLATED BETWEEN 1,000–4,000 MT.IN 2007, ABOUT 4,250 MT OF FISH WAS PRODUCED BY 4,742 FARMERS COUNTRYWIDE FROM 7,477 PONDS COVERING 217 HECTARES (HA), 301 DAMS AND RESERVOIRS (497 HA) AND 248 TANKS AND RACEWAYS**

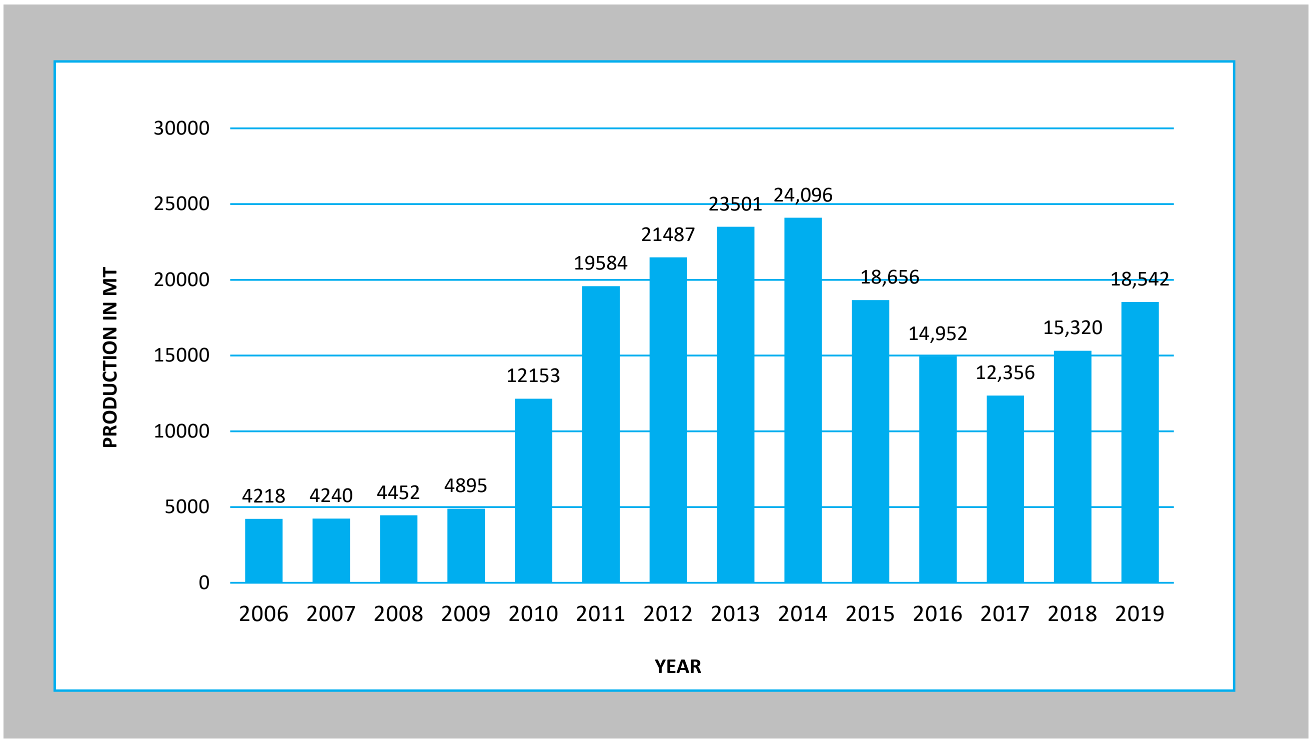


Figure 1.1: Trends in aquaculture production in Kenya 2006–2019 (KNBS, 2020)

Currently, the aquaculture value chain in Kenya is relatively sustainable from an economic point of view as it creates increasing jobs and incomes *(Rampa and Dekeyser, 2020)*. However, low production and consumption levels are currently limiting the economic role within the food system of this value chain, which has a great potential for growth. Aquaculture production in Kenya peaked in 2014, with nearly 25 000 tonnes, but then gradually declined, despite an increase in demand and in the country's per capita consumption of fish. In 2017, production was 12,356 tonnes, with only 0.014 percent of the part of the country that is potentially suitable for aquaculture used for that purpose *(Munguti et al., 2017)*. Given Kenya's growing population, income growth, increased awareness of the health benefits of fish consumption and changes in lifestyles and consumer preferences *(Ogello and Munguti, 2016; Obiero et al., 2019a)*, further fish consumption increases will come from either aquaculture or imports. While wild capture fisheries presently remain the dominant supplier of fish in Kenya, aquaculture is projected to play an important role in sustaining fish supply to meet increasing demand to 2030. Thus, quantitative assessment and monitoring of the aquaculture sector is essential for evidence-based policy making and sustainable development of the industry.

1.3 AQUACULTURE ENVIRONMENT, SYSTEMS AND PRACTICES

ENVIRONMENT

Kenya is endowed with a vast network of freshwater resources comprising lakes, rivers, dams/reservoirs, streams, and wetlands all suitable for different types of aquaculture development. The inland water resources include lakes, dams and rivers of varying sizes. Kenya also enjoys a vast coastline of 640 km on the Western Indian Ocean, besides a further 200 nautical miles Exclusive Economic Zone (EEZ) under Kenyan jurisdiction. The total area of the territorial waters is 9,700 Km^2 while the Kenyan EEZ is 142,400

Km². Kenya also lays claim to extended EEZ reaching 350 km with an extra area of approximately 103,320 Km². The total area for exploitation by the country is a massive 255,420 Km² which is about half of the Kenyan land cover area *(SDF&BE 2016).*

SYSTEMS AND PRACTICES

Aquaculture systems in Kenya are characterised into three categories depending on culture systems and scale of production: (i) extensive systems with low degree of control; low initial costs, low-level technology, and low production efficiency; (ii) semi-intensive systems where supplemental feed is required to maintain higher stocking rates; and (iii) intensive systems characterised by a high degree of control; high initial costs, high-level technology, and high production efficiency (Table 2). The aquaculture systems mainly include earthen, concrete and liner ponds, pens, tanks, raceways, and cages depending on the species cultured and the availability of land and water in the locality. The major production systems include earthen ponds, cages, concrete or earthen lined ponds and tanks *(Censkowsky and Altena, 2013).* The bulk of aquaculture production still originates from small-scale earthen pond-based farming systems and practices. Other production systems include wooden-raised lined ponds, circular and rectangular raceways, and recirculating systems *(Munguti et al., 2017).*

Table 1.2: Typology of aquaculture culture systems in Kenya (Oswald and Mikolasek, 2016)

Categories and characteristics	Extensive	Semi-intensive	Intensive
Culture systems	Earthen ponds, lagoons, small pens	Earthen, liner, concrete ponds and cages/pens	Tanks (flow/ recirculated), cages, and biofloc array systems
Species	Polyculture (tilapia spp. and catfish)	Polyculture and/or monoculture (Tilapia and/or African Catfish	Mainly monoculture of Tilapia, Catfish or Trout
Feeding	Zero to supplementary, mostly through pond fertilization	Scheduled to unscheduled using mainly farm-made feeds	Scheduled intensive feeding using commercial extruded feed or farm-made feeds
Production efficiency	Low to medium	Medium to high	High
Labour needs	Mainly family members	Mixed, presence of permanent employees	Salaried employees
Investment capital and operational costs	Low to medium from family members	Medium	High (shared ownership)
Management	Family only; little or no professional assistance	Mainly family members, with some professional assistance	Financial management with on-farm technical support
Access rights to land and water	Access to land through customary or family rights	Land owned by the operator or family, or rented	Legal concession for use
Integration in value chain	Zero to medium, mostly isolated and little access to inputs and markets	Medium to high, access to inputs but access to market may be constrained	High, key players in the value chain
Level of commercialization	Household activity	Household to farm operation	Full commercial farm operation and business

Since both land and water are becoming scarce for aquaculture due to competition from various sectors, many technological advancements have been promoted to achieve sustainable intensification of aquaculture. These include recirculating aquaculture systems (RAS), tank-based systems, hydroponics and aquaponics, as well as high density, high carrying capacity intensive production in cages. For instance, cage culture has emerged to become a significant supply system for Nile tilapia over the past decade. However, the development of RAS faces constraints mainly due to high initial investment costs, operating costs and lower market process of farmed fish which is likely to constrain uptake of these modern production systems *(Tschikof, 2018)*.

Cage culture emerged from relative obscurity over the past decade to become an important supply system of Nile tilapia to consumers, mostly in rural and urban areas in Kenya *(Aura et al., 2018)*. Cage installations have spread across the five riparian counties but its development varies from country to country (Aura et al., 2018). Currently, there is an estimated 6,000 cages installed on the Kenya portion of the lake (6% of total surface area) with increasing production capacity projected to be over 10,000 tonnes *(Munguti et al., 2017; Orina et al., 2018)*. Although cage culture is a promising venture to increase productivity, offer employment opportunities and enhance economic wellbeing, site suitability for cage installations is poorly regulated with over 45% of cages located within 200 m of shoreline acting as breeding grounds of fish and hence potential conflict with other lake users *(Njiru et al., 2018)*. With increasing number of cages in the lake, there is need for policy and regulations to guide its investment to ensure environmental sustainability and economic performance *(Aura et al., 2018; Njiru et al., 2018)*.

1.4 PODUCTION TRENDS OF MAIN CULTURE SPECIES

Aquaculture in Kenya is practiced in fresh, brackish and marine waters, with production limited to a smaller number of fish species compared to capture fisheries. The supply chain is focused on two species, Nile tilapia ***(Oreochromis niloticus)*** and African catfish ***(Clarias gariepinus)*** accounting for over 93% of Kenya's aquaculture production *(Munguti et al., 2017; Obwanga and Lewo, 2017)* (Table 1.2). These species are found in virtually all aquatic systems and have high demand in the local and regional markets. Polyculture of Nile tilapia and African catfish is often done to control the prolific breeding of the former. Other cultured species include Common carp ***(Cyprinus carpio)*** and, Rainbow trout (***Oncorhynchus mykiss),*** and Tilapia jipe ***(Oreochromis jipe)***. Trout is temperature restricted thus it is only cultured at temperatures below 19°C mainly in the Mt. Kenya region. A variety of freshwater species have been farmed on pilot scale including Nile perch ***(Lates niloticus)***, Largemouth bass African carp ***(Labeo victorianus)***, and Lung fish ***(Protopterus aethiopicus)*** *(Munguti et al., 2017)*.

Over the past decade, research efforts have been directed towards the culture of indigenous tilapiine species, namely Singidia tilapia ***(Oreochromis esculentus)***, Victoria tilapia ***(Oreochromis variabilis)***, Blue spotted tilapia ***(Oreochromis leucostictus, 1983)*** and Tilapia jipe ***(Oreochromis jipe)*** for commercial and conservation purposes *(Charo-Karisa and Maithya, 2010; Kinaro et al., 2016)*. Freshwater ornamental fish production and international trade are dominated by non-indigenous species comprising of a variety of Gold fish ***(Carassius auratus),*** Koi carps ***(Cyprinus carpio carpio)***, Swordtail ***(Xiphophorus hellerii)*** and Mollies ***(Poecilia spp.)*** *(Opiyo et al., 2017)*. The most commonly farmed finfish species in marine ecosystems are milkfish and mullets, accounting for over 90% of production. Shellfish culture in coastal Kenya has mainly been the culture of mud crabs, prawns, and ***Artemia*** (Mwaluma et al., 2017).

Table 1.3: Cultured fish species production (in MT) in Kenya from 2010-2019 (Source: FAO, 2021)

Year/Species	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Nile Tilapia	9115	16602	16115	17626	18072	13991	11962	9885	12356	15100
African Catfish	2188	3984	3869	4230	4337	3358	1944	1606	1960	2400
Common Carp	729	1328	1289	1410	1446	1120	299	247	300	300
Rainbow Trout	122	221	215	235	241	187	748	618	700	745
Total	12154	22135	21488	23501	24096	18656	14953	12356	15316	18545

1.5 ROLE OF AQUACULTURE IN FISH CONSUMPTION AND FOOD SECURITY

Fish provide a rich source of high-quality proteins containing all essential amino acids, minerals and micronutrients such as iron, zinc, omega-3 fatty acids and vitamins, often in highly bio available forms *(Golden et al., 2016)*. In addition, fish is an excellent source of high-quality animal protein and essential fatty acids, especially long-chain polyunsaturated fatty acids (LCPUFA), which are much greater in fishes than in terrestrial animal-source foods *(Beveridge et al., 2013).* The wide range of highly bioavailable micronutrients present makes fish a unique food commodity, recognized widely as "nature's superfood" (Figure 1.2; FAO 2017). However, micronutrient deficiencies affect hundreds of millions, particularly women and children in developing countries *(FAO, 2016)*. The associated burdens of micronutrient deficiencies include increased risks of perinatal and maternal mortality, growth retardation, child mortality, cognitive deficits and reduced immune function *(Black et al., 2008)*

Fish is often considered to be a 'rich food for poor people' and the most accessible and affordable source of animal protein, providing many of the key nutrients and calories that are needed for physical and mental development. There has been a steady decline in fish catch volumes from the fresh water bodies over the years (Figure 1.1). This has led to a significantly lower fish consumption per capita (<5kg/person/year) compared to global average of 20 kg/person/year *(Ogello and Munguti 2016).*

In Kenya, analysis by Ole-Moiyoi (2017) on the consumption patterns of different types of proteins in Kenya show that wild-caught, followed by pond fish, make up a large proportion of the total protein that is consumed by respondents from 'poor' socioeconomic classes (Figure 1.3). The results showed that as households become wealthier, "terrestrial sources of animal protein" (e.g., chicken, beef, mutton, and pork) occupy increasingly larger shares of total protein consumption. Conversely, as socioeconomic status declines, fish becomes increasingly important. This implies that the poorer the households, the more important fish is to their total protein intake. Obiero et al., (2019b) concluded that although formidable fish supply chain issues remain, many families—including poor families—had attained meaningful food security benefits from aquaculture. As a result, more action is needed to address the economic constraints that are plaguing the sector.

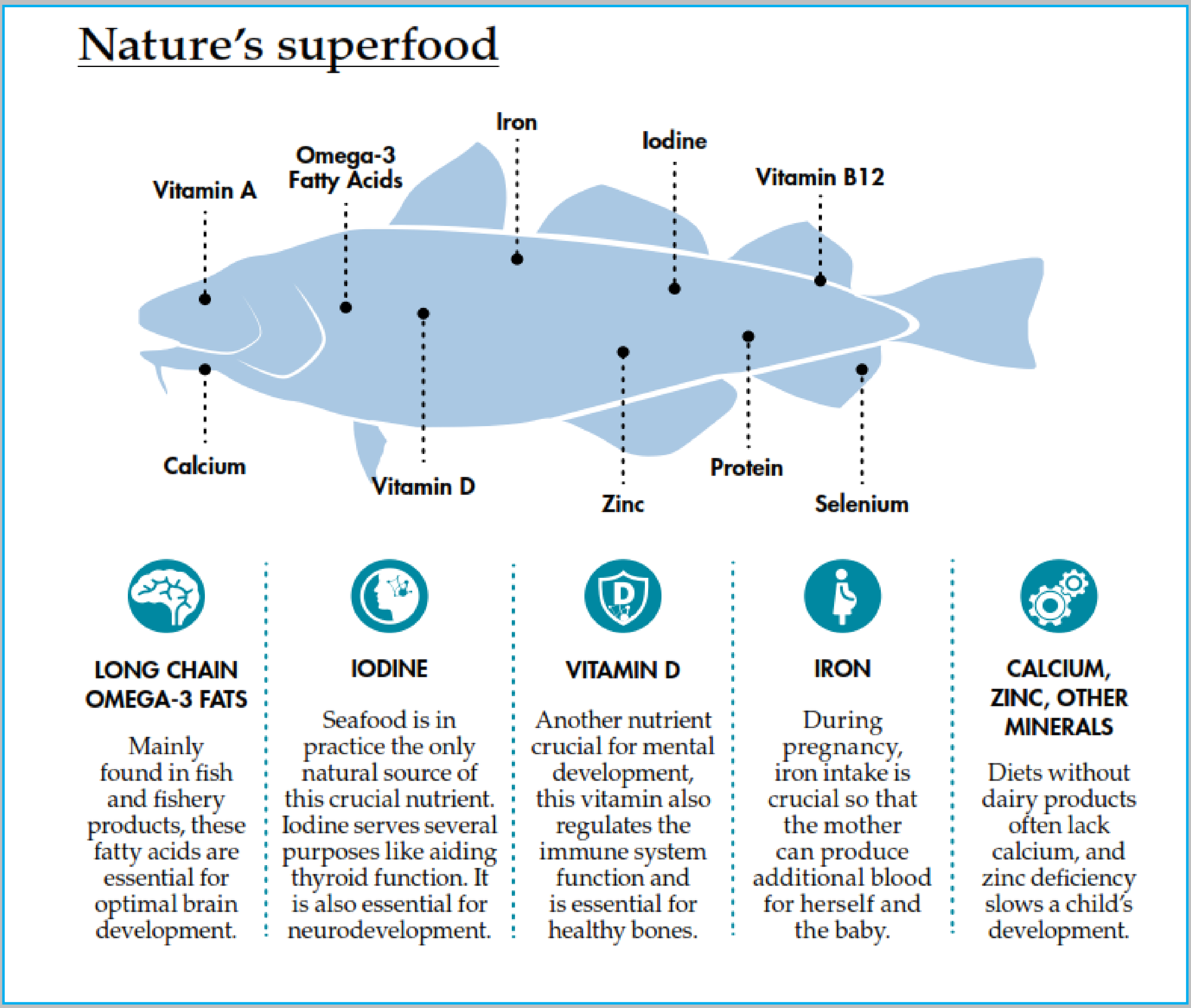


Figure 1.2: Fish as a source of proteins, healthy fats, and essential micronutrients (FAO, 2017)

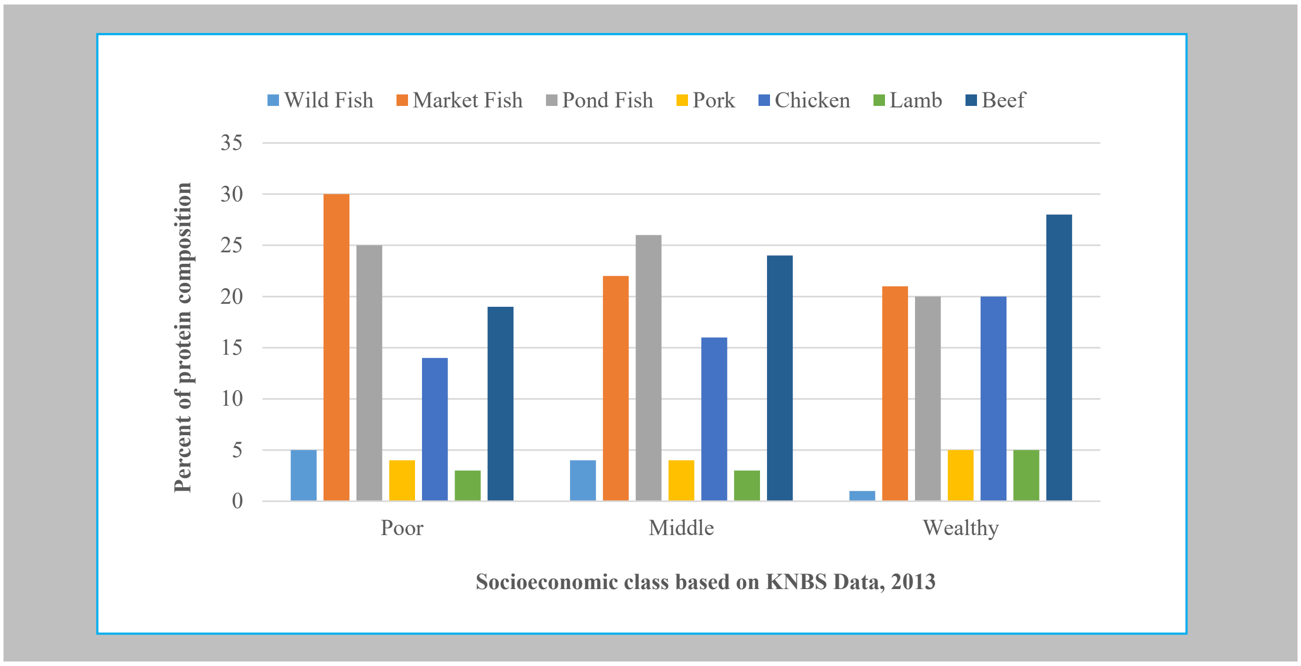


Figure 1.3: Protein consumption composition by socioeconomic classes (Adapted from Ole-Moiyoi, 2017

1.6 SOCIAL IMPACTS OF AQUACULTURE DEVELOPMENT IN KENYA

The Kenyan Government in its commitment to revitalize the economy introduced an intersectoral Economic Stimulus Programme (ESP) in 2009, under which aquaculture was identified as a key pillar in the agricultural production sector. The Fish Farming Enterprise Productivity Program (FFEPP) hoped to attain the following targets by 2030: (1) Increase national fish production by 10% annually by 2030; (2) Increase per capita fish consumption from 4.75 to 10 kg/capita/year by 2030; and (3) Increase employment opportunities in the fisheries and aquaculture sectors from 80,000 to approximately 2 million by 2030 (MoFD, 2012). The program resulted in the fourfold to sixfold growth of freshwater aquaculture production between 2006 and 2014 *(Rampa and Dekeyser, 2020).* In regards to fish farming specifically, the Program was meant to increase farmed fish production from 4,000 to 20,000 metric tonnes in the medium term, and 100,000 metric tonnes in the long term *(Charo-Karisa and Gichuri, 2010; ole-Moiyoi, 2017)*. Ole-Moiyoi (2017) explored the potential food security impact of Kenya's Fish Farming Program aimed at improving household level food security. The study measured "Access" in terms of (a) income generated by selling particular products, and (b) wages earned via direct employment and results are presented in Table 1.3.

From 2013, public support for the aquaculture value chain was partly slowed down by Kenya's devolution as certain counties, which became responsible for aquaculture, pulled back due to shift in investment priorities (Rampa and Dekeyser, 2020). With the devolution of the aquaculture sector to counties, there are lots of opportunities for young people, especially young women to engage in aquaculture production and value chain linkages. Already, counties are experiencing shortage of extension staff on basic aquaculture activities. This presents an opportunity for youths to become local consultants after short training periods in TVETs and or universities *(Ogello et al., 2021)*.

Table 1.4: Summary of results of impact of Kenya's Fish farming Program on "access" to fish-food as a measure of food security (Source: Ole-Moiyoi, 2017)

Key questions / Category	Pointer of Sustainability
1. Income	
To what extent do farmers make money from selling fish?	Most farmers make between $0 and $500 per pond. The median of $226 pond-1 year-1 is a more useful measure when seeking to understand 'typical' potential profit across the study sample, considering that many fish farmers in the region live below the poverty line ($26.64/month).
How do fish farmers spend the income they obtain through fish farming?	Most fish farmers spend the income on school fees (37%), or reinvest it back into their fish farming operation (45%). Only a relatively small group chooses to improve the household's "food security" situation by either buying more food (6%) or diversifying their food purchases (1%).
Do different types of farmers attain different benefits from fish farming?	Not all farmers obtain equal benefits based on their socioeconomic status. The poorest groups attain the lowest profits, the middle class attains the highest, and the wealthiest class is in the middle. The middle classes do disproportionately well as fish farmers – not just in terms of profitability, but indeed across numerous other measures of food security. One reason is that they are better equipped to succeed at fish farming as compared to poorer groups, and have more incentives to succeed at fish farming than wealthier classes, who do not seem to rely as heavily on fish farming for either income or food.
Are there particular on-farm practices that maximize yields and profitability?	Usage of monosex (all male) versus mixed sex fingerlings can impact yield. Ponds containing monosex male tilapia reach higher body weights (343 kilograms-1 pond-1 year-1; n=360), much faster than fish in a mixed-sex ponds (275 kgs-1 pond-1 year-1; n=395) in which females are reared. Farmers who fertilized their ponds attained higher yields (309 kgs-1 pond-1 year-1; n=783) than farmers who did not (207 kgs-1 pond-1 year-1; n=61). Farmers using purchased (formulated) pellets realized yields of 321 kgs-1 pond-1 year-1; n=285), farmers using their own formulated feeds obtained yields of 276 kgs-1 pond-1 year-1 (n=127), and farmers using "kitchen scraps" leftover from meals and food preparation obtained yields of 249 kgs-1 pond-1 year-1 (n=117).
2. Employment	
To what extent did the program lead to the creation of jobs?	Labor is classified into four different categories: "family" labor (part-time and full-time) and salaried labor (part-time and full-time). Majority of labor for smallholder fish farming is provided by the households themselves ("family labor"). On a per pond basis, households dedicate 1.3 family laborers, on a full-time basis on average. This is more than the mean number of full-time salaried employees ($\bar{x}$=0.22±0.04). Due to low on-farm labor requirements, across the sample of 844 "active" farmers, who collectively own 1,813 ponds, the total number of full-time salaried employees is 181 and the total number of part-time employees is 390. The greatest contribution of smallholder fish farming in terms of job creation might actually be in ancillary industries, such as input production, marketing and sales

1.7 FISH TRADE AND MARKETING DYNAMICS

Fish trade in Kenya has also increased the scope and choice of fish available to consumers because of improved logistics and market distribution systems coupled with expanding aquaculture production and technological innovations. Furthermore, as the distance becomes less of a barrier to trade, wholesalers and retailers source fish from all over the world, especially from China ***(Obiero et al., 2019).*** While demand for fish is growing in the Kenya, supply from capture and aquaculture sources are fluctuating in nature. The volume and value of fish exported from Kenya has been declining since 2010 (Figure 1.4). This can be attributed to the decline in fish catch from the main water bodies coupled with increasing domestic demand. Kenya imported 32,717 metric tons of fish and fishery products worth Kshs 3.96 Billion in 2018. The imports were composed of frozen Nile tilapia 16,966 metric tons (52%) of the fish and fish products imported during the year.

Fish traders rely on imported frozen fish due to ease of availability, steady supply and price. This results in dependency on the supply of imported frozen Tilapia fish which are sold in major cities and distant market at a lower price (Ogello et al. 2021). Price trends for imported frozen and filleted fish over the past 3 years reveal a slight price increase for all grades of 10 kg box whole tilapia in Nairobi (Table 1.4). This translates to an average price of 1 kg of fish at USD 2.5 per kg. In this scenario, most of the actors in the aquaculture value chain including producers and suppliers do not benefit due to out-competition, since fish producers need to sell at an average price of USD 4.5 and above to break even on production costs.

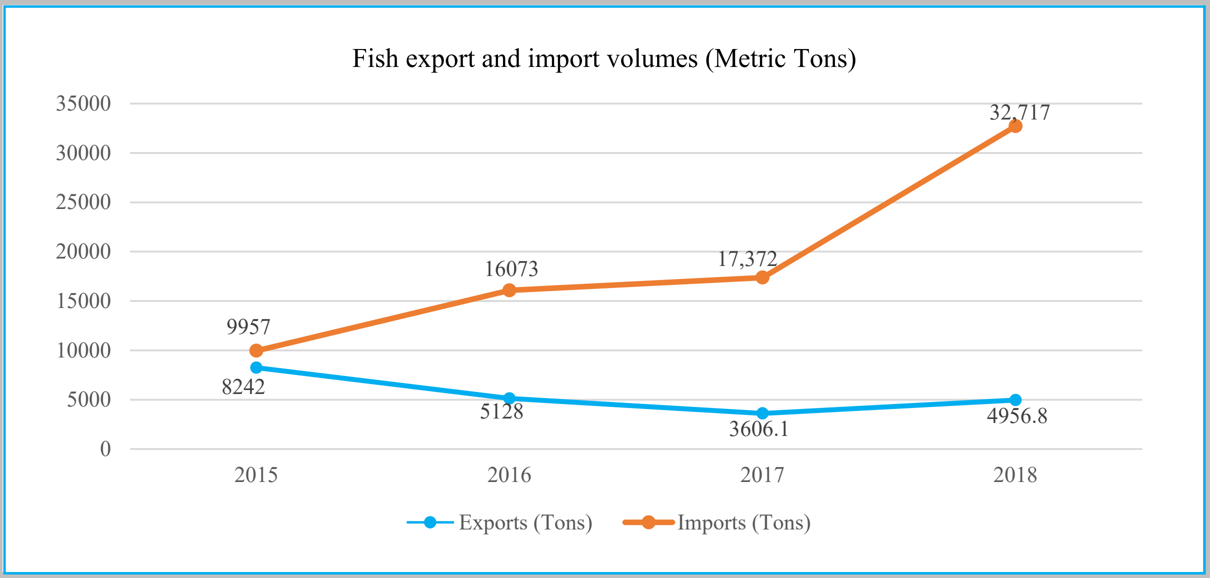


Figure 1.4: Fish import and export volumes (Mt) between 2015 to 2018 (Data: KNBS, 2020)

Table 1.4. Imported Frozen Whole Tilapia Prices in Nairobi showing changes in prices from May 2017 to September 2018. (Source: Obiero et al., 2019)

Grade per 10 kg Box	Price of Imported (Kshs) Frozen Tilapia in November 2017	Price in Kshs of imported Frozen Tilapia in September 2018
100/200	1,250	1,350
200/300	1,500	1,550
300/400	1,650	1,850
400/600	1,900	2,150
600/800	2,000	2,350
800/1000	2,200	2,400
1000/UP	2,250	2,500

1.8 CHALLENGES AND OPPORTUNITIES IN THE AQUACULTURE SECTOR

Presently, Kenya's aquaculture industry is evolving from traditional to modern aquaculture systems, but the sectors has been unable to realize its full potential due to the following constraints:

- Inadequate readily available and affordable quality fish seed (fingerlings);
- Inadequate high quality and affordable fish feeds;
- Inadequate supportive infrastructure e.g., fish propagation hatcheries, fish feed industries, fish marketing systems especially for rural producers
- Inadequate budgetary provision for aquaculture sector
- Weak research-extension-farmer linkages;
- Slow adoption rate of fish farming technologies, innovations and management practices;
- Lack of good credit facilities and schemes for fish farmers;
- Poor security and safety of fish in ponds and cages posed by thieves and predators;
- Poor book keeping and record management leading to inaccurate data from farmers along the aquaculture value chain e.g., input costs, labour, quantities of fish harvested and value;
- Sub optimal staffing levels especially extension personnel; inadequate facilitation in terms of transport and timely funds towards carrying out of fisheries extension service provision and increasing competition from cheaper imported farmed fish products (SDF&BE, 2016).
- In addition, the policy and legal framework for fish feed and seed certification and mechanisms to monitor compliance to fish seed production, supply, and quality are weak and inadequate to guarantee high performance (Amankwah et al., 2016; Obiero et al., 2019c).

A vibrant aquaculture sector has the capacity to absorb a substantial percentage of these youth through employment, farming, and agribusiness along the value chain. However, lack of access to capital and land ownership, low literacy levels, poor mentorship and markets are some of the critical barriers hindering the participation of women and youth in the aquaculture sector. The low uptake of aquaculture among women and especially the youth is a threat for the social sustainability of aquaculture (Obwanga and Lewo, 2017).

1.9 OPPORTUNITIES AND CRITICAL SUCCESS FACTORS

To achieve a rapid transformation of the aquaculture industry, there is need to upscale modern technologies, innovations and management practices (TIMPs) to realize sustainable development envisaged in the SDGs. Some of the culture technologies and innovations include development of model aquaparks, high-density intensive production cages in lakes and reservoirs, intensive recirculating aquaculture systems (RAS), tank-based systems, hydroponics and aquaponics. Recent empirical evidence shows the bulk of global aquaculture output originating from a segment of 'missing middle' producers, characterized by five features. They are: (1) highly commercially oriented; (2) span a broad spectrum of scales of production; (3) utilize a diverse range of production technologies which are increasingly intensifying through use of pelleted feeds; (4) produce multiple, predominantly low and medium value, species; and, (5) have emerged in an unplanned manner in response to opportunities created by changing fish demand patterns *(Belton, Bush, & Little, 2017).*

The Aquaculture Business Development Project (ABDP) has rolled out an interesting opportunity in Field Farmer Schools (FFS) for training local youth on aquaculture production technologies, management and aqua-preneurship. Since aquaculture is fast growing, there is a need for development of new production technologies in aquaculture to maximize production and profits. Technologies such as Recirculating Aquaculture Systems (RAS), which mainly useful for dry land aquaculture, Biofloc and Periphyton Technology (that uses less feeds), are modern innovations that can be adopted for better fish production. With the increasing demand for fingerlings and fish feeds, cottage industries managed by farmers and hatchery operators have an opportunity to engage in fish feed and fingerling production to supply the aquaculture sector. Today the total annual demand for fish feeds and fingerlings is estimated at 34,000 tons and 28 million, respectively (KMFRI 2018). In other studies, the majority (54 %) of fish farmers use locally manufactured feeds from the cottage industries, due to the high cost of commercial diets.

With adequate training on basic fish pond husbandry, fish farmers are able to eradicate these basic challenges by themselves. There is a need for competency-based training on special skills in aquaculture. The youth can be encouraged to join such training in various TVETs and Universities. Weak extension service is a perennial challenge in the aquaculture sector. This is because the government does not employ staff regularly. The devolution of fisheries and aquaculture sectors to County levels presents the need for local people to educate the local fish farmers, using local dialect. In fact, this is a perfect opportunity for the young people to be trained as extension officers so that they can offer consultancy services to the aquaculture farmers. Failure to secure direct markets lead to fish spoilage and low prices.

The proliferation of cage culture also presents immense opportunity for young people to form business units for example aqua-shops for selling cage accessories and offer consultancy services on cage construction technology and management. Currently, cage ownership and management activities are dominated by males with women occupying the upper segment of the cage value chain such as fish processing, value addition and trade. The water quality in the cages is remotely being monitored using a solar-powered electronic technology. Rio Holdings has developed an online fish marketing platform called 'Aquarech' through which farmers and traders can make online orders to improve marketing of fish and farm inputs.

To maximize on the available financial and market opportunities, fish traders (mostly women) can be organized into groups to attract funding. With the opportunities created by changing eating habits where more people are now eating fish, the youth can also venture and explore opportunities in value added product development and introduce the developed products into the markets. Examples of these products and of commercial importance include fish fillets, fish balls, fish fingers, sausages, fish gel from fish scales (used in pharmaceutical and cosmetics industries.). There are opportunities in training of youth in value addition techniques, and fabrication of value addition equipment. Opportunity also exists in investment in modern fish processing technologies and marketing techniques and platforms.

1.10 POLITICAL FEASIBILITY AND ENABLING POLICY ENVIRONMENT

The political feasibility and traction to support aquaculture value chain are clearly picking up, given the increasing market demand and the recent initiatives by the national and county governments, NGOs and international partners, as well as other political economy dynamics. Achieving the Kenyan Vision 2020 targets will require a solid framework of monitorable indicators and statistical data to track progress, inform policy and ensure accountability of all stakeholders. In 2010, a five year's National Aquaculture Strategy and Development Plan (2010–2015) was developed to facilitate the implementation of the policy (MoFD, 2010). The Strategic Plan created provided a greater impetus and institutional focus for aquaculture development in the country than at any time in the past. To sustain the momentum of aquaculture growth and maintain the gains from its development will require even more effort and investments.

Since the strategic plan is a live document, it needs update from time to time. A revised National Aquaculture Strategy and Development Plan 2021–2025 should align with Vision 2030 and policies put in place by the Kenyan Government and development partners. Overall, the goal of the new strategic plan is to "improve the welfare of the resource-poor Kenyans dependent on aquatic resources for their livelihood, create employment opportunities for the youth and women, conserve and, as much as possible, enhance the natural resources on which livelihoods are based, promote the sustainable development of rural communities, increase export earnings and contribute to the creation of national wealth and improvement in peoples' welfare". The new strategy should focus on four strategic objectives which are based on the pillars of sustainable development, as follows:

- **Social**: To enhance the health and well-being of the people through the production of nutritious food and the development of productive and secure livelihoods, women empowerment, and better income and market opportunities for smallholders and SMEs.
- **Economic:** To create investment opportunities for private actors and more employment opportunities in rural areas; and increase domestic production, subsequently lessening dependence on imports (reducing the necessary foreign reserves, which are already under constraint due to COVID-19, to satisfy food supply).
- **Ecological:** To promote the conservation of aquatic biodiversity, enhancement of genetic resources, conservation of natural resources, and climate-resilience of production systems.
- **Institutional**: To establish the enabling environment and develop the capability to effectively manage the sector, provide the support services needed for sustainable and responsible development, and ensure equity and fairness in the allocation of production resources and distribution of benefits.

1.11 FUTURE OUTLOOK: TOWARDS VISION 2030

Over the past 20 years, the aquaculture sector in Kenya has evolved from having a relatively minor role to playing a mainstream part in the national fish food system. Aquaculture is becoming more integrated into the national food system, with rapid growth in production and major transformations in feed ingredients, production technologies, farm management, and value chains. Three main patterns of aquaculture development have characterized the sector as it matures: continued growth in the volume and value chains of fresh water aquaculture; advances in feed technology and formulations; and, fish breeding and genetics, particularly for Nile tilapia and African catfish. The utilization of compound feeds in freshwater systems has steadily increased in the last decade, fertilization, combined with supplementary feeds, which remains a key approach to producing low-cost tilapia and catfish in semi-intensive systems, and will underpin the growth of commercial production in Kenya. Continued growth in the sector has important implications for achieving Kenya's Vision 2030 targets and the United Nations Sustainable Development Goals.

Looking ahead, the effective spatial planning and regulation of aquaculture sites will be paramount for achieving positive environmental outcomes, especially as aquaculture systems increase in scale and production intensifies. Thus, careful siting of aquaculture systems underpins the commercial and environmental success of the industry. Prudent siting and scaling are essential for maximizing the ecosystem services provided by farmed species and for mitigating critical challenges to the industry associated with effluent pollution and climate change. In conclusion, aquaculture has greater potential to continue to supply most of the nation's farmed aquatic food and contribute to food and nutrition security by complimenting fish supplies from inland and marine capture fisheries. Policies and investments that seek to increase the availability and accessibility of affordable and sustainable farmed aquatic foods should focus on aquaculture development.

REFERENCES

Adeleke, B., Robertson-Andersson, D., Moodley, G., & Taylor, S. (2020). Aquaculture in Africa: A Comparative Review of Egypt, Nigeria, and Uganda Vis-À-Vis South Africa. Reviews in Fisheries Science and Aquaculture, 0(0), 1–31. https://doi.org/10.1080/23308249.2020.1795615

Amankwah, A., Quagrainie, K. K., & Preckel, P. V. (2016). Demand for improved fish feed in the presence of a subsidy: a double hurdle application in Kenya. Agricultural Economics, 47(6), 633–643. https://econpapers.repec.org/RePEc:bla:agecon:v:47:y:2016:i:6:p:633-643

Aura, C. M., Musa, S., Yongo, E., Okechi, J. K., Njiru, J. M., Ogari, Z., Wanyama, R., Mbugua, H., Kidera, S., Ombwa, V., & Abwao, J. (2018). Integration of mapping and socio-economic status of cage culture: Towards balancing lake-use and culture fisheries in. Aquaculture Research, 49, 532–545. https://doi.org/10.1111/are.13484

Belton, B., Bush, S. R., & Little, D. C. (2017). Not just for the wealthy: Rethinking farmed fish consumption in the Global South. Global Food Security, October, 1–8. https://doi.org/10.1016/j.gfs.2017.10.005

Beveridge, M. C. M., Thilsted, S. H., Phillips, M. J., Metian, M., Troell, M., & Hall, S. J. (2013). Meeting the food and nutrition needs of the poor: The role of fish and the opportunities and challenges emerging from the rise of aquaculturea. Journal of Fish Biology, 83(4), 1067–1084. http://doi.org/10.1111/jfb.12187

Black, R. E., Allen, L. H., Bhutta, Z. A., Caulfield, L. E., de Onis, M., Ezzati, M., Mathers, C., & Rivera, J. (2008). Maternal and child undernutrition: global and regional exposures and health consequences. The Lancet, 371(9608), 243–260. https://doi.org/10.1016/S0140-6736(07)61690-0

Brummett, R. E., Lazard, J., & Moehl, J. (2008). African aquaculture: Realizing the potential. Food Policy, 33(5), 371–385. http://doi.org/10.1016/j.foodpol.2008.01.005

Censkowsky, U., & Altena, A. (2013). Scoping Study on Organic Aquaculture in 5 East African Countries. www.ifoam.org

Charo-Karisa, H., & Gichuri, M. (2010). Overview of the fish farming enterprise productivity program. In End of Year Report on Fish Farming Enterprise Productivity Program Phase 1. Aquaculture Development Working Group, Ministry of Fisheries Development, Kenya.

Kinaro, Z. O., Xue, L., Nyaundi, K. J., Shen, J., Kinaro, Z. O., Xue, L., Nyaundi, K. J., & Shen, J. (2016). The mitochondrial genome of an endangered native Singidia tilapia , Oreochromis esculentus : genome organization and control region polymorphism The mitochondrial genome of an endangered native Singidia tilapia , Oreochromis esculentus : genome organizati. 1394(December). https://doi.org/10.3109/19401736.2015.1089493

KNBS (2018). Basic Report on wellbeing in Kenya. http://www.knbs.or.ke/download/basic-report-well-kenya-based-201516-kenya-integrated-household-budget-survey-kihbs/. Accessed on 21st January 2019.

KNBS (2020). Economic Survey 2020. Kenya National Bureau of Statistics https://s3-eu-west-1.amazonaws.com/s3.sourceafrica.net/documents/119905/KNBS-Economic-Survey-2020.pdf

KMFRI 2018 State of cage culture in Kenya, KMFRI publication series

Ministry of Fisheries Development (MoFD). (2010). National Aquaculture Strategy and Development Plan, November 2. Retrieved from http://www.kilimo.go.ke/fisheries/wp-content/uploads/2015/05/National-Aquaculture-Strategy-Plan.pdf

Munene, B., & Wanjiku, A. (2020). Contribution of Fisheries to Job Creation Among the Youth in Kenya. Kenya Institute for Public Policy Research and Analysis (KIPPRA) Discussion Paper No. 233 of 2020

Munguti J., Obiero, K., Musa S., Mwaluma J., Orina, P., Opiyo M., Kyule D., Mirera D., and Ochiewo J. James M. Njiru., Ogello E., Hagiwara A (Eds) (2020). State of Aquaculture Report 2020: Towards Nutrition Sensitive Fish Food Production Systems. Kenya Marine and Fisheries Research Institute, Mombasa, Kenya

Munguti, J. M., Kim, J.-D., & Ogello, E. O. (2014). An Overview of Kenyan Aquaculture: Current Status, Challenges, and

REFERENCES

Opportunities for Future Development. Fisheries and Aquatic Sciences, 17(1), 1–11. https://doi.org/10.5657/FAS.2014.0001

Musa, S., Aura, C., Owiti, G., & Nyonje, B. (2012). Fish farming enterprise productivity program (FFEPP) as an impetus to Oreochromis niloticus (L.) farming in Western Kenya: Lessons to learn. African Journal of Agricultural Research, 7(8), 1324–1330. https://doi.org/10.5897/AJAR11.1606

Ngugi, C. C., & Manyala, J. O. (2009). Assessment of National Aquaculture Policies and Programmes in Kenya.

Njiru, J. M., Aura, C. M., & Okechi, J. K. (2018). Cage fish culture in Lake Victoria: A boon or a disaster in waiting? Fisheries Management and Ecology, 1–9. https://doi.org/10.1111/fme.12283

Njiru, J. M., Aura, C. M., & Okechi, J. K. (2019). Cage fish culture in Lake Victoria: A boon or a disaster in waiting? Fisheries Management and Ecology, 26(5), 426–434. https://doi. org/10.1111/fme.12283

Obiero, K., Cai, J., Abila, R., & Ajayi, O. (2019a). Kenya: high aquaculture growth needed to improve food security and nutrition. Rome, Italy http://www. fao. org/3/ca4693en/ca4693en. pdf.

Obiero, K., Meulenbroek, P., Drexler, S., Dagne, A., Akoll, P., Odong, R., ... & Waidbacher, H. (2019b). The contribution of fish to food and nutrition security in Eastern Africa: Emerging trends and future outlooks. Sustainability, 11(6), 1636.

Obwanga, B., & Lewo, M. R. (2017). From aid to responsible trade: driving competitive aquaculture sector development in Kenya; Quick scan of robustness, reliability and resilience of the aquaculture sector. https://doi.org/10.18174/421667

Ogello, E. O., & Munguti, J. M. (2016). Aquaculture: a promising solution for food insecurity, poverty and malnutrition in Kenya. African Journal of Food, Agriculture, Nutrition and Development, 16(4), 11331-11350.

Ogello, E. O., Obiero, K. O., Kyule-Muendo, D., Ochieng, S., Munguti, J., Owelle, M. L. (2021). Diagnostic Study on Blue Economy for Strategic Planning. March 2021, MasterCard Foundation PP 111.

Ole-MiYoi (2017)

Ole-MoiYoi, L. K. (2017). Fishing for Answers: Can aquaculture transform food security in rural Kenya? (Issue March 2017) [PhD Dissertation, Standford University]. http://purl.stanford.edu/zf051hh9063

Opiyo, M. A., Marijani, E., Muendo, P., Odede, R., Leschen, W., & Charo-Karisa, H. (2018). A review of aquaculture production and health management practices of farmed fish in Kenya. International Journal of Veterinary Science and Medicine, 6(2), 141-148.

Rampa, F., and Dekeyser, K. 2020. Agri-Invest-Food Systems Project – Political economy analysis of the Kenyan food systems. Key political economy factors and promising value chains to improve food system sustainability. Rome, FAO. https://doi.org/10.4060/cb2259en

Republic of Kenya (2017). National Food and Nutrition Security Policy Implementation Framework (2017–2022). Nairobi, Kenya

Republic of Kenya. (2019). Agricultural sector transformation and growth strategy: Towards sustainable agricultural transformation and food security in Kenya. Nairobi: Republic of Kenya.

Rothuis, A., Duijn, A. P. van, Rijsingen, J. van, Pijl, W. van der, & Rurangwa, E. (2011). Business opportunities for aquaculture in Kenya: With special reference to food security. http://www.wur.nl/en/Expertise-%0AServices/Facilities/Library.htmponds, in the top ten counties in Kenya in 2019 is presented in Figure 1.1. Kakamega county had the highest number of households rearing fish (2110), followed by Bungoma county (1408) then Meru county (1011). The distribution of households rearing fish in all the counties in the country is indicated in Appendix 1.

CHAPTER 2

INLAND AQUACULTURE: TRENDS AND PROSPECTS

SAFINA MUSA, CECILIA GITHUKIA, JOHN OKECHI, ELIJAH KEMBENYA, VERONICA OMBWA, SHEBAN HINZANO, JACOB ABWAO

Key Messages

- In Kenya, inland aquaculture development has been driven by social and economic needs, such as nutritional improvement in rural areas, generation of supplementary income, diversification of income activities, and creation of employment opportunities.
- However, lack of quality feed and seed is a major bottleneck to the industry. If available, the costs of feed and seed are still high for resource-poor farmers.
- Most fish farming in Kenya is still pond based with low stocking density (3 fish/m2) hence low productivity. Low adoption of improved technologies e.g. RAS systems continue to constrain efforts to increase aquaculture productivity.
- Inadequate funding by the Government and other financial institutions:
- Insufficient budgetary allocation for the aquaculture sub-sector is a key constraint. This
- allocation has reduced human resource and service delivery.
- Limited capital and access to affordable credit: Aquaculture is considered highly risky by the formal banking sector; thus, it gives aquaculture little attention.
- Conflicts in water resource use: Unregulated cage culture has emerged in Lake Victoria hence competing with other resource users e,g, boat operators and fishers.
- Climate change: Variability of floods and droughts is likely to increase with global climate change, hence negatively affecting aquaculture.

Policy Recommendations

- Value addition: Fish farmers needs to embrace value addition in order to add value to their products and improve shelf life of the products.
- New and expanding markets: The local, regional and international markets are still unexploited. The ever rising local and regional demand for fish creates an avenue for production of more fish.
- Embrace new technologies: Need for investment in intensified aquaculture without major environmental costs/impacts.
- Develop market information system: Use of ICT e.g. Mobile telephones will increase market information and access especially among the rural community.
- Development of aquaculture policy and legislation to create an enabling environment.
- Develop marketing infrastructures e.g. roads.
- Weak and inadequate legislation and aquaculture regulations: fragmented legal and regulatory framework remains a challenge to development in the sub-sector
- Intensive culture of fish in ponds, raceways, tanks and other facilities results in effluents with high levels of nutrients which when released in the natural water body can cause eutrophication and conflicts with other water users.
- Therefore, implementation of the Ecosystem Approach to Aquaculture (EAA) could facilitate sustainable utilization of water resources in cage culture and hence overcoming constraints in facing the above-mentioned challenges

Musa, S., Githukia C., Okechi, J., Kembenya E., Ombwa, V., Hinzano S., & Abwao J. (2021). Inland Aquaculture: Trends and Prospects. In: Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition-Sensitive Fish Food Production Systems; Chapter 2: pp 21–38

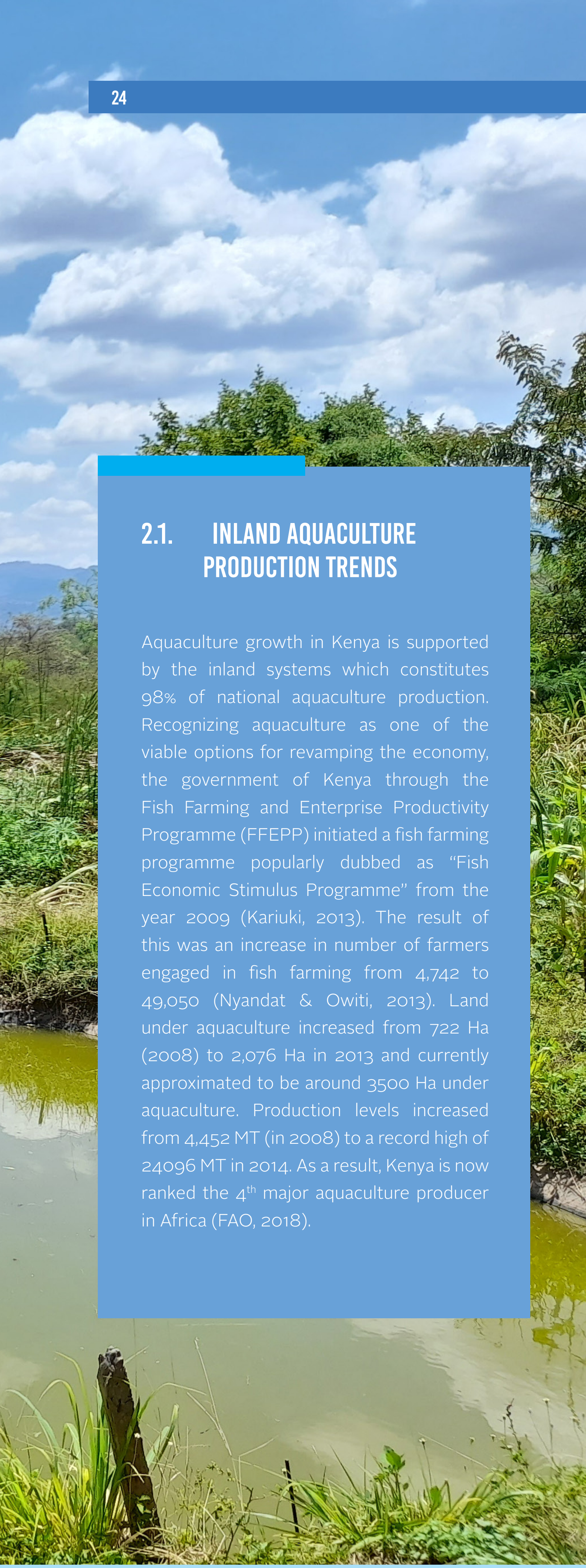
2.0. INTRODUCTION

In Kenya, inland aquaculture development has been driven by social and economic needs, such as nutritional improvement in rural areas, generation of supplementary income, diversification of income activities, and creation of employment opportunities. The 2019 budget policy statement, the basis of the national budget, pegs local fish production at 180,000 tonnes a year. That is against the country's requirement of 500,000 tonnes a year (GOK, 2019). Business entrepreneurs have taken the advantage of the fish supply deficit to import frozen tilapia mainly from China. However, the fish imports still do not satisfy the deficit. Aquaculture is therefore viewed as an activity likely to augment national shortfalls in fish supplies, thereby reducing fish imports.

Inland finfish culture in the country has been practiced in earthen ponds and more recently in cages. In Lake Victoria, there has been a rapid increase in the cage numbers and cage production, reaching 4,000 cages and over 6,000 tonnes of Nile tilapia and further growth is expected (Njiru et al., 2018, Aura et al., 2018, Hamilton et al., 2020). Taking in to account the anticipated environmental pressures of the cages, coupled with mutiple user-conflicts, the government through the National Fisheries office issues licence for cage culture after ensuring that the investor meets the necessary requirements (Aura et al., 2017).

For improved aquaculture production there is need to identify priorities to enhance national, regional and county cooperation and strengthen technical inland aquaculture capacities. Such priority areas include mapping aquaculture site selection and carrying capacity estimates for inland aquaculture in the country for example, the huge unexploited potential in inland dams, reservoirs and flood plains.

Additionally, there needs for more research on the ecological capacity of inland water bodies for cage fish farming; inland aquaculture production sustainability (profitability versus socio-economic considerations), and integrated aquaculture farming systems to make production more profitable. Up to date records on aquaculture production are critical to the sustainable management of aquaculture in the country. This is more so for policy planning in the sector and bridging food deficit in the country. There should be renewed efforts to improve data quality collection on inland aquaculture production. This can be addressed both at National and County levels of governance.



2.1. INLAND AQUACULTURE PRODUCTION TRENDS

Aquaculture growth in Kenya is supported by the inland systems which constitutes 98% of national aquaculture production. Recognizing aquaculture as one of the viable options for revamping the economy, the government of Kenya through the Fish Farming and Enterprise Productivity Programme (FFEPP) initiated a fish farming programme popularly dubbed as "Fish Economic Stimulus Programme" from the year 2009 (Kariuki, 2013). The result of this was an increase in number of farmers engaged in fish farming from 4,742 to 49,050 (Nyandat & Owiti, 2013). Land under aquaculture increased from 722 Ha (2008) to 2,076 Ha in 2013 and currently approximated to be around 3500 Ha under aquaculture. Production levels increased from 4,452 MT (in 2008) to a record high of 24096 MT in 2014. As a result, Kenya is now ranked the 4th major aquaculture producer in Africa (FAO, 2018).

> **"BY 2016, THERE WERE 6 COMMERCIAL RACEWAY ESTABLISHMENTS IN KENYA ALL LOCATED IN MOUNT KENYA REGION. PRODUCTION FROM THE RACEWAY FARMS WAS 214 MT IN 2016 WHICH WAS VALUED AT 1,430, 000 USD.**

The post FFEPP has seen total fish output dropping by 19.8 per cent from 24096 MT in the year 2015 to 13656 MT in 2016 and a corresponding reduction in the number of ponds from 69,194 to 60,277. However, the output from aquaculture increased by 24% from 15320 MT in 2018 up from 12356 in 2017 (figure 1).

Aquaculture sector has been supported by other government-initiated projects through multi-institutional collaboration frameworks. Briefly discuss achievements of ASARECA, KAPPAP, KCDP in the Kenyan aquaculture sector and insert the acronyms in the list.

Between 2014 and 2016, KMFRI, Maseno University and Nagasaki University, Japan conducted Joint research project titled 'Lake Victoria Comprehensive and Aquatic Environment Research for Development' ***(LAVICORD)*** funded by the Japanese Government. The aquaculture component of the project, which was domiciled in Maseno University and KMFRI produced significant strides in the domestication and culture of Nile Perch ***(Lates niloticus)*** (Outa and Ogello 2019)., and native fish Labeo victorianus (Labeo) (Kembenya et al. 2016). The study revealed that ***L. niloticus*** attained up to 400 g in cages and 120 g in ponds systems within 6 months of culture. However, the major challenge was suitable feeds for *L. niloticus* under captivity. The project also supported cage culture of tilapia in several beaches in Siaya and Homabay Counties. The increase in production is as a result of the cage culture system being adopted in Lake Victoria and freshwater dams in Kenya. Production from cages is estimated to produce 40,000 tons of fish per year (Njiru, & Aura, 2019), which is expected to triple fish production from the inland aquatic systems.

2.2. CULTURED SPECIES

Nile tilapia ***(Oreochromis niloticus)*** and African catfish ***(Clarias gariepinus)*** are the major farmed fish species in Kenya. Nile tilapia contributes 75% of cultured fish followed by catfish at 18%. These species are found in almost all aquatic systems in Kenya (Musa et al., 2017) and have high consumer preference locally and regionally. Common carp ***(Cyprinus carpio)*** and Rainbow trout ***(Oncorhynchus mykiss)*** contributes 4% and 1% respectively (Opiyo et al, 2018). Both common carp and rainbow trout were introduced to Kenya in the colonial era. Nile tilapia and African catfish can be reared in any freshwater culture system. However, Rainbow trout is limited to cold areas at the slopes of Mount Kenya where water temperature do not rise above 19° C. Some ornamental fishes produced in small scale mostly for regional market include Koi carp, Goldfish, and Sword tail. KMFRI has made efforts to culture indigenous species; African carp *(Labeo victorianus), Oreochromis jipe* and *Oreochromis niloticus baringoensis.* Domestication and breeding trials for *Protopterus aethiopicus* are ongoing. Photos of the main cultured fish species in Kenya are in plate 1.

a) Nile tilapia (Oreochromis niloticus)

b) Catfish (Clarias gariepinus)

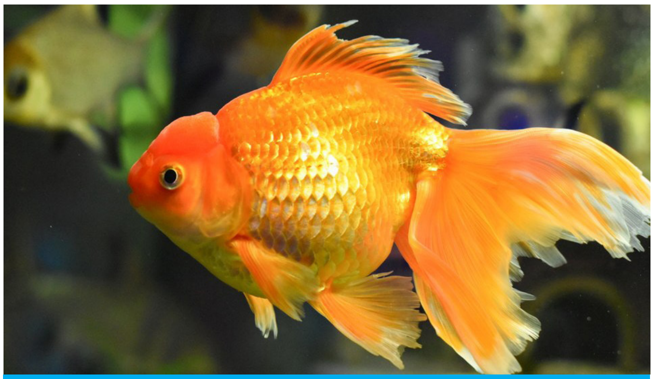
c) Common carp (Cyprinus carpio)

d) Tilapia jipe (Oreochromis jipe)

e) Rainbow trout (Oncorhynchus mykiss)

f) Oreochromis niloticus baringoensis

g) Lungfish (Protopterus aethiopicus)



h) Goldfish (Carassius auratus)

i) African carp (Labeo victorianus)

2.3. FORMS OF FRESHWATER AQUACULTURE IN KENYA KENYA

Kenya's aquaculture systems range from small-scale, medium scale and large-scale operations with some farms being intensive, semi-intensive and extensive systems. The culture techniques include pond, tanks, raised wooden boxes, raceways, aquaponics, recirculating aquaculture systems (RAS), dams and cages. There are also different forms of integration which include agri-based fish farming such as fish-vegetable and rice-fish; and livestock fish farming e.g. pig-fish and fish-poultry integration (Ogello et al. 2013). Integration ensures efficient water and waste utilization, reduced cost of fertilization and results to economic efficiency. Classification of Fresh water aquaculture in Kenya include; i) Coldwater culture, involving the cultivation of rainbow trout *(Oncorhynchus mykiss)* in highland areas, ii) Warm water culture, involving the cultivation of *Tilapine* fishes, the African catfish *(Clarias gariepinus)*, common carp *(Cyprinus carpio)* and a variety of ornamental fishes in low land regions of the country. The common culture techniques include: -

(a) Pond Aquaculture

Pond aquaculture is the predominant practice in Kenya. During the Economic Stimulus Package (ESP) in the year 2009-2012, ponds were constructed in many parts of the country after mapping areas which were suitable for aquaculture (Fig. 2). The distribution of aquaculture activities by region indicates a high concentration of activities in several counties and low concentration in others (Table 2). Highest pond numbers and aquaculture related activities are found in Kakamega, Bungoma, Busia, Kisii, Meru, Nyeri, Kisumu, Muranga, Embu counties, among others, while relatively lower activity are noted in Kitui, Lamu and Elgeyo Marakwet.

The ESP intervention resulted in an upward and significant growth to a peak of 24,096 MT in 2014 (Munguti et al., 2017). However, when the support ended, the sector registered a decrease in production to about 14,952 MT in 2016 (KMFRI, 2017). Therefore, the sustainability of aquaculture in the country was challenged after the government support through ESP ended.

Plate 1: Ultraviolet-treated Pond liners and earthen pond in Kenya

(b) Cage culture

Fish farming in cages is done in existing water bodies (ponds, rivers, lakes, dams, and oceans) and this culture method is a plausible livelihood alternative for those investors without land suitable for fish farming. The fish are enclosed in the cage net that allows free water exchange as feeding is done as required. Only strong, durable, and nontoxic materials are used to construct the cages, which vary in size and shape. The location of the cage in the water body is critical for proper water circulation and stipulated guidelines should be followed. Kenya Marine and Fisheries Research Institute (KMFRI) has mapped areas that are dimmed suitable for cage fish farming in Lake Victoria, Kenya. Recent studies by Orina et al., 2018 on fish cage culture in Lake Victoria have revealed a relatively remarkable increase in the number of cages from < 2000 in 2016 to > 3696 in 2018. With the high stocking densities and impressive growth rates, cage culture sounds a probable solution to aid in filling the demand-supply gap of fish in Kenya. However, environmental pressures emanating from cage farming should be closely monitored to ensure sustainability taking in to account other water uses.

In this regard, the carrying capacity of the cages should be estimated based on limnological and farming field data. This data is vital in evaluating the area-specific nutrient loads that can be assimilated and in determining the scale of operation(s). To reduce the environmental impact of cage culture specifically in relation to excess feeds and faecal matter release, use of multi-layered cage farming has been proposed.

This is based on the principle that uneaten feeds provided for the species in the inner cages are consumed by those fish in the outer cages (Li et al., 2018). This technique also reduces feed utilization efficiency cutting on production costs and increasing returns. Further, this system is effective in improving resistance to wind and waves and reducing the risk of escape of cultured species *(Wang et al., (2015).*

Plate 4: Cage fish farming in pond

Plate 5: Tilapia fish cages in Dunga beach, Lake Victoria, Kenya

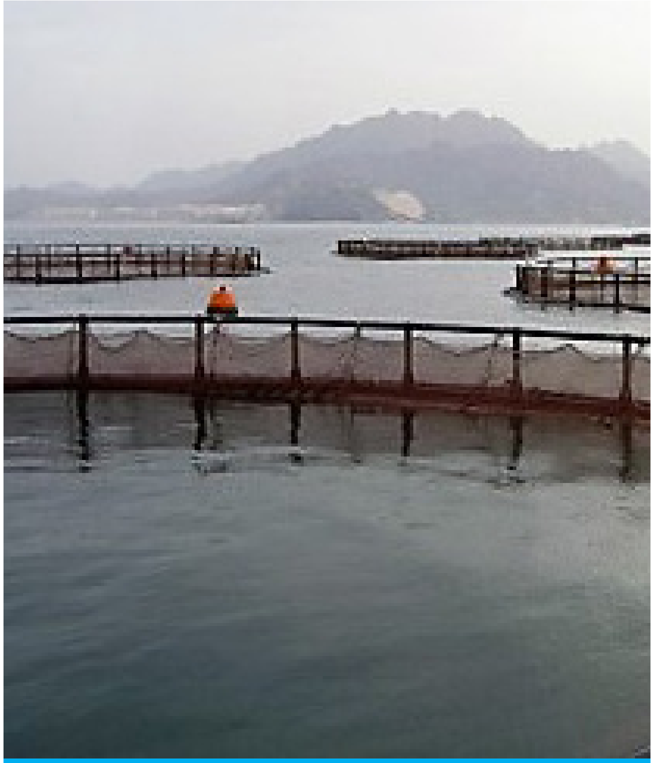


Plate 6: High Density Polyethelyne (HDPE)) fish cage farming in Mfangano Island, Kenya

(c) Integrated fish farming

An integrated fish culture approach involves the connection of agricultural systems to fish farming in a design that allows waste from one system to be used as input in another system, conserving resources and boosting returns *(Shoko et al., 2011)*. Common forms of integration in Kenya include fish-poultry and vegetable poultry *(Ogello et al., 2013)*. The advantages of integration include farm waste and water recycling, which is highly advantageous to the farmers as it improves the economy of production and decreases the adverse environmental impact of farming.

(d) Rice-Fish Farming

This involves the use of rice fields to grow rice and raise fish concurrently or rotationally as a way of increasing productivity without increasing the area under cultivation. The general acceptance of integrating rice-fish farming often increases rice yield by up to 10% and at the same time produces fish while using the same resource base of land, water and labour. Rice-fish farming has diversified livelihood options for poor farmers, increased their incomes while reduced their vulnerability *(Rasowo and Auma, 2006)*. By using this technique, farmers are relieved of birds chasing as fish find shelter under the dense rice plants, while they, in turn, provide a source of fertilizer with their droppings, eat insect pests and help to circulated oxygen around the rice field. Therefore, relevant to Kenya's Agricultural development Plan of increasing productivity, farmer's income and improving the nutrition of the rural population

(e) Recirculating Aquaculture Systems (RAS)

Recirculation aquaculture system (RAS) is a new and unique way to farm fish in Kenya although has been in existence since the mid-1950s. This system rears fish at high densities, in tanks or raceways probably under greenhouses or in a "controlled" environment. RAS conserve both water and land because they maximize production in a relatively small area of land and use a relatively small volume of water. The system filters and cleans the water back through culture tanks with the occasional addition of clean water, only to make up for evaporation and for water used to flush out waste material. Fish grown in RAS need a continuous supply of clean water at a predetermined temperature and dissolved oxygen content that is optimum for growth. Use of a filtering (biofilter) system is necessary as it helps in the purification of water and removal or detoxification of harmful waste products, and uneaten feeds. In this system, fish must be fed a nutritionally complete feed daily to encourage fast growth and high survival.

Plate 7: Recirculating Aquaculture System (RAS) in Mwea Aquafish farm Picture by Prof. C. Ngugi

2.4. INTENSIVE AQUACULTURE SYSTEMS

There are three major aquaculture production systems classified based on the level of feeding namely extensive, semi-intensive and intensive systems. Extensive systems depend entirely on endogenous food produced by the system such as plants, planktons and benthos whereas semi-intensive systems supplement endogenous food with commercial feed *(Billard and Dabbadie 1993).* The endogenous food produced in the two systems sometimes is enhanced by the application of fertilizer. Intensive systems on the other hand exclusively supply commercial feed to the fish cultured. Intensive systems are less common in Kenya probably due to the high initial investment cost required to set up the systems. Nevertheless, a few farmers in Kenya have embraced intensive aquaculture production systems.

Plate 8: Raceways fish farming

AQUAPONICS

A conventional aquaponics model consists of a recirculatory aquaculture system (RAS) integrated with plants production whereby nutrients-rich water from fish production units is channeled to plants beds which utilize the nutrients before the water returns to the fish rearing units *(Timmons and Ebeling 2010, Palm, et al. 2018, Dijkgraaf et al. 2019).* In a well-designed aquaponics system, there are provisions for eliminating solid waste such as faecal matter and uneaten feed by mechanical filtration or settling tanks, and partial reduction of soluble nitrogenous wastes by biofilters before the water reaches the plant's beds (*Timmons and Ebeling 2010)*. Improved aquaponics models allow one-way flow of water from fish rearing units to plant beds while permitting regular top-ups with new water in the fish culturing units. In such settings, higher nutrients levels in the plants' beds can be maintained unlike in conventional aquaponics models where nutrients in the water from fish units are low due to the continuous biofiltration in the system *(Dijkgraaf et al. 2019).* In Kenya, aquaponics is a new technology of fish farming that has so far received low uptake. Currently, there is one commercial aquaponics farm (Kikaboni farm) located south-west of the capital, Nairobi. The layout of the farm is as presented in Figure 2.1. The advantage of aquaponics is that it provides an opportunity to produce an extra product (plants) using the same resources hence increasing the revenues generated.

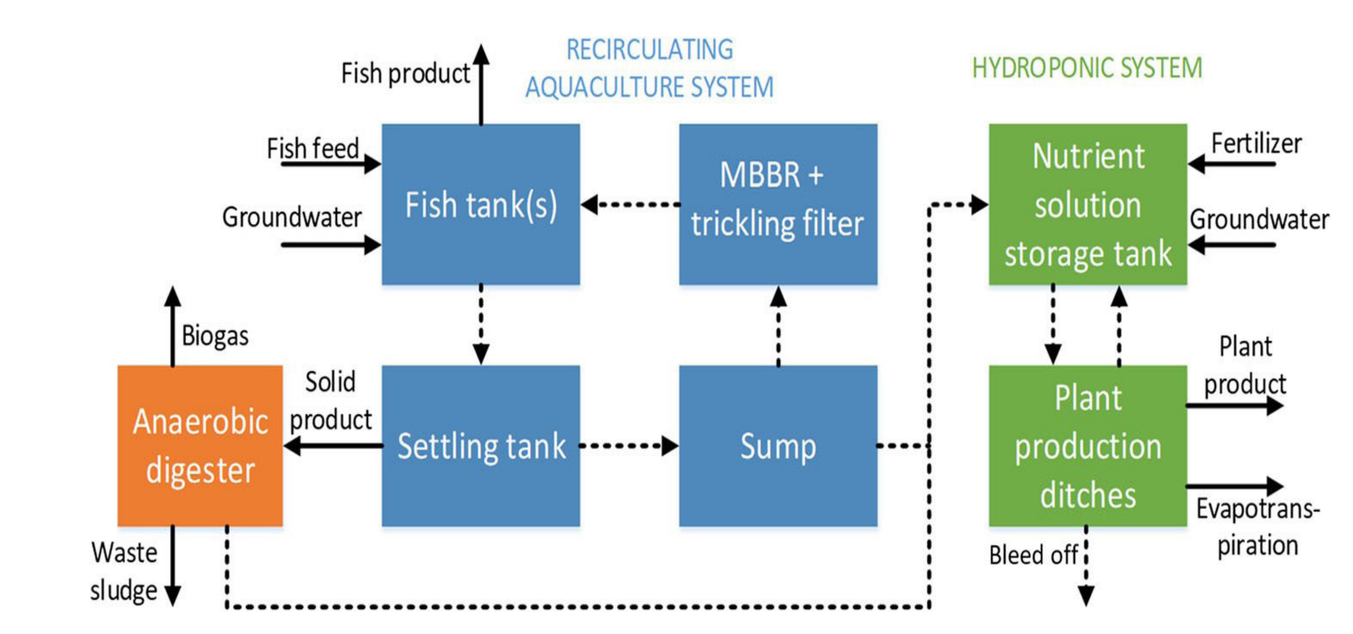


Figure 2.1: Layout of Kikaboni aquaponics farm in Kenya. Source (Dijkgraaf et al. 2019)

RECIRCULATORY AQUACULTURE SYSTEM (RAS)

It is a system of fish production where wastewater from fish culture units is purified before is pumped back into the fish culturing units. The water purification systems in RAS involves filtration using mechanical filters or settling tanks to remove solid wastes, biofiltration to remove soluble nitrogenous wastes and disinfection of the filtered water using UV light or ozone to lower microbial load (Jenner 2010, Timmons and Ebeling 2013). Some adjustments of water quality could be done through oxygenation to raise levels of dissolved oxygen, the addition of calcium carbonate or hydrochloric acid to adjust pH, and heating and cooling to bring temperature to the optimal range for the species being cultivated (Timmons and Ebeling 2013). The system is suitable in areas with limited water supply and land (Jenner 2010). According to Opiyo et al (2018), the RAS system in Kenya consists of tanks placed indoor or under greenhouses and is largely used for rearing Nile tilapia and African catfish. Normally, fish in RAS are reared at high stocking rates of between 5 and 20 fingerlings per cubic metre for the investment to make economic sense (Opiyo et al 2018).

A total of eight RAS farms in the country have been reported out of which one (Kamuthanga farm) has received EcoMark Africa (EMA) certification making it the first fish farm to receive such accreditation in Africa *(FTA 2019).* As of 2016, the total production from RAS in the country was about 200 tonnes/ha/year. Recirculatory Aquaculture System is a new technology being implemented in Kenya and the low uptake of the technology observed could be associated with the high initial investment cost required to set up a fully operational RAS system (Opiyo et al. 2018). With RAS system, farmers have been able to scale down the grow out period of tilapia to market size from eight months in traditional ponds to four months at the same time reducing the amount of water required for production to 20% (Volkers 2014).

Plate 10. Layout of recirculatory aquaculture systems at Kamuthanga farm (a) and Mwea fish farm (b). (Source Volkers 2014)

CAGE CULTURE

Cage farming uses existing water bodies such as lakes, rivers, lagoons and Open Ocean. The fish reared are confined in a netting structure that is enclosed in all or all sides except the top (Michael 2008). Intensive cage farming began in Kenya in 2013 after successful cage farming trials were conducted by KMFRI in partnership with Dunga Beach Cooperative Society and Association for Strengthening Agriculture Research in East and Central Africa (ASARECA) in Kisumu (Opiyo et al. 2018).

Cage farming is exclusively done in Lake Victoria mainly by counties bordering the lake which include Migori, Kisumu, Siaya, Homabay and Busia. By 2017, 3696 cages were reported in the lake with volumes ranging between 8 to 27 m^3 and a stocked rate ranging from 100 to 125 fingerlings/ m^3 *(Orina et al. 2018, Opiyo et al. 2018).*

The cage designs used in the lake are variables and the choice on which design to use is determined by factors such site, cost, water current and the intended investment period. The cage designs reported as of 2017 include mild metal (Plate 1), polyvinyl-chloride, wooden frame and HDPE cages (Plate 2). Majority of cages are owned by groups and the management of cages is dominated by men. In 2017, the total yields from cage farming were estimated at 3,180 MT which was valued at 9.6 million USD (Orina et al. 2018). The potential of cage culture in Kenya is great considering the huge deficit in the supply of fish in the country. It's important to note that there are key challenges that need to be addressed regarding cage farming such as resource use conflicts, lack of quality fish seed and feeds as well as emerging fish disease and lake mixing that has been associated with fish kills in cages *(Aura et al. 2018, Orina et al. 2018).*


Plate 1: A locally designed cage using metal and plastic drums at Bondo, Siaya County (a) and (b) HDPE cage at Rio Holdings Ltd Homabay County. (Source Oketch 2014, Oduor 2018)

RACEWAYS/ FLOW-THROUGH SYSTEM

In raceways system, water runs continuously through the fish rearing units. Raceways are mainly associated with areas having plenty of water supply more so near streams and springs. The system can be used to produce fish species such as rainbow trout, catfish, tilapia (WA 2015). In Kenya, raceways have been mainly used to produce rainbow trout. By 2016, there were 6 commercial raceway establishments in Kenya all located in Mount Kenya region. Production from the raceway farms was 214 MT in 2016 which was valued at 1,430, 000 USD. The growth of the sector has been slow probably due to the high quality feeds need that is only affordable to a few farmers *(SDF 2014, Opiyo et al. 2018).* This is system is being considered for the culture of *Labeo victorious* in the National Aquaculture Research Development and Training Centre, (NARDTC) Sagana.

2.5. ENVIRONMENT AND SOCIAL IMPACTS OF INLAND AQUACULTURE

Aquaculture provides employment, income and food nutrition and security across the globe. While the natural fish stocks from Lake Victoria appear to be declining from overfishing among other factors (LVFO, 2018), demand for fish protein continues to rise as a result of rapid population growth and increasing awareness of health benefits of eating fish (FAO, 2016). Aquaculture, with its intensification, therefore, serves as an alternative to reducing the widening gap between fish demand and supply (Munguti et al., 2017). Notably, as the aquaculture sector continues to grow rapidly across the globe so are the social and environmental impacts.

However, for fish farming to be sustainable, environmental and social sustainability of the operations should be put in place to create a win-win situation for the investors and the communities dependent on the shared resources. Common criticisms in aquaculture are related to nutrient loading, escapee and chemical (some hormonal) effluents which affect the water quality and natural biodiversity. The environmental impact of aquaculture is mainly dependent on the intensity of production (which determines the discharge of waste such as chemicals, feed remains and excreta), and the location of the farm. Sustainable aquaculture requires the adoption of new strategies for fish farming to ensure low waste discharge. Different aquaculture systems have different environmental and social impacts.

> **“AQUACULTURE, WITH ITS INTENSIFICATION, THEREFORE, SERVES AS AN ALTERNATIVE TO REDUCING THE WIDENING GAP BETWEEN FISH DEMAND AND SUPPLY"**

(a) Environmental impacts on Fisheries

Aquaculture impacts heavily on fisheries because of the heavy reliance of fish as a source of animal protein for feed formulation. Use of fish meal also creates competition for food currently used for human consumption *(Naylor et al., 2009)* especially *Omena (Rastrineobola argentea).* This negatively impacts on the fisheries causing overfishing and affecting recruitment and creates an imbalance in the ecosystem. Use of alternative feed sources such as plant-based protein rich in essential, non-essential proteinogenic amino acids with high levels of omega 3 FA such as many species of freshwater macrophytes can act as an alternative source of protein (Appenroth, 2018) and reduce overdependence on already overfished stocks.

(b) Cage culture

The Kenyan side of Lake Victoria has an estimated surface of 4128 km^2 which supports several economic sectors such as navigation, ecotourism, water transport, capture fisheries, water abstraction, and recently cage culture among others *(Aura et al., 2013).* Therefore, this resource needs to be well utilized for the benefits of multiple users and environmental sustainability. Environmental concerns in cage culture include released waste resulting from uneaten feeds and faecal waste causing nutrient loading, organic enrichment and sediment build-up. The number of cages should be monitored to avoid depletion of dissolved oxygen which may affect community diversity with negative implication on food chains and biodiversity. Some cages are installed on sites that are breeding grounds for the wild stocks. This may pose a danger to fish recruitment and ultimately affecting the fishery. Given the high stocking densities in the cages, there are chances of disease occurrence which may ultimately affect the wild stocks causing mass mortalities. Therefore, the need for regular monitoring and screening the stocked fish.

Social concerns in cage culture include conflicts between cage investors and other lake users such as navigational challenges and competition for space with traditional fishers and boat parking bays (Mwainge et al., 2018). There have also been reported cases of fish theft from the cages. Some investors suffer huge losses as the fish was stolen when almost ready for market.

These challenges can be addressed by proper stakeholder engagement through BMUs and cage investors to ensure community participation in the process. As a result of the multifaceted uses of the water body, it is vital to take into account issues of environmental sustainability and social impacts of cage fish farming to cater for waste assimilation and multiple users respectively (Kairo et al., 2017).

(c) Land-based intensive culture and crop-livestock- fish (CLF) integration

Intensive culture of fish in ponds, raceways, tanks and other facilities results in effluents with high levels of nutrients which when released in the natural water body can cause eutrophication and conflicts with other water users. Thus, such effluent should go through a constructed wetland or settling ponds before disposal. Farmers can also adopt the use of a biofloc system where waste materials like uneaten feeds and faeces are converted in to feed fish and shrimp, thereby reducing waste output while driving down feed costs and enhancing farm productivity. On the other hand, integrated crop-livestock-fish (CLF) culture systems pose a challenge of accumulation of pesticides and heavy metals in fishponds and pond sediments (Munguti et al., 2017). To curb this, farmers should minimise the use of chemicals and veterinary drugs; they should embrace use natural alternatives. Most importantly, when treating sick fish, it is far better to conduct treatments in a separate quarantined environment where chemicals are not released into the natural environment. Before any aquaculture system is put in place, an Environmental Impact Assessment (EIA) should be conducted to ascertain its effectiveness and feasibility; it should have minimal negative effects on the environment. Besides, environmentally sensitive areas such as swamps should be avoided as this may have severe consequences on

(d) Invasive non-native species (INNS)

These are plants and animals which do not naturally occur in a specific location and can spread quickly enough to rob native species of resources. They can eventually overtake and replace native species or hybridize them resulting in adulteration of a gene pool of the natural stocks altering the species composition and diversity with irreversible effects. Such species threaten the ecological stability of the habitats affecting the native species interactions in the environment such as predation, competition and herbivory. Aquaculture operations should, therefore, be monitored to contain the species within the rearing facilities.

(e) Other inputs in the rearing facilities.

Inputs in rearing facilities for example chemicals, drugs and hormones, can adversely affect the water quality of the recipient water body, pose a risk of diseases and genetic distortion. There has been a debate on the effluent of water used for the preparation of sex-reversal feed. If this water finds its way into the natural system, it can affect the fauna causing sterility or sex reversal. The effluent should be well managed, probably by treating it through a constructed wetland for 14 days to allow a combination of processes such as photolysis, plant uptake, microbial degradation and soil resorption which reduce the effectiveness of the hormone ***(White et al., 2006).*** However, after rearing the hormonal treated fish for six months, the fish is usually free of the hormone and therefore not detected in table size fish (Guerero, 2008; Megbowon and Mojekwu, 2014).

(f) Water Abstraction

Fish farming should positively contribute to existing socioeconomic activities e.g. use of water for other purposes e.g. irrigation and domestic, other forms of farming within the locality and the overall development of communities. Therefore, water abstraction should be legally approved by authorities so as not to cause conflicts between the users. Additionally, the volume abstracted should not negatively affect the biological integrity of the environment.

2.6. CHALLENGES AND WAY FORWARD

Aquaculture in Kenya is one of the fastest-growing sectors in Sub-Saharan Africa. This expansion has been due to increasing demand coupled with rapid dwindling catches from capture fisheries. Notably, the rapid growth of the sector has also been due to government support under the Fish Farming Enterprise Productivity Program (FFEPP), under the Economic Stimulus Program (ESP). Despite the rapid growth, the sector still faces myriads of challenges, which needs deliberate efforts to address them. Some of the most important challenges include:

1. Absence of linkages between farmers and research/ extension hence most of these research programs are not demand-driven.
2. Lack of quality feed and seed is a major bottleneck to the industry. If available, the costs of feed and seed are still high for resource-poor farmers.
3. Poor market linkages: Most of the aquaculture fish is sold at the farm gate due to lack of awareness of available markets and poor road networks. Fish being a perishable commodity, farmers are forced to sell at a lower price at the farmgate.
4. Lack of certification process in aquaculture operations, therefore, inability to meet export markets' stringent conditions.
5. Low adoption rate of aquaculture technology: Most fish farming in Kenya is still pond based with low stocking density (3 fish/m2) hence low productivity. Low adoption of improved technologies e.g. RAS systems continue to constrain efforts to increase aquaculture productivity.
6. Weak and inadequate legislation and aquaculture regulations: fragmented legal and regulatory framework still remains a challenge to development in the sub-sector

7. Inadequate funding by the Government and other financial institutions: Insufficient budgetary allocation for the aquaculture sub-sector is a key constraint. This allocation has reduced human resource and service delivery.
8. Limited capital and access to affordable credit: Aquaculture is considered highly risky by the formal banking sector; thus, it gives aquaculture little attention.
9. Conflicts in water resource use: Unregulated cage culture has emerged in Lake Victoria hence competing with other resource users e.g., boat operators and fishers.
10. Climate change: Variability of floods and droughts is likely to increase with global climate change, hence negatively affecting aquaculture.
11. Cross-cutting issues: Increasing incidences of HIV and AIDS, and most recently Corona Virus diseases have resulted in the loss of productive personnel and of the manual labour force with sustained farming knowledge and have resulted in diversion of resources to treat these diseases.

WAY FORWARD

1. Value addition: Fish farmers needs to embrace value addition in order to add value to their products and improve shelf life of the products.
2. New and expanding markets: The local, regional and international markets are still unexploited. The ever rising local and regional demand for fish creates an avenue for production of more fish.
3. Embrace new technologies: Need for investment in intensified aquaculture without major environmental costs/impacts.
4. Develop market information system: Use of ICT eg. Mobile telephones will increase market information and access especially among the rural community.
5. Development of aquaculture policy and legislation to create an enabling environment.
6. Develop marketing infrastructures e.g. roads.
7. The implementation of the Ecosystem Approach to Aquaculture (EAA) could facilitate sustainable utilization of water resources in cage culture and hence overcoming constraints in facing the above-mentioned challenges.

REFERENCES

Appenroth K., Sree, K.S., Bog, M., Ecker, J., Seeliger, C., Böhm, V., Lorkowski, S., Sommer, K., Vetter, W., Tolzin-Banasch, K., Kirmse, R., Leiterer, M., Dawczynski, C., Liebisch, G., and Jahreis, G. (2018). Nutritional Value of the Duckweed Species of the Genus Wolffia (Lemnaceae) as Human Food 6: 483. doi:10.3389/fchem.2018.00483

Aura M. C., Musa S., Njiru J., Ogello E.O., Kundu R., (2013). Fish-Restocking of Lakes in Kenya: Should solemnly be an Environmental Issue, 39-60pp. In: Adoyo, W.A. &Wangai, C. I. African Political, Social and Economic Issues: Kenya Political, Social and Environmental Issues. NOVA Science Publishers, Inc. New York. ISBN: 978-1-62081-085-9.

Aura, C. M., Musa, S., Yongo, E., Okechi, J. K., Njiru, J. M., Ogari, Z and Ombwa, V (2018). Integration of mapping and socio-economic status of cage culture: Towards balancing lake-use and culture fisheries in Lake Victoria, Kenya. Aquaculture research, 49(1), 532-545.

Billard, R and Dabbadie, L (1993). Production systems in aquaculture. Proc. 4th Natl. Symp. Oceanogr. Fish, pp. 405-417

Otieno, M.J. (2011). Fishery Value Chain Analysis – Background Report –Kenya http://www.fao.org/fileadmin/user_upload/fisheries/docs/Background_Report_-_Kenya.doc.

Brummett, R. E. and R. Noble, (1995). Aquaculture for African Smallholders. ICLARM Tech. Rep. 46, 69p.

Charles, C. N., |James, R. B., |Bethuel, O. (2007). Introduction to the basic concepts of fish farming in Kenya available to all who need it.

Denny, P. W., Shams-Eldin, H., Price, H. P., Smith, D. F. & Schwarz, R. T. (2006). The protozoan inositol phosphoryl ceramide synthase: A novel drug target that defines a new class of sphingolipid synthase. Journal of Biological Chemistry 281(38): 28200-28209.

Dijkgraaf, K. H., Goddek, S., & Keesman, K. J. (2019). Modeling innovative aquaponics farming in Kenya. Aquaculture International, 27(5), 1395-1422.

FAO. (2006). Regional Technical Expert Workshop on Cage Culture in Africa. Entebbe, Uganda, 20-23 October 2004. FAO Fisheries Proceedings, No.6. Rome, FAO. 2006. 113p.

FAO. (2016). The state of World Fisheries and Aquaculture. Contributing to food security and nutrition for all. Rome, Italy.

FAO. (2018). The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. In AqTHE STATE OF THE WORLD series of the Food and Agriculture Organization of the United Nations.uaculture (Vol. 35). https://doi.org/issn 10.

FoodTechAfrica (March 13, 2019). Africa's first certified fish farm with EcoMark Africa label. Larive International. Retrieved March 9, 2020.

GOK. (2019). Republic of Kenya, the National Treasury and Planning. Medium Term 2019 Budget Policy Statement. Creating Jobs, Transforming Lives-Harnessing "The Big Four" February 2019.

Guerrero III, R.O., (2008). Tilapia Sex reversal. http://archive.today/OFxil.

Hamilton, S.E., Gallo, S.M., Krach, N., Nyamweya, C.S., Okechi, J.K., Aura, C., Ogari, Z., Roberts, P., ... Kaufman, L. (2019). The use of unmanned aircraft systems and high-resolution satellite imagery to monitor Tilapia fish-cage aquaculture expansion in Lake Victoria, Kenya. Bulletin of Marine Sciences. https://doi.org/10.5343/bms.2019.0063.

Jenner, A (February 24, 2010). Recirculating aquaculture systems: The future of fish farming? Christian Science Monitor. Retrieved March 10, 2020.

Kairo J., Wanjiru C., Musa S., Mutune D. M., Munguti J.M. (2017) Aquaculture and Environmental sustainability in Kenya. In: State of Aquaculture in Kenya. Laxpress Services, Nairobi, Kenya. 133p.

REFERENCES

Kariuki, N. M. (2013). Strategic Practices For Effective Implementation Of Fish Farming Enterprise Productivity Programme In Kenya : A Case Study Of Molo Constituency ISSN 2319-9725. International Journal of Innovative Research, 2(8), 127–146. Kembenya et al 2016 insert

LVFO. (2018). Guidelines for establishment and Operation of Cage Fish Farming in the East African Community. Lake Victoria Fisheries Organisation, Jinja, Uganda. Pp. 95.

Megbowon I., and Mojekwu T.O. 2014. Tilapia sex reversal using Methyl testosterone (MT) and its effect on fish, man and environment. Biotechnology, 13: 213-216. DOI: 10.3923/biotech.2014.213.216URL: https://scialert.net/abstract/?doi=biotech.2014.213.216

Michael, M (2008). What is Cage Culture? SRAC Publication No. 160.

Mulanda, A.M., Njiru, N., Okechi, J. (2018). Cage fish culture in Lake Victoria: A boon or a disaster in waiting?

Munguti J.M., Obiero K.O., Orina P.S., Musa S., Mwaluma J., Mirera D.O., Ochiewo J., Kairo J., Njiru J.M., (2017). State of Aquaculture in Kenya. Laxpress Services, Nairobi, Kenya. 133p.

Munguti, J.M., Jeong-Dae K., Ogello, E.O. 2014. An Overview of Kenyan Aquaculture: Current Status, Challenges, and Opportunities for Future Development.

Musa S., Opiyo M.A, Obiero K.O, Ogello E.O., Githukia C.M., Ombwa V., Kembenya E., Boera P., and Okechi J., (2017). Status of Frehwater Aquaculture in Kenya. In: State of Aquaculture in Kenya. Laxpress Services, Nairobi, Kenya. 133p.

Musa, S., Aura, C.A., Owiti, G., Nyonje, B. (2012). Fish farming enterprise productivity program (FFEPP) as an impetus to Oreochromis niloticus (L.) farming in Western Kenya: Lessons to learn

Naylor R.L., Hardy R.W., Bureau D.P., Chiu A., Elliot M., Farell A.P., Forster I., Gatlin D.M., Goldburg R.J., Hua K.,Nichols P.D. (2009). Feeding Aquaculture in an era of Finite resources. Proc. Natl. Acad. Sci. 106 (2009), Pp 15103-15110, 10.1073/pnas. 0910577106.

Njiru, J.M., Aura, C.M., & Okechi, J.K. (2018). Cage fishing culture in Lake Victoria: A boon or disaster in waiting? Fisheries Management and Ecology, Review Article: 1 – 9.

Njiru, James M. & Aura, C. (2019). Cage farming can protect Lake Victoria's fish. But regulations need tightening. The Conversation Newsletter. Retrieved from https://theconversation.com/cage-farming-can-protect-lake-victorias-fish-but-regulations-need-tightening-112641.

Oduor, B (January 27, 2018). Cage fishing nets millions for community. Daily Nation, Kenya. Retrieved March 17, 2020.

Ogello, E.O. and Opiyo, M.A. (2011). A review of the African Catfish Production in Kenya: opportunities and Challenges.

Ogello, E.O., Mlingi, F.T., Nyonje, B.M., Charo-Karisa, H., Munguti, J.M. (2013). Can Integrated Livestock-Fish Culture be a Solution to East Afircan's Food Insecurity? A Review. African Journal of Food, Agriculture, Nutrition and Development.

Oketch, A (September 19, 2014). Cages restock dwindling fish stock in lake.Daily Nation, Kenya. Retrieved March 17, 2020.

Opiyo Mary A., Esther Marijani, Patriciah Muendo, Rezin Odede, William Leschen & Harrison Charo-Karisa (2018) A review of aquaculture production and health management practices of farmed fish in Kenya, International Journal of Veterinary Science and Medicine, 6:2, 141-148, DOI: 10.1016/j.ijvsm.2018.07.001.

Opiyo, M.A., Marijani, E., Muendo, P., Odede, R., Leschen,W., Karisa, H.C., 2018. A review of aquaculture production and health management practices

REFERENCES

of farmed fish in Kenya. International Journal of Veterinary Science and Medicine 6:141-148

Orina, P. S., Ogello, E., Kembenya, E., Githukia, C., Musa, S., Ombwa, V and Okechi, J. K. (2018). State of cage culture in Lake Victoria, Kenya.

Palm, H.W; Knaus, U; Appelbaum, S; Goddek, S; Strauch SM, Vermeulen T, Haissam Jijakli M and Kotzen B (2018). Towards commercial aquaponics: a review of systems, designs, scales and nomenclature. Aquac Int 26(3): 813–842

Rasowo J. and Auma,E. O. 2006. On-Farm Trials with Rice-Fish Cultivation in the West Kano Rice Irrigation Scheme, Kenya. NAGA, WorldFish Center Quarterly Vol. 29 No. 1 & 2. Integrating BOMOSA cage fish farming systems in reservoirs, ponds and temporary water bodies in Eastern Africa

Rothuis, A., A.P. van Duijn,J.van Rijsingen, W.van der Pijl, E.Rurangwa. Business opportunities for aquaculture in Kenya; With special reference to food security LEI report 2011 067/ IMARES report C131/112011Wageningen UniversityWageningen28http://library.wur.nl/WebQuery/wurpubs/fulltext

Shoko, A., P., Getabu, A., Mwayuli, G and YD Mgaya4, (2011)., growth performance, yields and economic benefits of Nile tilapia Oreochromis niloticus and kales brassica oleracea cultured under vegetable-fish culture integration

State Department of Fisheries (SDF). Fisheries Annual Statistical Bulletin 2014. Nairobi, State Department of Fisheries: 2014. p. 59.

Timmons, M.B and Ebeling, J.M (2013). Recirculating Aquaculture (3rd ed.). Ithaca Publishing Company Publishers. p. 3.

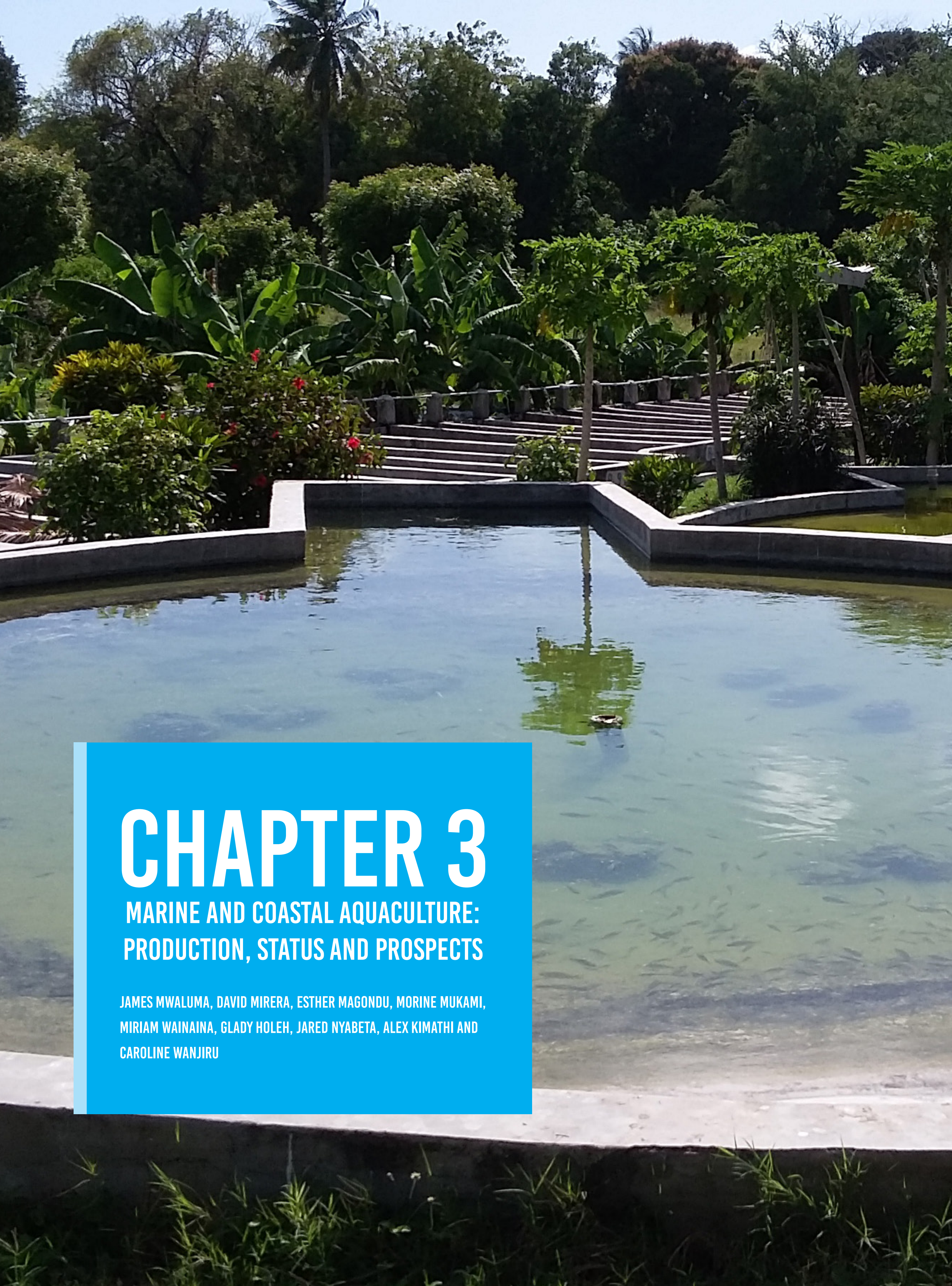
Timmons, M.B, and Ebeling, J.M (2010) Aquaculture Production Systems, 3rd edn. Ithaca Publishing Company, Ithaca Tomovic R (1963) Sensitivity analysis of dynamic systems. McGraw-Hill, New York.

Volkers, V (May 10, 2014). Entrepreneurship Aquaculture: Total concept in Machacos County, Kenya. Retrieved March 11, 2020.

White J.R., Belmont M. A., Metcalfe C.D (2006). Pharmaceutical compounds in wastewater: Wetland treatment as a potential solution. Sci World J., 6: 1731-1736.

Worldwide Aquaculture (WA) (January 22, 2015). Quick and Easy Fish Farming: The Raceway Aquaculture System. Retrieved March 16, 2020)

> **BY 2016, THERE WERE 6 COMMERCIAL RACEWAY ESTABLISHMENTS IN KENYA ALL LOCATED IN MOUNT KENYA REGION. PRODUCTION FROM THE RACEWAY FARMS WAS 214 MT IN 2016 WHICH WAS VALUED AT 1,430, 000 USD.**



CHAPTER 3

MARINE AND COASTAL AQUACULTURE: PRODUCTION, STATUS AND PROSPECTS

JAMES MWALUMA, DAVID MIRERA, ESTHER MAGONDU, MORINE MUKAMI, MIRIAM WAINAINA, GLADY HOLEH, JARED NYABETA, ALEX KIMATHI AND CAROLINE WANJIRU

Key Messages	Policy Recommendations
• The country has a 640 km coastline, a territorial sea extending 12 nautical miles and an exclusive economic (fishing) zone extending 350 nautical miles offering significant opportunities for sustainable marine aquaculture to address food security, employment, wealth creation and social welfare. • Mariculture was introduced in Kenya in 1980s to provide economic opportunities to coastal communities to bring about development in the rural coastal areas • Target mariculture species for culture have been milkfish, mullets, mud crab, prawns, artemia, seaweeds and marine tilapia. • Shellfish culture in coastal Kenya has mainly focused on the culture of mud crabs, prawns, and Artemia which to date have attained different levels of production. • Prawn production at the coast is low and varies between semi-intensive and extensive levels since most of the ponds are below 0.1 ha while the feed is mostly from natural productivity resulting in production below 1600 kg/ha/yr. • The current production of dry seaweed has increased from less than one ton in 2008 to more than 45 tons valued at $12,000 in 2017. • Currently, the fish biomass in territorial and offshore waters by R.V Mtafiti is estimated to be between 150,000-300,000 MT worth KES 21– 42 billion	• The Government should create a legal framework for establishment mariculture fisheries subsector mandated to deal with the development of strategic plans for enhancing sustainable mariculture production • The government should invest in building capacity in marine science to provide prerequisite skills for the progressive future development of mariculture industry. • To sustain seaweed production to meet investor volume demand culture trials through field experiments should be conducted in northern coastal areas to provide additional areas with potential for commercial cultivation. • The government should view mariculture subsector as a commercial enterprise with the potential to provide employment opportunities and alleviate extreme poverty from coastal communities. • The Kenyan government is in the progress of establishing a National Mariculture Resource and Training Centre (NAMARET Centre) 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. • Mariculture suitability map needs to be done for the whole coastline to demarcate suitability areas for different species to be exploited under the blue economy.

Mwaluma, J., Mirera, D., Magondu, E., Mukami, M., Wainaina, M., Holeh, G., Nyabeta, J., Kimathi, A., & Wanjiru, C. (2021). Marine and Coastal Aquaculture: Production, Status and Prospects. In: Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition-Sensitive Fish Food Production Systems; Chapter 3: pp 39–57.

3.1. INTRODUCTION

The Kenya government intervention to stimulate fish production through aquaculture experienced tremendous growth in the subsector over the past decade. This growth was mainly experienced in the freshwater aquaculture systems. Owing to the government policy to promote fish production, the focus has shifted to exploring and promoting marine aquaculture in the country. Kenya has a significant potential to be a major player in aquaculture due to diverse water resources in terms of brackish, freshwaters and marine which can be harnessed for mariculture and coastal aquaculture. The country has a 640 km coastline, a territorial sea extending 12 nautical miles and an exclusive economic (fishing) zone extending 350 nautical miles offering significant opportunities for sustainable marine aquaculture to address food security, employment, wealth creation and social welfare. The large expanses of brackish waters at the River Tana and Athi River deltas, rivers and small water bodies can also be harnessed for coastal aquaculture.

This potential has led to the concept of the blue economy, which recognizes the productivity of healthy freshwater and ocean ecosystems is a pathway for freshwater and maritime-based economies and promotes the conservation, sustainable use, and management of associated marine resources (UNECA, 2016). Some aquaculture technologies to actualizing the aspirations embodied in the blue economy concept include; cage culture in ocean, lakes, dams, and rivers; recirculatory aquaculture systems (RAS), aquaponics/ hydroponics, pens, breeding and restocking of commercially important indigenous species and live fish markets.

KMFRI acts as a facilitator and regulator to help achieve improved livelihoods of the local communities through an economic approach where communities and business entrepreneurs along the coast of Kenya are empowered to realize profits from aquaculture in a healthy environment as outlined in the vision 2030.

3.2. CURRENT STATUS OF MARICULTURE IN KENYA

Coastal aquaculture development in Kenya can be traced back to the early 1980s mainly through small scale mariculture initiatives by community groups (Mirera, 2011). Most of these groups initially began with a conservation focus but deviated to different forms of mariculture. Target species for culture have been milkfish, mullets, mud crab, prawns, artemia, seaweeds and marine tilapia. Milkfish has been fronted as one of the key culture species because of its faster growth, tolerant to high fluctuations in salinity and temperature and availability of seeds from the wild.

Comparatively, mullets have similar characteristics, but they grow at a slower rate in the local conditions thus not preferred by farmers. Culture of marine tilapia ***Oreochromis niloticus*** in ponds is currently taking shape due to its ability to breed thus assuring seed supply ***(Mwaluma et al., 2017)***. Commercialization of mariculture especially of milkfish and seaweeds was mainly achieved through a World Bank-funded project "Kenya Coastal Development Project" (KCDP) implemented between 2012 and 2017 (Mirera, 2019; Mirera ***et al.,*** 2020). The main challenges faced in finfish culture include inadequate seeds, seasonal availability of seeds, inadequate extension services amongst others. These issues are being addressed with investment on development of a marine hatchery by the Kenya government at Shimoni and small private investors in Kilifi County ***(Mtoni Ltd and Che Chale).***

Fig 3.1. Community ponds used for fish production and Milkfish and mullets species commonly farmed at the Kenyan coast.

Shellfish culture in coastal Kenya has mainly focused on the culture of mud crabs, prawns, and ***Artemia,*** which to date have attained different levels of production. Experimental oyster culture of *Saccostrea cucullata* was also started in Gazi in the 1990s by KMFRI but was not sustainable due to lack of market linkages despite successful culture. These initiatives despite taking off late between the early '80s to '90s were mainly done at subsistence level by the local communities.

Commercialization of prawn farming was initiated by FAO in Ngomeni in collaboration with the Fisheries Department but could not continue due to challenges of seed. Mud crabs are largely been produced in cages and lately in earthen ponds. Current challenges being faced in crab farming are seasonal seed supply and high maintenance cost of the cages and ponds in addition to inadequate feeds. Commercialization of mud crab farming and consumption in Kenya has been enhanced through development of eco-restaurant by Dabaso crab shack that has also increased the income from the sale of crabs from value added products e.g. crab samosas, crab sausages and cooked whole crab. To address high maintenance costs, KMFRI is now testing the use of plastic crab cages fabricated and modified from plastic crates. The plastic cages potentially have lower maintenance costs and would, therefore, improve the profits from the culture *(Mwaluma et al., 2017).*

Fig. 3.2: Plastic cages used for farming mud crabs in Dabaso, Watamu Kenya

Prawn farming is continuously being undertaken in earthen ponds in small-scale farms after the collapse of the large-scale farm at Ngomeni. The prawn species cultured are *Penaeus monodon* and *Fenneropenaeus indicus* and seed is obtained from the wild. Recent advances to obtain prawn seed has seen the development of backyard marine prawn hatchery at Vipingo, Kilifi County by Mtoni Ltd.

Fig. 3.3 Fenerropenaeus indicus and Penaeus monodon harvested from ponds at Kibokoni (Kilifi County)

Currently, prawn production at the coast is low and varies between semi-intensive and extensive levels since most of the ponds are below 0.1 ha while the feed is mostly from natural productivity resulting in production below 1600 kg/ha/yr. Prawn production by communities in Kibokoni under KCDP have varied between 0.02–0.05 kg prawns/m^2 in 2013 and 0.25 kg in 2019 respectively. Challenges faced in prawn farming include low production was associated with the inability to stock at the required densities, low technological knowhow, limited extension work and lack of trained manpower, inadequate/lack of seeds.

Artemia was first inoculated in Kenyan coast 30 years ago *(Rasowo and radul 1986)*. The *Artemia* biotopes have so far established substantial populations in Kenya, and is being used by various commercial and artisanal salt companies for salt production (Ogello et al. 2014a and b). KMFRI has hosted various projects to optimize and commercialize artemia production and significant information is now available on the potential for Artemia in promoting local aquaculture initiatives.

Artemia farming involves farmers producing salt integrated with artemia in farms located at Kadzuhoni village, approximately 132 km from Mombasa. Most artisanal salt producers also undertake *Artemia* farming although not on a commercial scale. To enhance *Artemia* production, the KCDP project implemented between 2012–2017 supported artisanal salt producers at Kadzuhoni in Gongoni to upscale the farming through construction of additional eighteen (18) ponds (Mwaluma et al., 2017). *Artemia* production at the Kenya coast is mainly hampered by land ownership problems and lack of interest to produce cysts by commercial salt producers.

Seaweed farming was introduced in the south coast of Kenya to improve the wellbeing of communities initially with one village (Kibuyuni) but has currently spread to five other villages. The main seaweed species farmed commercially in Kenya using off-bottom method is ***Eucheuma denticulatum*** commonly known as "spinosum" while ***Kappaphycus alvarezzi*** commonly known as "cottonii" is farmed at experimental scale using different methods.

Fig. 3.4: Kappaphycus alvarezii and Eucheuma denticulatum farmed in Kibuyuni

The current production of dry seaweed has increased from less than one ton in 2008 to more than 45 tons valued at $12,000 in 2017 ***(Mirera et al., 2019).*** Furthermore, farming is attracting an entry of new farmers from Kibuyuni and other coastal areas. Currently, more focus is being given to upscaling production to other areas, increasing production per unit area and value addition in the manufacture of soaps, shampoos and gels under the support of the government's Blue economy initiative.

3.3. MARICULTURE SYSTEMS, HOLDING FACILITIES AND TECHNOLOGIES

Mariculture was introduced in Kenya in 1980s to provide economic opportunities to coastal communities to bring about development in the rural coastal areas *(Ochiewo et al., 2020).* Mariculture is largely practiced in brackish or marine waters. Mariculture structures and systems can occupy nearshore intertidal and subtidal areas and also in offshore waters where submersible cages and longlines are placed. The description of mariculture systems depends on the species of culture and the scale of production.

The scale of production also determines the kind of mariculture system to be used. For example, pond systems are normally used in extensive production systems of Artemia and finfish. However, ponds are also used for the intensive production of penaeid shrimp in coastal areas. Offshore cages and tanks are used for intensive culture systems of mostly finfish.

3.3.1 MARICULTURE SYSTEMS BY PRODUCTION INTENSITY

Mariculture systems are mainly determined by the intensity or scale of production of the culture organisms. *Extensive culture systems* are mostly practiced in large earthen ponds and sea pens. These systems require low levels of inputs, low capital investments and technology. Culture organisms like finfish and shrimp depend fully on natural feeds with no supplementation.

The level of production is also normally low. However, it is the most environmentally sustainable method of mariculture system and with the least impact on ecological systems. The level of pollution is normally low or negligible due to low effluent levels from the system. Water recharge is through tidal changes.

Semi-intensive culture systems Include medium-sized earthen ponds in mangrove areas. In these systems, the inputs are moderate. The level of production is higher than in extensive system since the stocking densities are higher and natural feed is supplemented with formulated or commercial feeds. In ponds, there is some level of management including liming, fertilization and water recharge is by use of pumps. These systems are more labour intensive and cost more.

Intensive systems are technologically advanced and capital intensive and the most profitable systems. The stocking densities are highest in these systems with stocks being fed only formulated feeds. The water environment is controlled using aerators and pumps are used to change a percentage of the water daily. Due to high incidences of diseases and pests, antibiotics, antifungals and probiotics are used. These systems are deemed environmentally destructive due to the release of effluent into coastal systems. The high nutrient levels in the effluent lead to eutrophication and unused antibiotics bioaccumulating in marine fauna. Table 3.1 gives a summary of the mariculture systems.

Table 3.1: Mariculture systems

Culture System	Structures	Characteristics
Extensive	Pens, earthen ponds	• low degree of control • Low initial capital • Low-level technology • Low production
Semi-intensive	Liner ponds,	• Medium degree of control • Slightly higher initial capital • Lightly sophisticated technology – use of liners, supplemental feeds, water exchange or aeration sometimes • Production is better than in the extensive systems
Intensive	Cages, hatcheries, concrete raceways, concrete tanks	• High degree of control • High initial capital • High level technology – aeration, feeding • High production

EARTHEN PONDS

A typical earthen fishpond system consists of the following basic components: pond compartments enclosed by earthen dykes, canals for supply and drainage of water and gates or water control structures. Ponds in coastal areas are normally constructed in mangrove areas where the soil is suitable for pond construction and tides can naturally recharge the water in the ponds as shown in Fig. 3.5. These types of ponds are common in the Western Indian Ocean (WIO) region including Kenya.

Earthen ponds are mostly used for the culture of milkfish ***(Chanos chanos)***, acclimatized marine tilapia ***(Oreochromis niloticus)***, Artemia ***(Artemia salina)*** and penaeid shrimp ***(Penaeus indicus*** and ***P. monodon*)**. The scale of production is mostly semi-intensive.

CAGES

Inshore cages are found in protected, shallow areas with less water circulation. Offshore cages are situated in deep water and open areas with less protection from storms but with better water exchange. In coastal areas , crab cages have been used in mangrove areas to fatten crabs ***(Scylla serrata).*** These cages are made from different materials depending on their ease of acquisition to the farmer. For a long time, crab fattening cages in the WIO have been constructed using bamboo, sticks and timber (Fig. 3.6a.). Plastic crab cages, which are deemed more durable have been introduced recently (Fig. 3.6b). Inshore cages targeting deeper water finfish culture have also been deployed in Kibokoni in Kilifi County and Kijiweni in Kwale County. The cages are mostly made of net with a wooden platform for support and access (Fig. 3.7). Although these cages are experimental in nature, the results are promising for up-scale and out-scale.

Fig. 3.5 Artemia and milkfish earthen ponds

Fig. 3.6a: Crab cages made of fito and bamboo

Fig. 3.6b: Plastic crab cages

Fig. 3.7: Wooden finfish cages in subtidal areas

MONOLINES

Seaweed farming is practised in Kibuyuni, Mkwiro, Funzi and Gazi villages. The off-bottom monolines are used as the culture structures. Two stakes are fixed 50m apart in soft substratum in inshore areas. A 50m polyethene rope is tied to the stakes 20cm off the ground (Fig. 3.8). A model farm is made of 300 monolines which are divided into six blocks each with 50 lines for ease of management. The seaweed plant parts are tied to the monoline using tie ties. The seaweed species cultured is in Kenya are red seaweeds of *Euchema spinosum* and *Kappaphycus alverezii* species. Other seaweed farming structures in coastal areas include rafts and longlines which are normally used in deeper coastal waters.

Fig. 3.8: Monolines in a seaweed farm in Kibuyuni Kwale County.

LONGLINES AND/OR RAFTS

These are unique kind of holding facilities since they hold plants, unlike the others which are used to hold animals. Long lines are used in countries with advanced mariculture systems for the culture of seaweed and mussels.

SEA PENS

Nets and fish pens are installed in shallow water and their edges are anchored to the bottom. They are made up of the fencing material locally referred to as *Uzio*, binding wire, polypropylene ropes. These pens are normally used for crab culture and in other countries in the WIO, they are used for sea cucumber culture.

RACEWAYS

These are made from concrete. They can have different shapes and can be of different sizes. They are mostly used for finfish whereby water is continuously supplied in these structures. Since water is moving, there is normally no need for aerators.

3.3.3 MARICULTURE TECHNOLOGIES

Mariculture technologies are mostly targeted at increasing the production of seed (fry or larvae) as well as improving grow-out conditions to make them sustainable i.e. economically, socially and environmentally viable. Mariculture has been criticized for its use of wild-caught fish fry and larvae further depleting the capture fisheries that it is meant to protect from overfishing. It has also, especially for the semi-intensive and intensive scales of production, been found to be a major environmental polluter of coastal waters. Technologies have therefore been developed to encourage sustainable production from mariculture systems.

MARINE HATCHERY

A marine hatchery is a facility where healthy broodstock of marine species is kept in captivity under controlled conditions while at the same time mimicking the natural environment to enable the broodstock to spawn. The Kenyan government is in the progress of establishing a National Mariculture Resource and Training Centre (NAMARET Centre) 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.

With conservative estimates of total pond area of between 60-120 ha available for each species, it is estimated that demand for milkfish fingerlings is most likely in the region of 278,125 and prawns 2.14 million per annum *(Hecht et al 2019)*. If the industry expands from 20 to 160 ha in 5 years, then the demand will increase to 4.5 to 34.3 million *(Hecht et al 2019)* generating substantial income for the hatchery and profoundly increasing the production of milkfish and prawns by farmers and private partners. In tandem with the establishment of NAMARET, a Mariculture Master Plan needs to be developed and put in place which recognizes the exploitation of nearshore and offshore aquaculture resources (blue economy) and a legal framework put in place to regulate the development of the sector.

INTEGRATED MULTI TROPHIC AQUACULTURE SYSTEMS (IMTA)

IMTA refers to a more intensive cultivation of different species in the proximity of each other, connected by vertical nutrient and energy transfers through water movements *(Sukhdhane et al., 2018)*. It allows one species uneaten feed and waste, nutrients, and by-products to be recaptured and converted into fertilizer, feed, and energy for other crops. Fed organisms like finfish and shrimps are usually combined with extractive organisms such as filter feeders and marine plants to take up excess nutrients from fed aquaculture *(Chopin, 2013)*.

IMTA is a flexible concept that has been developed in different parts of the world according to prevailing economic, societal, environmental, biological, and physical conditions (Chopin, 2013). The concept can be applied in open water or pond systems, marine or freshwater, and both temperate and tropical environments. In IMTA integration of different organisms has been done which have exhibited different functions.

Kenya is endowed with vast coastal and inland aquatic resources that portray high prospects for IMTA systems. The application of the concept will come in handy under the blue economy frontier to boost aquaculture production through species diversification and to mitigate associated environmental impacts of aquaculture. The most suitable species integration that can be investigated includes finfish/shellfish/water plants and seaweed combinations. Feasibility studies on suitable sites in water bodies like ponds, dams, lakes and creeks will assist in identifying potential areas where IMTA can be implemented to achieve both social economic and environmental gains.

3.4. CULTURED SPECIES

The plant and animal species cultured in mariculture systems are categorized into four general categories. The species of culture in a category may require similar or different culture method and structure. The categories of the culture species are:

- Molluscs culture e.g. oysters:
- Crustacean culture e.g. Artemia, shrimps, crabs:
- Seaweed: Red seaweed
- Finfish Culture – Milkfish, rabbitfish, mullet:

The most commonly farmed fish species is milkfish ***(Chanos chanos),*** which accounts for about 90% of production, followed by mullet ***(Mugil cephaus)*** contributing about 10% of aquaculture production.

These species are found in the mangrove systems especially during the rainy season and demand is increasing among coastal communities interested in mariculture. Experimental trial is ongoing for culture of Rabbitfish ***(Siganus sutor)*** since 2018. Results of cage growth trials are showing good prospects with possibilities of upscaling. Available ready market, acceptability of this fish with the local are the key drivers towards its promotion in mariculture. Other finfish species under consideration for growth trials is *Trachnotus blochii* (Silver pompano) in cages. Other species cultured are mud crabs ***(Scylla serrata)*** which are cultured in floating cages in the mangrove ecosystems and prawns on earthen ponds. Common species being ***Penaeus monodon*** and ***Fenerropenaeus indicus.*** Other species found incidentally in the ponds are silver pompano *Trachnotus blochii* indicating that potential for culture in ponds is high.

Most recently (2018-2020) trials are underway for the experimental culture of Marine tilapia, ***Siganus argenteus*** and ***S.sutor*** in cages at Kibokoni and Kijiweni under the National Research Fund (NRF) sponsored project between Kenya Marine Fisheries Research Institutes (KMFRI), Kenya Industrial Research Development Institute (KIRDI) and Technical University of Mombasa.

Fig. 3.9: Penaeus monodon and Fenerropenaeus indicus under culture in ponds at Kibokoni

Fig. 3.10. Trachinotonus blotchii (Pompano) a species with high potential for culture in Kenya and marine tilapia under trials in Kibokoni (Kilifi County)

The current production from mariculture is based on diverse species with varying degrees of success and failures *(Ochiewo et al., 2020).* The mariculture production in terms of quantity produced annually is ranked as follows: Seaweeds *(Eucheuma denticulatum* (spinosum) and **KAPPAPHYCUS** *alvarezii* (cottonii)) at 48 MT, mud crab (Scylla serrata) at 15 MT, milkfish *(Chanos chanos),* 10 MT, Prawns *(Peneaus monodon* and *Penaeus indicus)*, 3 MT, and Artemia *(Artemia franciscana)* at 0.03 MT (*Munguti et al., 2017).*

Fig. 3.11: Cage trials of rabbitfish under NRF in Kijiweni, Shimoni

To upscale production from pilot to commencial levels, there is need to adopt and develop existing technologies and fully engage coastal communities and private partners for the uptake of these technologies. Inshore and offshore waters in all depth range also provide the potential for mariculture in cages and pens. However, a mariculture suitability map needs to be done for the whole coastline to demarcate suitability areas for different species to be exploited under the blue economy.

In terms of seaweed production, initial farm trials at Kibuyuni, Gazi and Mkwiro showed two species i.e., *Eucheuma denticulatum* (spinosum) and *Kappahycus alvarezii* (cottonii) were feasible for commercial exploitation in Kenya. The two species were imported from Tanzania (Wakibia et al, 2006). With a relative growth rate (RGR) of 4.3 % d^{-1} and net yield of 2.5 kg wet wt m-2 30d-1), *Eucheuma denticulatum* has been resilient overtime thus being intensified in all the growing areas (*Kimathi et al., 2018).*

Fig.3.12: Kappaphycus alvarezii and Eucheuma denticulatum farmed seaweeds in Kenya

Kappahycus alvarezii has failed to grow in areas where *Eucheuma denticulatum* establishes despite exhibiting signs of success in the culture trials. To remedy growth challenges in shallow water environments, relocation of farms to deeper water environment using deepwater techniques such as floating rafts and tubular nets *(Msuya et al., 2014).* While growth improvement in *Eucheuma denticulatum* has been observed in the deepwater environment, *Kappaphycus alvarezii* has continued to show dismal growth and yield performance in Kenya**.**

Therefore, farmers in the southern coast have focused on the culture of *Eucheuma denticulatum* (spinosum) to meet production that is convincing to the investment companies and sustain the local livelihood. Although *Kappaphycus alvarezii* fetches a higher gate price than *Eucheuma denticulatum* (spinosum), its poor growth performance has undermined the potential economic benefits and livelihood needs of the farmers *(Macharia et al., 2018).*

3.5. BLUE ECONOMY PROSPECTS

The Kenyan Government has declared full interest in developing the Blue Economy under the Presidential Executive Order of 2016. Consequently, an implementing committee on the Blue Economy under the office of the President was established. Kenya Marine and Fisheries Research Institute (KMFRI) was assigned the role of a clearinghouse for information and data on Blue Economy. KMFRI is the national custodian of data and information on fisheries and aquaculture, limnology and oceanography, marine spatial plans and bioprospecting of aquatic environment; thus, being integral in contributing towards the attainment of the Blue Economy and SDG 14 goals. The key pillar of for a thriving blue economy is anchored on fisheries, mariculture, ecotourism and mangrove conservation, coral conservation and payment of ecosystem services.

FISHERIES

Marine fisheries in Kenya are an important source of economic development and food security and supports livelihoods for thousands of people involved in the sector, particularly in the coastal zone. Artisanal capture fisheries represent ~80% of the total income of ~70% of Kenya's coastal communities *(Njiru et al., 2019).* There is a general increase in fishing pressure along the coast annually, with 13,426 small-scale fishers reported to have been involved in fishing during 2016, representing a 10% increase from the previous years *(Njiru et al., 2019)*. About 80% of the fish production is by small scale artisanal and subsistence fishers

The offshore fishery urgently needs stringent management regulations due to significant losses from Illegal, Unlicensed and Unregulated (IUU) fishing. The fishery is mainly exploited by foreign nations through annual fishing licenses and targeting skipjack, yellowfin and bigeye tuna. The offshore fishery has shown that some key commercial species stocks are healthy including those of bigeye and skipjack, albacore and yellowfin tuna stocks. Currently, the fish biomass in territorial and offshore waters by R.V Mtafiti is estimated to be between 150,000-300,000 MT worth KES 21– 42 billion *(Njiru et al., 2019)*. If these species are harnessed sustainably, they may offer numerous opportunities for local and private investors in generating income and employment under the blue economy. Other offshore fisheries which could be exploited include the semi-industrial shrimp fishery where only about 3 trawlers and recreational fishing fleets are licensed.

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MARINE FISHERIES IN KENYA ARE AN IMPORTANT SOURCE OF ECONOMIC DEVELOPMENT AND FOOD SECURITY AND SUPPORTS LIVELIHOODS FOR THOUSANDS OF PEOPLE INVOLVED IN THE SECTOR, PARTICULARLY IN THE COASTAL ZONE.

MARICULTURE

Mariculture is the future economy to contribute to economic development and food security of the country. The country has a 640 km of coastline, a territorial sea extending 12 nautical miles and an exclusive economic (fishing) zone extending 350 nautical miles offers significant opportunities for sustainable marine aquaculture to address food security, employment, wealth creation and social welfare. Despite this enormous potential, the few mariculture trials on prawns, oysters, mud crabs, seaweeds, and finfish have largely stopped at experimental or subsistence levels.

Mariculture development in Kenya has had consistent development since early 2000. In 2007, the total area under mariculture was 6.9 ha, mostly being under earthen ponds. Presently, mariculture production at the coast is low mainly relying on harvesting seeds from the wild hence limiting production to one crop per year with the most cultured candidate species being milkfish and prawns. Aquaculture development needs to be undertaken in a business context where there is a shift in paradigm necessitated by the need to sustain aquaculture interventions. Scientific expertise will be applied in the development of sustainable culturing techniques, design of different grow-out systems and production of fish and fishery products for use by the community.

> **"MARINE FISHERIES IN KENYA ARE AN IMPORTANT SOURCE OF ECONOMIC DEVELOPMENT AND FOOD SECURITY AND SUPPORTS LIVELIHOODS FOR THOUSANDS OF PEOPLE INVOLVED IN THE SECTOR, PARTICULARLY IN THE COASTAL ZONE.**

Seaweed farming is one of the major mariculture activities in the south coast of Kenya, especially at Kibuyuni, Funzi and Nyumba site. It is a significant export earner as well as an income and employment generator in the coastal villages. Seaweed farming has also increased the economic purchasing power as well as creating more social empowerment for women and families that can educate their children. The focus of seaweed farming has been mainly on ***Eucheuma denticulatum*** (spinosum) and ***Kappaphycus alvarezii*** commercially known as "cottonii". The number of seaweed farmers has consistently increased from 26 farmers in 2010 to 46 in 2014 of whom 90% are women (*Mwaluma et al., 2014*). The total production in 2010 and 2011 from Kibuyuni and Mkwiro was 3.1 MT, valued at about KES 30,000 ***(Mwaluma et al., 2014)***. Currently, Kenya's Blue Economy Committee is supporting the women seaweed farming group in Kibuyuni with equipment for value addition, with seaweed soap, lotion, juice and salads being produced. The potential for seaweed production is still currently underexploited.

ECOTOURISM AND MANGROVE CONSERVATION

Communities living along the coast in practicing coastal aquaculture have often combined it with conservation. Conservation efforts have mainly targeted mangrove reforestation and afforestation and coral reef restoration. Other activities which have consequently been added are beekeeping, traditional dances, canoe riding and restaurants. These business/conservation models are currently taking shape at the coast and have enormous potential for exploitation in the blue economy.

For example, the Dabaso Creek Conservation Group which has successfully combined the culture of mud crabs with mangrove conservation and a restaurant. Other groups that have followed suit are Comensum in Mtwapa (combining milkfish farming, prawns, mangrove conservation and a restaurant), Comtouch Conservation group in Tsunza (combining, prawn culture, milkfish farming, mangrove conservation, boat riding, terrestrial tree planting). There is a total of 62 community groups that are participating in mariculture productions at different levels along the coast, with membership in each group varying between 15 and 70 (*Mwaluma et al., 2014*). Thus, there are more than 2000 people who are direct beneficiaries, with more than 5,000 people indirectly benefiting from the mariculture activities if properly supported with initial capital and training they can be self-sustaining earn income in the blue economy agenda.

CORAL CONSERVATION

KMFRI and other stakeholders have also implemented programmes and strategies towards restoring degraded coral reefs, including the establishment of Marine Protected Areas (MPAs), Locally Managed Marine Areas (LMMAs), 'coral gardening' and management tracking tools. There have been trial experiments to assess the suitability of coral species for culture at the Mombasa Marine Park (GOK 2017), as well as collaborative initiatives to restore degraded coral reefs involving communities at the south coast of Kenya at Wasini (Murage and Mwaura 2015). The collaborative initiatives entail hands-on training on coral gardening as well as the development of a step-by-step guidebook on coral transplantation (GOK 2017). Initial transplantation trials have given a survival rate of 75% and improved fish density by two folds within one year (*Mwaura et al., 2013).*

While the purpose of the MPAs is conservation, they also support tourism, which is a key industry promoted as a means of providing alternatives to fishery-based livelihoods. The LMMAs locally known as "tengefu" have been established along the Kenyan coast of Kenya with the possibility to establish several others in the coming future. Recent field surveys showed that these recent and small community-managed areas play an important role in the conservation and restoration of hard corals and fish (*Mwaura et al., 2013).* Restored areas become a major attraction for tourist visiting the rehabilitated reefs with an observable increase in fish and coral populations within the transplanted areas.

The restoration process or "coral gardening" uses donor corals that are survivors of previous bleaching events; thus, increasing the spread of bleaching resistant corals and improving the health of coral reefs. Local fishers in surrounding areas are also benefiting from fish spillover and hence an increase in their fish catches. A Good example is in Wasini where corals have been restored and tourists come there to snorkel for a small fee. This community-based reef restoration ranks as the first ever to be implemented successfully in Kenya and by extension in East Africa region.

PAYMENT FOR ECOSYSTEM SERVICES (PES)

The Kenyan government is pursuing market-based approaches to environmental protection, with a strategic focus on Ecosystem Services (ES). Payments for Ecosystem Services (PES) schemes are attractive because they reward those that supply or provide ES *(Kairo et al., 2019)*. However, the concept of PES is still new to many policymakers and academic experts in the south, and as a result, limited examples of demonstrable PES projects exist. Through the Kenya Marine and Fisheries Research Institute (KMFRI) mangrove livelihood projects, experience has been gained in facilitating the development and implementation of small-scale mangrove PES projects, with income from the sale of carbon credits supporting community development and mangrove conservation *(Huff and Tonui 2017, Kairo et al 2019).*

at least 3000 tCO_2-equivalent per annum generating an income of approximately US$ 15,000 per annum *(Kairo et al., 2019)*. Project activities include mangrove reforestation, avoided deforestation, enhancement of carbon stocks, and sale of carbon credits. Income from the sale of carbon credits, worth over KES 4,300,000 each year, is used to fund continued mangrove conservation activities as well priority projects chosen by communities such as water and sanitation, health and education (Kairo **ET AL.,** 2019). Mikoko Pamoja and Vanga Blue Forests, are an example of successful blue carbon projects that have been implemented in mangroves of Gazi and Vanga in Kenya respectively and can be replicated elsewhere.

3.6. CHALLENGES

Mariculture production at the coast has been low and underexploited. Overall, production volumes from the community-based prawn and fish operations are low and estimated to be <50 tons per annum and comprised principally (>90%) of milkfish and prawns *(Hetch et al 2019)*. Most production has been by community groups mostly at subsistence level *(Mwaluma et al., 2014).* Given that there are over about 100 groups engaged in some form of mariculture and the area available for mariculture the potential is enormous. The recent growth in the seaweed sector in southern Kwale County is encouraging and must be expanded. Prices for fish, prawns, crabs and Artemia are relatively high and are economically viable *(Hetch et al 2019)*. However, despite this viability and good price mariculture trials on prawns, oysters, mud crabs, seaweeds, and finfish have largely stopped at experimental level and underexploited.

Several reasons contributed to this scenario include:

- Unsustainability of initiatives (lack of ownership by groups (donor syndrome/attitude,
- Lack of finances (no business know-how) and market information
- Lack of technical knowhow and leadership wrangles,
- Poor siting of projects due to poor soils, the permeability of water, poor quality ponds leading to breaking dykes
- Low productivity due to lack of quality seeds, insufficient feeds, small-sized ponds, low stocking density (understocking),
- Low variety of cultured species and limited culture techniques) and
- Lack of extension services *(Mwaluma et al., 2013).*

The government is aware of these obstacles and is in the progress of establishing a National Mariculture Resource and Training Centre (NAMARET Centre) which will incorporate a marine hatchery, wet and dry laboratory, training resource centre, administration block, accommodation and museum. The most critical component the marine hatchery is intended to provide a consistent supply of high-quality seed of finfish and shellfish for the growth of the industry. In this effort, KMFRI will work with different stakeholders including SDFA &BE, KeFS, Universities, County Governments and other practitioners to add value to the services.

CONCLUSION AND RECOMMENDATIONS

The development of coastal aquaculture has recently gained momentum in Kenya, courtesy of stronger emphasis on private-sector involvement. Despite these positive developments, however, it is not possible for mariculture in Kenya to grow from its current state into a dynamic, commercial/private sector driven state without a sector-specific policy, clear strategic objectives and an all-inclusive development plan (Hetch et al 2019). Investors will remain hesitant until the state has invested in the formulation of enabling frameworks and platforms for mariculture sector development (Hetch et al 2019). Seaweed does not provide vital protein for local consumption but does generate livelihoods and needed incomes.

The combinations of these factors thus become a real motivating factor for mariculture investments in Kenya. To support mariculture productions in Kenya and attract potential investors, the following recommendations are made:

1. To sustain seaweed production to meet investor volume demand culture trials through field experiments should be conducted in northern coastal areas to provide additional areas with potential for commercial cultivation. Meanwhile, research to develop hybrid seaweed strains with the ability to resist environmental challenges should be intensified.

2. The Government should create a legal framework for establishment mariculture fisheries subsector mandated to deal with the development of strategic plans for enhancing sustainable mariculture production

3. The government should view mariculture subsector as a commercial enterprise with the potential to provide employment opportunities and alleviate extreme poverty from coastal communities. This attitude will provide a basis on which adequate funding for the sector will be accorded.

4. The government should invest in building capacity in marine science to provide prerequisite skills for the progressive future development of mariculture industry. Lack of adequate number of qualified social scientists to provide adequate information on the drivers that underpin successful initiatives such as understanding attitudes perceptions and fisher's willingness to consider aquaculture as a viable livelihood may limit coastal aquaculture development. Although the fisherfolk communities may have the same resource potential their involvement in aquaculture may be limited by input costs, knowledge, management skills and job satisfaction related to strong fishing traditions.

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THE RECENT GROWTH IN THE SEAWEED SECTOR IN SOUTHERN KWALE COUNTY IS ENCOURAGING AND MUST BE EXPANDED. PRICES FOR FISH, PRAWNS, CRABS AND ARTEMIA ARE RELATIVELY HIGH AND ARE ECONOMICALLY VIABLE

REFERENCES

Chopin, T. (2013). Aquaculture, Integrated Multi-trophic Aquaculture (IMTA). http://www.springerreference.com/index/chapterdbid/226358. Springer-Verlag Berlin Heidelberg 2013.

Government of Kenya (2017) State of the Coast Report II: Enhancing Integrated Management of Coastal and Marine Resources in Kenya. National Environment Management Authority (NEMA), Nairobi.

Hetch T, J. McCafferty, N. Gitonga, C. Gatune, L. Oellermann, T. Bean-Klette, J. Mwaluma, D. Mirera and G.Njagi (2019) Mariculture scoping study with respect to Kenyan Marine waters. Final Report, Ref: KE-MOALF/KEMFSED-40631-CS-QCBS Project ID No. P163980 pp 140

Huff, A. and Tonui, C. (2017). Making 'Mangroves Together': Carbon, conservation and co-management in Gazi Bay, Kenya, STEPS Working Paper 95, Brighton: STEPS Centre

Kairo, J.G., Hamza A.J., Wanjiru C. (2019). Mikoko Pamoja – A demonstrably effective community-based blue carbon project in Kenya. In: A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice, and Policy, Lisamarie W.-M., Stephen C., and Tiffany G.T. (eds), CRC Press: Boca Raton, London

KenSea (2007) The KenSea II Project Tsunami Damage Projection for the Coastal Area of Kenya

Kimathi A.G, Wakibia J.G, Gichua M. K (2018) Growth rates of Eucheuma denticulatum and Kappaphycus alvarezii (Rhodophyta; Gigartinales) cultured using modified off-bottom and floating raft techniques in the Kenyan coast. Western Indian Ocean Journal of Marine Science

Macharia I, Kimani E, Syanda J, Kosiom T, Koome F. (2018) Post-Monitoring of seaweed, Kappaphycus alvarezii in Coast region of Kenya. http://www.kephis.org/phytosanitary2018

Mirera HOD (2011) Experimental polyculture of milkfish (Chanos chanos) and Mullet (Mugil cephalus) using earthen ponds in Kenya. Western Indian Ocean Journal of Marine Science 10 (1): 59-71

Mirera H.O.D. (2019). Small-scale milkfish (Chanos chanos) farming in Kenya: An overview of the trends and dynamics of production Western Indian Ocean Journal of Marine Science10.4314/wiojms.v18i2.2

Mirera H. O. D., Kimathi, A., Mwaluma, J., Wainana, M. and Wairimu, M. E. (2019). Seaweed farming policy brief 1: Seaweed farming Industry in Kenya; tapping into the blue economy and mitigating climate change impacts. KMFRI Mariculture publications number 001/2018

Mirera, O. D., Kimathi, A., Ngarari, M. M., Magondu, E. W., Wainaina, M., Ototo, A. (2020). Societal and environmental impacts of seaweed farming in relation to rural development: The case of Kibuyuni village, south coast, Kenya. Ocean and Coastal Management (in press).

Msuya, F. E. (2006). The impact of seaweed farming on the social and economic structure of seaweed farming communities in Zanzibar, Tanzania. In A.T. Critchley, M. Ohno & D.B. Largo, eds. World seaweed resources: an authoritative reference system. Amsterdam, ETI BioInformatics

Munguti, J.M., Obiero, K.O, Orina P.S., Musa, S., Mwaluma, J., Mirera, D., Ochiewo, J., Kairo, J., and Njiru, J.M. (eds.) 2017. State of Aquaculture in Kenya. Laxpress Services, Nairobi, Kenya. 133p.

Mwaluma J., Nyonje B., Mirera D., Wanjiru C., Wainaina M., Wairimu E., Ototo A., Ochiewo J., Munyi F., Kamakya G., Ngisiange N. (2014). Status of Mariculture in Kenya aquaculture baseline site assessment, social-economic dynamics, production status, challenges and possible interventions along the coast of Kenya. KCDP Technical Report.

Mwaluma J, Mirera D., Mukami M., Wanjiru C., Anyango J., Mang'ondu E.W., Nyonje B., Ochiewo J., Munyi, F. (2017). Status of Mariculture in Kenya. KMFRI RESEARCH REPORT NO.2 AQUA/2016-2017 KMFRI, KENYA.

Mwaura, J.M., Murage, D. (2013). Strengthening community-based management of coastal and marine resources: Baseline surveys and capacity building for protection and management of coral reefs. KMFRI/ANO Technical Report.

Murage, L.D., Mwaura J.M. (2015). Wasini community rallied to secure its future: People and the environment, WIOMSA Issue no. 7

Ochiewo, J. O., Wakibia, J., and Sakwa, M. M. (2020). Effects of monitoring and evaluation planning on implementation of poverty alleviation mariculture projects in the coast of Kenya. Marine Policy, 119, 104050.

Ogello E.O., Kembenya, E., Githukia, C.M., Nyonje, B.M. and Munguti, J.M. 2014a. The occurrence of the brine shrimp, Artemia franciscana (Kellog 1906) in Kenya and the potential economic impacts among Kenyan coastal communities. International Journal of Fisheries and Aquatic Studies, 1 (5): 151-156

Ogello, E.O., Nyonje B.M. and Van Stappen G. 2014b. Genetic differentiation of Artemia franciscana (Kellogg, 1906) in Kenyan coastal salt-works. International Journal of Advanced Research, 2 (4): 1154-1164

Njiru J, Ruwa RK, Kimani EN, Mkare TK, Okemwa G, Kairo JG, Mwaluma J, Mirera D, Uku and J Mwaura J. (2019). Towards sustainable blue economy- A case study of Kenya (unpublished KMFRI report)

Sukhdhane, K.S., Kripa, V., Divu, D., Vase, V.K., Mojjada, S.K., (2018). Integrated Multi-trophic aquaculture systems: A solution for sustainability. Aquaculture, Vol 22, No 4.

UNECA (2016) United Nation Economic Commission for Africa Economic Report for Africa 2016. https://www.uneca.org/publications/economic-report-africa-2016

Wakibia, J. G., Bolton, J. J., Keats, D. W., and Raitt, L. M. (2006). Factors influencing the growth rates of three commercial eucheumoids at coastal sites in southern Kenya. Journal of Applied Phycology, 18, 565 - 573.

CHAPTER 4

FISH FEED DEVELOPMENT, PRODUCTION TRENDS AND DISTRIBUTION NETWORKS IN KENYA

JONATHAN MUNGUTI, SAFINA MUSA, MORINE MUKAMI, ESTHER MAGONDU, ROBERT ONDIBA, JACOB ABWAO, MASAI MUTUNE, GLADY HOLEH AND JAMES NJIRU

Key Messages	Policy Recommendations
• Fish feeds are essential for semi-intensive and intensive aquaculture farming systems. • Aquaculture feeds are among the most expensive animal feeds in Kenyan markets. In semi-intensive and intensive aquaculture systems, feed costs typically account for between 50 and 70% of production costs • The Kenyan fish feed industry has been boosted by the development of fish feed quality standards, which is expected to ensure access to high quality fish feeds by all fish farmers. • The fish feeds produced by small-scale manufacturers is not closely monitored by quality standard agencies and thus majority are of poor quality. The improvement in the quality of these feeds is likely to lead to increased productivity and profitability because they are cheaper and more readily available to fish farmers compared to imported fish feeds. • Farmers and small-scale feed manufacturers need to be made aware of the availability of these ingredient sources, and how they can best be incorporated into their formulations. Currently, information networks are either inefficient or lacking and there is a need to promote programs that use local media to supply farmers with up-to-date feed ingredient availability, quality, and price and supplier details. • Feed management practices markedly impact on both the growth and economic performance of fish production, thus adopting appropriate feed management strategies is instrumental in the maximization of fish production and economic returns.	• For optimum fish production in Kenya, the feed industry must be improved to provide quality and affordable feeds to fish farmers. • Appropriate feed formulation techniques and processing technologies must be communicated to the feed processors. Training needs should focus on the need to improve feed formulations; formulate species- and life-stage specific diets; and improve the understanding of ingredient quality, nutrient composition and selection, manufacturing processes, storage, and on-farm feed management practices. • Access to up-to-date market information for small-scale feed manufacturers and farmers producing farm-made feeds is an issue that needs to be addressed. Contemporary market information including sources, suppliers, quality and cost is a prerequisite to the development of cost-effective farm-made feeds. Furthermore, the use of appropriate local and seasonally available feed ingredients that can be incorporated into farm-made should be encouraged. • The potential to develop public-private partnerships with farmer groups to improve access to information is worth considering. Programs that use the local media to provide farmers with extension services must be encouraged. The government should frequently carry out spot checks on feeds supplied to Agrovets to ascertain its quality. Fish farmers should also be trained on feed formulation, transportation and storage to maintain a constant feed supply and save on costs. • Besides the existence of the quality standards, close monitoring of the feed manufacturers by the relevant authority is necessary to ensure the consistency of quality feeds and to avoid what is being witnessed in the livestock feed sectors where unscrupulous dealers are formulating substandard feeds despite the existence of the relevant feed standards.

Munguti, J., Musa, S., Mukami, M., Magondu, E., Ondiba, R., Abwao, Masai Mutune, J., Holeh, G. & Njiru, J. (2021). Feed Developments, Production Trends and Opportunities in Kenya. In: Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition-Sensitive Fish Food Production Systems; Chapter 4: pp 58-88

4.0. INTRODUCTION

Fish feeds are essential input for semi-intensive and intensive aquaculture farming systems. Fish nutrition has therefore become one of the most important subjects in aquaculture. Aquaculture nutrition and feeding is concerned with the supply of dietary nutrients to fish either directly in the form of an exogenous 'artificial' diet or indirectly through the increased production of natural live food organisms within the water body in which the fish are cultured. Natural food organisms, play a crucial role in the nutrition of fish within extensive and semi-intensive ponds. In intensive culture systems, which are characterized by high stocking density, natural food organisms play an insignificant or no role in the nutrition of the farmed fish. In order to maximize fish production, the nutrition and feeding of fish within each culture system must be considered uniquely and evaluated on its own merits.

Additionally, the nutrient requirements for fish will inevitably vary between herbivorous omnivorous and carnivorous fish. Omnivorous fish will eat a host of materials including plant matter, insects, crustaceans and other animal proteins while carnivorous fish will mostly consume animal protein. (This is a very short paragraph, it may be expanded. On this basis artificial fish feeds are formulated to match the trophic status of the target fish. Artificial feeds may be produced by mixing various feedstuffs or ingredients, which may themselves vary in composition. The choice of raw materials for making fish feeds will depend on locality, seasonality and availability, economics and the quality of the products. The chemical composition of feedstuffs also plays an important role in the formulation of balanced and economical rations for various classes of Fish, which is only possible when exact knowledge of the chemical composition of feedstuffs is available. Studies on the nutritive value of feedstuffs that are available in the East African region show differences between analytical values. (This sentence is incomplete)

According to the estimates of the Food and Agriculture Organization (FAO 2014), in order to adequately feed the world population by 2050, agricultural output originating from fisheries and aquaculture must increase by over 60 percent (FAO, 2014). However, meeting this target is a formidable challenge for the aquaculturist considering that there is n large number of people, mostly in developing countries who suffer from hunger and poverty. To meet such a demand for food fish for an a wealthier global population by the year 2030, it would be necessary that the aquaculture production rate needs significant acceleration sine the capture fisheries production is expected to stagnate ***(FAO, 2012).***

In response to this development, nations around the world have continuously developed aquaculture technologies, especially on feed and feed management practices to increase production efficiencies for a range of aquatic organisms (FAO, 2012). Despite significant inter-country differences in production capacities, aquaculture has collectively achieved the highest average growth rate and is the fastest growing food production sector worldwide. In 2010, global aquaculture production reached 79 million tones, growing at an annual rate of 9.7 percent (FAO, 2012). The technological advances in feed processing equipment and feed management practices have led to an increased contribution to the total aquaculture production, which is now comparable to the levels of capture fisheries. However, this increased contribution is largely from Asian countries, as Asia alone accounted for about 92% of total world aquaculture production in 2010, while the Americas, Africa and Europe combined contributed only 8.3 % (Rana and Hasan, 2013). In 1988, aquaculture contributed only 15 % of total global fisheries production but by 2010, this contribution had reached 47 % (Rana and Hasan 2013).

Development of aquaculture in Kenya dates back to 1950s, but by 2006, the total annual Kenyan aquaculture production had never exceeded 2,000 MT yr-1 (FAO, 2010). Presently the performance of the aquaculture sector has remained dismal due to a number of constraints such as scarcity of efficient and cost-effective fish feeds for different developmental stages of fish, poor feed management practices, limited varieties of the cultured fish species and

> **THE NUTRITION AND FEEDING OF FISH WITHIN EACH CULTURE SYSTEM MUST BE CONSIDERED AS BEING UNIQUE AND EVALUATED ON ITS OWN MERITS.**

low quality fish seeds (Munguti et al., 2012), However, besides the dismal performance, the Kenyan aquaculture sector has undergone remarkable revolution. Over the last ten years, fish production has increased from 1,012 metric tons in 2003 to the current levels of 24,096 metric tones (fig. 1). The implementation of a government supported program in fish farming in 2009 triggered an immediate short-term demand for about 28 million certified tilapia and catfish fingerlings and over 14,000 MT of formulated fish feeds, which could not be adequately supplied, even by the private sector (Musa et al., 2012). The ripple effect of the program triggered some farmers to construct their own ponds, further increas¬ing the demand for fish seed and feed to over 100 million and 100,000 MT, respectively (Musa et al., 2012; Charo-Karisa and Gichuri, 2010). Currently through the Aquaculture Business Development Programme (ABDP), the GoK with funding from IFAD is supporting smallholder aquaculture fish production to accelerate and consolidate the expansion of aquaculture production and trade within the country by enhancing the productive potential of smallholder farmers The program is projected to stimulate further aquaculture growth, and consequently expected to play a significantly greater role in contributing to food security, poverty alleviation and economic improvement of the vulnerable population

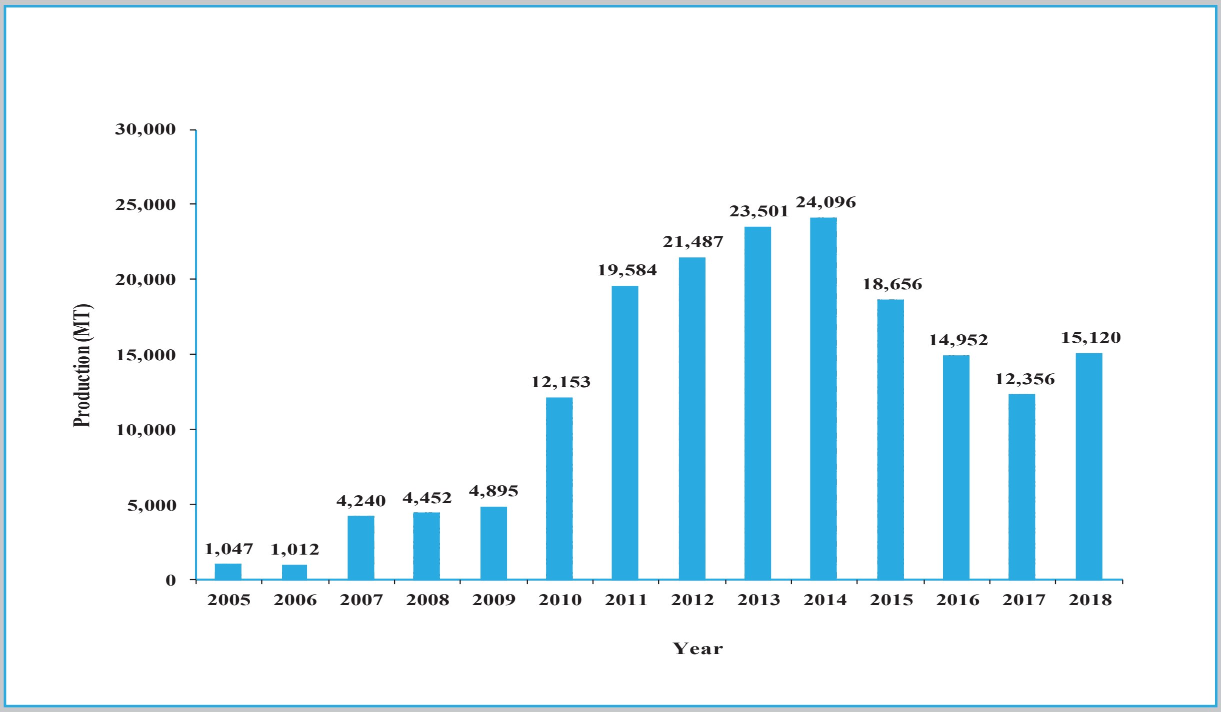


Figure 4.1: Trends in aquaculture production in Kenya 2005 – 2018 (FAO 2018) (Explain the reasons for the steady rise and drop in aquaculture production graph in F1)

Many authors concur that growth of the aquaculture is positively correlated to the progressive use of quality feeds, which meet the nutritional requirements of the cultured fish (FAO, 2018). Indeed, the increase in aquaculture production must be supported by a corresponding increase in high grade formulated feeds. Most Kenyan fish farmers have identified fish feed quality and proper feeding management practices as their major challenges.

4.1. THE CURRENT STATUS OF KENYAN FISH FEED INDUSTRY

In semi-intensive and intensive aquaculture systems, feed costs typically account for between 40 and 60 % of production costs (Shitote et al., 2000; Ali, 2003). The first step towards making the aquaculture industry more profitable and viable is to ensure that farmers have access to quality and affordable feeds. Furthermore, the optimization of feed use by instituting appropriate on-farm feed management practices cannot be overemphasized. Over 90% of cultured fish in Kenya is produced in earthen ponds with sizes between 150 to 500 m2, which are normally fertilized and the fish fed with low cost agricultural byproducts (Ngugi et al., 2007). Prior the availability of compounded feeds, most fish farmers used locally available feedstuffs including rice bran, wheat bran, cassava meal and corn meal to feed their fish. In extreme traditional systems fish were reared in ponds fertilized with manure usually with or without supplementary feed (Liti et al., 2006). Single feed ingredients of plant origin are low in macro and micro-nutrients and deficient in one or more amino-acids. They also have high content of crude fiber in which reduces the digestibility and palatability of the feed thus, leading to low fish yields (Liti et al., 2006)

4.2. FEED PRODUCT QUALITY AND FOOD SAFETY – KEBS REGULATORY STANDARDS

IIn Kenya, one of the most pressing challenges in aquaculture is the availability of efficient and cost-effective farm made feeds for different stages of fish development. As mentioned previously, the Kenyan fish farming Economic Stimulus Project caused tremendous fish feed demand. Due to the increased demand for fish feed, unscrupulous feed dealers took advantage to compromise the quality of fish feed, prompting the government to establish fish feed standards.

The formulation of fish feed standards was a culmination of several negotiations between all aquaculture stakeholders (Kenya Marine & Fisheries Research Institute - KMFRI, State Department of Fisheries, Commercial feed companies, fish farmers and Kenya Bureau of Standards KBS). The fish feed standards were created as part of the efforts to streamline the aquaculture sector and ensure high quality fish feed in the market. The feed quality challenges in aquaculture can be addressed by enforcing the recently formulated standards for fish feed, as well as maintaining best feeding aquaculture practices amongst others. The Kenya fish feed standards for tilapia, catfish and trout are shown in Tables.4.1, 4.2, 4.3 respectively.

Table 4.1 Specific nutritional requirements for compounded tilapia feeds - FDEAS 902: 2018 ICS 65.120

S/N	Parameter	Starter feed	Grower feed	Finisher feed	Brood stock feed	Test method
i.	Moisture content of pellets, %, max.	10	10	10	10	ISO 6496
ii.	Crude protein, %, min.	35	30	25	35	ISO 5983-1
iii.	Energy (DE) Kcal/Kg, min.	2 500	2 750	2 900	2 800	ISO 9831
iv.	Lysine, %, min.	2.1	1.7	1.7	1.7	ISO 13903
v.	Methionine, %, min.	0.9	0.8	0.8	0.8	ISO 13903
vi.	Methionine + cysteine, %, min.	1.4	1.1	1.1	1.1	ISO 13903
vii.	Crude fibre, %, max.	5	10	10	10	ISO 6865
viii	. Crude fat, %	5 - 12	5 - 15	5 - 15	5 - 15	ISO 6492
ix.	Calcium, %,	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	ISO 6490-1
x.	Phosphorus, %	0.6 - 2.0	0.6 - 2.0	0.6 - 2.0	0.6 - 2.0	ISO 6491
xi.	Sodium chloride, %	0.25 - 0.4	0.25 - 0.4	0.25 - 0.4	0.25 - 0.4	ISO 6495

Table 4.2 — Specific nutritional requirements for compounded catfish feeds FDEAS 902: 2018 ICS 65.120

S/N	Parameter	Starter feed	Grower feed	Finisher feed	Brood stock feed	Test method
i.	Moisture content of pellets, %, max.	10	10	10	10	ISO 6496
ii.	Crude protein, %, min.	45	35	30	35	ISO 5983-1
iii.	Energy (DE) Kcal/Kg, min.	3 000	3 000	3 000	3 000	ISO 9831
iv.	Lysine, %, min.	2.1	1.7	1.7	1.7	ISO 13903
v.	Methionine, %, min.	0.9	0.8	0.8	0.8	ISO 13903
vi.	Methionine+cysteine, %, min.	1.4	1.1	1.1	1.1	ISO 13903
vii.	Crude fibre, %, max.	5	10	10	10	ISO 6865
viii.	Crude fat, %	5 -12	5 - 15	5 -15	5 - 15	ISO 6492
ix.	Calcium, %	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	ISO 6490-1
x.	Phosphorus, %	0.6 - 2.0	0.6 - 2.0	0.6 - 2.0	0.6 - 2.0	ISO 6491

Table 4.3 — Compositional requirements for compounded feeds for trout (KS 871:2018)

S/N	Parameter	Starter diet	Grower diet	Brood-stock diet	Test method
i)	Energy (digestible energy), min, kJ/kg	15 500	15 500	15 500	KS ISO 9831
ii)	Crude protein, %, min.	45	40	35	KS ISO 5983-1
iii)	Amino acids: Methionine Lysine Threonine	 1 1.4 0.8	 1 1.4 0.8	 1 1.4 0.8	KS ISO 13903
iv)	Moisture, %, max.	10	10	10	KS ISO 6496
v)	Crude fibre, %, max	4	4	4	KS ISO 6865
vi)	Crude fat, %	15 – 20	10 – 15	10 – 15	KS ISO 6492
vii)	Acid insoluble ash, %, max.	4.	4	4	KS ISO 5985
viii)	Calcium, %, max.	1	1	1	ISO 6490-1
ix)	Phosphorus, %, min.	0.8	0.7	0.6	KS ISO 6491

4.3. FORMULATED FISH FEED

Compounded fish feed shall meet the requirements of the nutrients and digestible energy in Table 4.4and Table 4.5. Compounded fish feed may contain additional micronutrients and when added shall comply with the limits provided in Annex C.

Table 4.4 Description and proximate composition of common feedstuffs - FDEAS 902: 2018 (It would be more informative if the proximate composition is given)

Product	Description	Main nutritional constituent
1. Alfalfa meal	Alfalfa as grown, dried and processed, and to which no other matter has been added	Crude protein, Crude fibre
2. Barley meal	The meal obtained by grinding barley, as grown, which shall be the whole grain together only with such other substances as may reasonably be expected to have become associated with the grain in the field.	Crude protein, Crude fibre
3. Bean meal	The meal obtained by grinding commercially pure leguminous beans (other than soya bean).	Crude protein, Crude fibre
4. Blood meal	The meal has been dried out to which no other matter has been added	Crude protein, Dry matter
5. Bone meal	Commercially pure steamed bone, raw or degreased, which has been ground or crushed and which contains phosphorus not less than 4.5% phosphorus.	Crude protein, Phosphorus, Calcium
6. Brewery and distillery grains	The product obtained by drying the residue from distillery mash-tube, and to which no other matter has been added	Crude fibre, Crude protein
7. Cassava, dried	The dried root of the species *Manhot esculanta*	Crude fibre, Crude protein
8. lover meal	Clover as grown, dried and processed and to which no other matter has been added	Crude protein, Crude fibre
9. Coconut cake	The residue resulting after part removal of oil and cortex from commercially pure coconut kernels	Crude protein Crude fibre
10. Cottonseed cake	The residue resulting after part removal of oil and cortex from commercially pure cottonseed	Crude protein, Crude fibre
11. Sorghum meal	The meal obtained by grinding sorghum as grown which shall be the whole grain together only with such substances as may reasonably be expected to have become associated with the grain in the field.	Crude protein, Crude fibre
12. Fish meal	A product, which may contain an added antioxidant but to which no other matter has been added, obtained by drying and grinding or otherwise treating fish or fish waste.	Crude protein, Oil, total ash.
13. Grass, meal	Any product which, (i) is obtained by artificially drying any of the following: grass, clover, lucerne, green cereal, or any mixture consisting of any of them, and (ii) is otherwise as grown (that is to say including any growths harvested there with but with no other substance added thereto), and contains not less than 13 % crude protein calculated on the assumption that it contain 10 % moisture.	Crude protein, Crude fibre
14. Groundnut cake	The residue resulting after part removal of oil and part of non-removal of cortex from commercially pure groundnuts	Crude protein, Oil, crude fibre
15. Maize	Maize kernel or crushed maize kernel as grown for commercial purposes	Crude protein

Product	Description	Main nutritional constituent
16. Maize germ meal	Consisting mainly of the embryo of kernel not less than 10 % oil, and not more than 5 % ash	
17. Maize and cob meal	Ground maize on the cob	Crude protein, Oil, crude fibre
18. Maize meal	Milled whole maize	Crude protein, Oil, crude fibre
19. Maize gluten meal	A by-product resulting from the removal of a bran starch and germ from maize	Crude protein, Oil, crude fibre
20. Meat and bone meal	A product, which may contain an added antioxidant but to which no other matter has been added, containing not less than 65 % protein, obtained by drying and grinding animal carcasses or portions thereof but excluding hair, has been preliminarily treated for the removal of fat	Crude protein, Oil, crude fibre
21. Milk powder	Dried milk from which a substantial amount of fat has been removed and to which no other substance is added	Crude protein
22. Millet	Finger millet of the species ***Eleusine coracana***	Crude protein, Crude fibre
23. Mineral mixture	Mixture of substances used whether in the form powder or licks and purporting to be essential for livestock	Percent of the mineral and trace elements
24. Molasses	A concentrated syrup product obtained in the manufacture of sugar from sugar cane to which no other matter has been added	Dry matter, sugar as sucrose
25. Oats, ground	The product obtained by grinding commercially pure oats	Crude protein, Crude fibre
26. Pea meal	The meal obtained by grinding or crushing commercially pure peas including pods	Crude protein, Crude fibre
27. Rice bran	The outside husk or rice kernel to which no other matter has been added	Crude protein, Crude fibre, oil
28. Rice meal	The product obtained by grinding commercially pure rice after the removal of hulls and to which no other substance is added	Crude fibre, Crude protein, oil
29. Rice polishings	The product obtained when polishing kernels after the removal of hulls and bran	Crude protein, oil, Crude fibre
30. Sesame cake	The residue resulting after the part removal of oil from commercially pure simsim kernels	Crude protein, oil, Crude fibre
31. Soya bean meal	The residue resulting after the part removal of oil from commercially pure soya bean seeds	Crude protein, oil, Crude fibre
32. Sweet potatoes	The dried tubers of the species ***Ipomea batatas***	Crude protein, Crude fibre
33. Wheat meal	The meal obtained by grinding commercially pure wheat as grown and to which no other substance has been added	Crude protein, Crude fibre
34. wheat bran	Outside husk of what kernel to which no other matter was added	Crude protein, Crude fibre
35. Wheat pollard	A by-product of wheat separated during production of flour not mentioned otherwise in this schedule containing not more than 4 % of other than wheat vegetable substances	Crude protein, Crude fibre
36. Yeast dried	The product obtained by drying of yeast or yeast residues, and to which no other matter has been added.	Crude protein
37. Other feedstuffs	As may be described by the Department of Animal Resources from time to time	

TTable 4.5Vitamins and mineral requirements for tilapia FDEAS 902: 2018

Sl.No.	Parameters	Starter feed	Grower feed	Finisher feed	Brooder feed
	Vitamin A IU/Kg	3000	1500	3000	3000
	Thiamine mg/Kg	18	9	18	18
	Copper mg/Kg	6	3	6	6
	Zinc mg/Kg	100	50	100	100
	Manganese mg/Kg	50	25	50	50
	Iodine mg/Kg	6	3	6	6
	Iron mg/Kg	60	30	60	60
	Vitamin B_{12} mg/Kg	0.015	0.0075	0.015	0.015
	Vitamin A IU/Kg	3000	1500	3000	3000
	Vitamin D IU/Kg	1500	750	1500	1500
	Choline mg/Kg	1200	600	1200	1200
	Vitamin E mg/Kg	120	60	120	120
	Riboflavin mg/Kg	24	12	24	24
	Pyridoxine mg/Kg	18	9	18	18
	Pantothenic mg/Kg	48	24	48	48
	Biotin mg/Kg	0.2	0.1	0.2	0.2
	Ascorbic acid mg/Kg	300	150	300	300
	Institol mg/Kg	150	75	150	150
	Thiamine mg/Kg	18	9	18	18

Table 4.6 Vitamin and mineral requirements for catfish FDEAS 902: 2018

Sl.No.	Parameters	Starter feed	Grower feed	Finisher feed	Brooder feed
	Vitamin A IU/Kg, min	900	900	900	900
	Ascorbic acid mg/Kg, min	60	60	60	60
	Copper mg/Kg	4.8	4.8	4.8	4.8
	Zinc mg/Kg	20	20	20	20
	Manganese mg/Kg	2.4	2.4	2.4	2.4
	Iron mg/Kg	20	20	20	20
	Vitamin A IU/Kg	900	900	900	900
	Vitamin D IU/Kg	220	220	220	220
	Choline mg/Kg	400	400	400	400
	Vitamin E mg/Kg	23	23	23	23
	Niacin mg/kg	14	14	14	14
	Riboflavin mg/Kg	9	9	9	9
	Pyridoxine mg/Kg	3	3	3	3
	Pantothenic mg/Kg	15	15	15	15
	Ascorbic acid mg/Kg	60	60	60	60
	Thiamine mg/Kg	1	1	1	1

4.4. FEED DEVELOPMENTS, PRODUCTION TRENDS, AND DISTRIBUTION NETWORKS

4.4.1 NUTRIENT REQUIREMENTS AND DIET FORMULATIONS

Good nutrition in fish production is essential for economic gains, quality and healthy products. In fish farming nutrition is a critical factor to consider as feed represents over 50% of the production costs. The amount of nutrients needed for fish maintenance, growth, reproduction, and good health needs to be determined for appropriate feed formulation. In Kenya the development of quality feed formulations and pellet extrusion for fresh water fish has recently been started with support from KMFRI, Sangoro station. The aim is to support the expanding fish farming industry so as to satisfy the increasing demand for affordable, safe, and high quality fish products.

TYPES OF FISH DIETS

1. Complete diets: They are diets given to fish when reared in high-density systems and cannot forage freely to look for natural feeds.
2. Supplemental diets: They are diets intended to help support the natural food available in fish ponds and raceways. They do not contain full complements of vitamins and minerals but support the naturally available feed with additional proteins, carbohydrates, and lipids.

FISH NUTRIENT REQUIREMENTS

The nutrient requirements of different fish species differ within species and may be affected by age, stage of development, gender, the culture environment, and physiological factors. The common nutrients for fish are proteins, lipids, carbohydrates, vitamins, and minerals.

PROTEIN:

Protein is the is the body building nutrient and is the most expensive component of a fish feed. To avoid incurring aquaculture losses, accurate determination of protein requirements for each species and size of cultured fish is important. In aquaculture the protein requirement for commonly culture fish average at 30-40% for marine shrimps, 28-32% for cat fish, 25-30% for Tilapia. Protein requirements are usually higher for carnivorous fish than for herbivorous (plant consumers) and omnivorous (Plant-animal consumers) fish. Protein requirements are also generally higher for smaller fish and decreases as the fish increases in size.

LIPIDS

Lipids are high energy nutrients utilized to spare protein for energy production in aquaculture. Lipids supply twice as much energy as protein and carbohydrates. Lipids comprise about 15% of fish diets supplying essential fatty acids and also serving as transporters for fat soluble vitamins. Lipids are classified as: Saturated, polyunsaturated and highly unsaturated fatty acids. Omega 3 fatty acids have been classified as excellent sources of lipids in manufacture of fish diets.

CARBOHYDRATES

Carbohydrates are inexpensive sources of energy in fish diets. The ability of fish to utilize dietary carbohydrate for energy varies considerably; many carnivorous species use it less efficiently than the herbivorous and omnivorous species (Wilson, 1994). Some of the carbohydrate taken by the fish is deposited into body tissues such as liver and mussles in form of glycogen and becomes a ready source of energy. The rest is converted to fat and deposited into the body tissues.

MICRONUTRIENTS

MINERALS

Fish require minerals for tissue formation, osmoregulation, and metabolic functions (Lall, 2002). Besides, minerals in fish also regulate osmotic balance and aid in bone formation and integrity. They are normally required in small amounts as components in enzyme and hormone systems. Common trace minerals are copper, iodine, zinc, chromium and selenium whereas macro minerals are calcium, phosphorous, magnesium, chloride, sodium, potassium and Sulphur. In case of deficiency of minerals in supplied diets, fish normally absorbs the available minerals from the water through their gills and skin.

VITAMINS

Vitamins are organic compounds necessary in the diet for normal fish growth and health. They are often not synthesized by fish and therefore must be supplied in the diet. Vitamins are grouped into two; the water-soluble and fat-soluble vitamins. The water-soluble vitamins include Folic acid, pantothenic acid, biotin and ascorbic acid (vitamin c) that is used as an antioxidant and also help the fish in immune system building. Fat-soluble vitamins include; retinol for vision development, vitamin D for bone integrity, Vitamin E used as an antioxidant, vitamin K for blood clotting and skin integrity. Vitamin and mineral premixes are now available in Kenya in agricultural products outlets. They are added to prepared diets so that fish receives adequate levels of each micro or macronutrient independent of levels in dietary ingredients. Formulation of feeds for different species takes into account the specific nutrient requirements of the targeted species, the nutrient composition, and availability of nutrients in various foodstuffs, the cost, and processing characteristics of ingredients.

4.4.2 FEED ADDITIVES

Fish feed additives are substances that are usually added to fish feeds during formulation to ensure the dietary nutrients are ingested, digested, absorbed and transported to the cells (Pedro, 2015). Certain feed additives target feed quality, including pellet binders, antioxidants and feed preservatives. The main functional feed additives include probiotics, enzyme es, microalgae, organic acids, mycotoxin binders, phytogenic compounds, and yeast.

PHYTOGENIC COMPOUNDS

These are plant derivatives added in the feed to improve the growth and health performance of fishes. The plant products operate like antioxidants, antimicrobial, anticarcinogenic, antiparasitic appetitie enhancers and digestion activities *(Asimi and Sahu,2013).*The phytogenic compounds are used in different forms of oils, powder or extracts *(Alemayehu et al., 2018)*.

Table 4.7 Functions of different phytogenic compounds and their effects on various fish species cultured in Kenya. Source: Bharathi et al., 2019.

Phytogenic Compound	Effect
Allicin - Garlic (Allium sativum)	It controls & increases immune stimulation against bacterial diseases in cultured fishes
Rosemary (Rosmarinus officinalis)	It reduces mortality against Streptococcus inae in Nile Tilapia
Moringa oleifera	It gives better results against Aeromonas hydrophila infection and transportation – induced stress in Nile tilapia
Psidium guajava	Dry leaf powder and ethanol extract of Psidium guajava controls A. hydrophila infection in Tilapia
Astragalus radix	Astragalus radix root extract increases the leucocytic phagocytosis and Lysozyme activity in Nile tilapia
Withania somnifer	Root extract of Withania somnifer increase Nitro blue tetrazolium level, Phagocytic cell activity, Lysozyme activity and Total immunoglobulin level in Labeo rohita
Ipomoea batatas	The peel of sweet potato in the diet improve the growth performance and feeding efficiency in Nile tilapia
Allium sativum	Garlic peel improve the haematological parameters and develop the resistance against Aeromonas hydrophila infection in African catfish fingerlings
Astragalus sp	The root and stem extract of these Chinese herbs showed a humoral and cellular immune response in Common cap.

MICROALGAE

These are a large group of unicellular photosynthetic microorganisms ranging from 2 to 20 µm in size. They are a source of protein, fat, polysaccharides, vitamins, pigments and trace elements ***(Li et al., 2015)***. They are presently used as a live feed for fish and shellfish larvae ***(Muller-Feuga, 2000).***

Table 4.8 Effects of different microalgae and their effects on fish. Source: Bharathi et al., 2019

Microalgae	Effect
Spirulina	5% and 10% of spirulina in diet show better growth and bright colouration in *(Regalecus glesne),* Koi and Goldfish It increases Superoxide dismutase and lysozyme serum activity in Silver carp
Haematococcus Pluvialis	It enhances the antioxidant system and certain biochemical parameters in Rainbow trout.
Crypthecodinium cohnii	It improves growth performance and good survival in juvenile Seabream

Probiotics

Probiotics are live microbes supplemented to the fish gut through feeds (Pedro, 2015). They help improve the microbial balance in fish intestines. They have antimicrobial effects, they are capable of modulating the immune system and regulating the allergic response of the body. Use of probiotics in different fish feeds and its effects is shown in the table below.

Table 4.9. Effects of different probiotics and their effects on fish. Source: Bharathi et al., 2019

Probiotic	Effect
Streptococcus faecium	Improves the growth and protein and lipid content of the Nile tilapia
Bacillus subtilis and Streptomyces	Improves the ornamental fishes (swordtail, guppy) growth and survival
B. subtilis, B. licheniformis, and Enterococcus Faecium	Supplemented diet improves the growth performance of rainbow trout
Bacillus coagulans and Rhodopseudomonas palustris	Concentration of 1 X 9107 CFU/ml increase the Specific Growth Rate and weight gain in Nile tilapia
Lactobacillus rhamnosus	Show immune enhancement in Rainbow trout
Enteroccus faecium	Enhances the growth performance and immune response of the tilapia

Feed additives are used for higher productivity and enhanced resistance to infectious diseases as a possible solution to sustainable aquaculture.

OTHER FEED ADDITIVES AND PROVISIONS RELATED TO THEIR USE

Additives in the following categories may be used in fish feeds and if used, they shall comply with the requirements given in Annex D.

(a) Antioxidants;
(b) Colourants;
(c) Emulsifiers;
(d) Stabilisers;
(e) Thickeners and gelling agents; binders;
(f) Anti-caking agents and coagulants;
(g) Aromatic and appetizing substances;
(h) Enzymes; and
(i) Preservatives.

NOTE Materials intended for mixing with animal feed as additives for use as feeding stuffs should specify the kind of and, if appropriate the age group of the animal for which the feed is intended. Also, the quantity in grams per kilogram (or percent by weight) of the complete feed which conform to the provisions of this standard should be stated in the label. No antibiotic, hormone substance, drug or mineral shall be added to or included in a feed other than such ingredients required to satisfy this standard and approved by World organization for animal health (OIE).

4.5 CONTAMINANTS, PACKAGING AND LABELLING

AFLATOXINS

Fish feeds shall comply with the maximum aflatoxin requirements stated in Table 4.10 when tested as per the methods specified therein.

Table 4.10 — Maximum tolerable limits for aflatoxin

S/N	Aflatoxin	Type of fish feed	Maximum limit, µg/kg	Test method
i.	Total aflatoxin	Starter feed, grower feed, finisher feed, broodstock feed	100	ISO 16050
ii.	Aflatoxin B1	Starter feed, grower feed, finisher feed, broodstock feed	10	ISO 14718 ISO 17375

PESTICIDE RESIDUES

Fish feeds shall comply with those maximum pesticide residue limits established by the Codex Alimentarius Commission for the ingredient used in fish feed.

HEAVY METALS

Fish feeds shall comply with the limits of heavy metals as specified in Table 4.11 when tested as per the methods specified therein.

Table 4.11 — Heavy metal limits for fish feeds

S/N	Heavy metal	Maximum limit, mg/kg	Test method
i.	Arsenic	2.0	ISO 27085
ii.	Lead	5.0	ISO 27085
iii.	Cadmium	1.0	ISO 27085
iv.	Mercury	0.1	ISO 27085

PACKAGING

Fish feeds for sale shall be packaged in suitable containers that are of sufficient strength, and sufficiently sealed to withstand reasonable handling without tearing, bursting or falling open. The containers shall be clean and not previously used.

LABELLING

Each package of compounded fish feed shall be legibly and indelibly labelled with the following:

(a) Name of the feed for example "tilapia grower feed" or "catfish finisher feed";
(b) Name and physical address of the manufacturer;
(c) Declared proportions of crude protein, crude fibre, crude fat, phosphorus, calcium, lysine, and methionine;
(d) Additives, if included, shall be declared;
(e) Net weight in metric units;
(f) Directions for use;
(g) Information about the species or category of animals for which the feed is intended;
(h) Floating pellets feeds shall be labelled as "floating feeds";
(i) Batch number/ lot identification;
(j) Manufacturing date;
(k) Storage instructions; and
(l) Expiry date.

4.6 FISH FEED PROCESSING TECHNOLOGY

Aquaculture is the fastest growing sector in the food industry. To sustain the rapid growth, there is need to produce high quality feeds for sustainable development of the sector. To develop quality fish feeds is to ensure that the unique requirements of different species and stages of fish are adequately met. This is in cognizant of physiological features of the fish, feeding habits and environmental issues. Processing is meant to increase digestibility, pelletability and inactivation of anti-nutrients (Jauncey & Ross, 1982). Before fish feed ingredients are incorporated into a formulated feed, they are subjected to processing in one way or the other. After mixing, the ingredients undergo further processing until they acquire the intended form. Below is the stepwise processing chain.

4.6.1 PROCESSING STEPS

Selection of ingredients- Grinding- Weighing- milling- Mixing-Conditioning (When extruding) -Pelleting/extruding-Sieving-drying and cooling- Packing

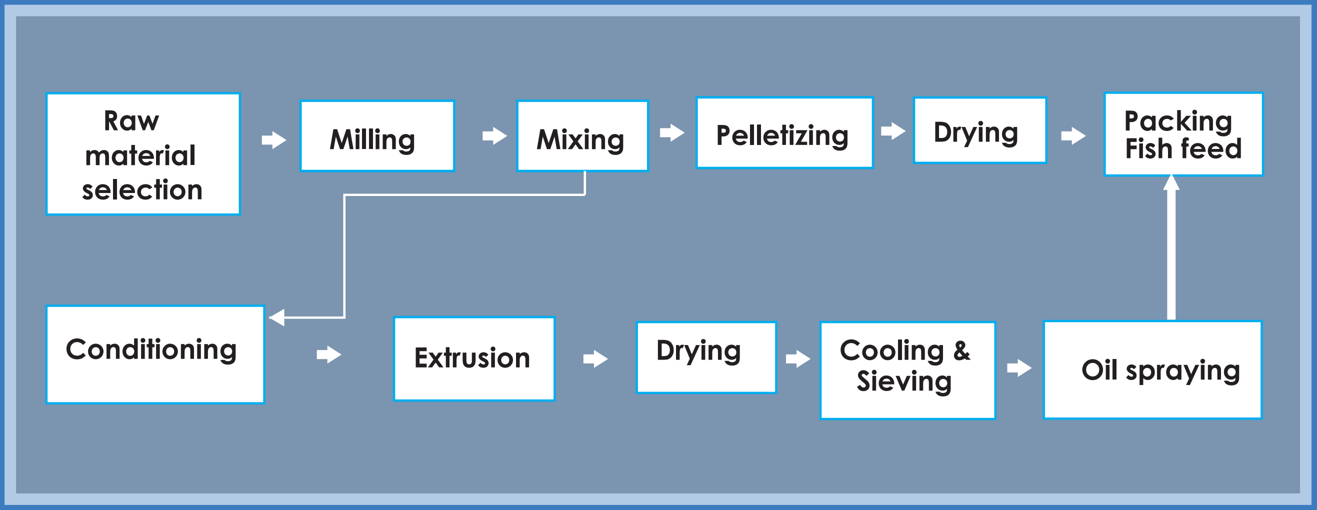


Figure 4.2. General outline of fish feed processing steps

(i) Selection of ingredients for fish feed

In the selection of fish feed ingredients, the following factors have to be considered:

- The ingredients have to be in a state of supplying the intended nutrients,
- Low energy consumption during processing,
- Promote good stability of pellets in water,
- Have appropriate starch levels to support the preparation of either sinking or floating pellets. The starch level in fish feeds ranges between 5-60%. Sinking pellets have a starch content of 10-15% whereas floating fish feeds have starch content above 20%. In extrusion, carbohydrates act as adhesives, emulsifiers and suspending agents.

(ii) Grinding/Milling

Grinding is a major step in raw material preparation. Grinding helps in the reduction of raw material sizes to the desired particle size. Milling is usually done to ingredients with low moisture content. Particle size is critical to mechanical and chemical activity. In most cases, a hammer mill is used in the production of between 150-700kg/h. When producing 1 tonne and beyond, a water-drop crusher is used. For commercial-scale production of aqua-feeds, the crushing process entails two levels of crushing: Coarse grinding and fine grinding. The other benefits of grinding include:

- Easy conditioning, better water penetration and improved gelatinization due to reduced particle size; Increased water stability
- Improved retention of liquid coatings due to small cell structure
- Improved product appearance and reduced incidence of die blockages
- Fast and ease of cooking and Increased palatability and digestibility
- Ingredients should be milled efficiently to pass-through of 1, 1.5 & 2mm mesh screens.

(iii) Mixing:

Mixing is an important step in the processing of aquafeeds. Usually, physical properties of fish feed ingredients such as particle size, particle shape, density, viscosity, hygroscopicity etc. are varied. However, if they were same for all use intended ingredients then mixing would be made so easy.

During mixing, ingredients with smaller particles such as drug pre-mixtures, vitamins and minerals are added last. Before adding liquid ingredients like oil, dry ingredients must be dry mixed well and then liquid ingredients are sprayed on top and then mixed (wet mixing). Mixing is accomplished using horizontal twin screw mixer. It is recommended to add about 10% of liquid. Mixing should be done homogenously. Mixing has the following benefits:

- To assist in realizing homogenous mixture
- Helps in obtaining grinding efficiency, especially, when ingredients with high oil levels like fish meal, are mixed with low-fat ingredients. When high-fat ingredients are ground individually they can clog the hammer mill screens. For instance, grinding a complete ration lowers mixture oil content and improves grinding performance. Every formulation has specific mixing time.

(v) Conditioning /heat treatment

Conditioning involves adding water and heat to the mixed material before making fish feed. This kill pathogenic bacteria improves digestibility and water resistance. Usually, conditioning, applies for the wet extrusion process, however, for dry extrusion conditioning is not necessary. When feedstuffs are subjected to heat treatment it helps in destroying anti-nutrients. Further, heat treatment improves nutritional value. Ingredients containing large quantities of starch gelatinize and this improves digestibility and binding properties.

(vi) Fish feed pelletizing or extruding

There are two ways of making fish feed pellets, by pelletizing or extruding. Pelletizing is accomplished by using a common feed pellet mill to produce sinking fish feed. In extrusion, a single screw fish feed extruder type is used. Extrusion is recommended in producing high quality aquafeeds. A fish feed extruder can produce floating pellets, sinking pellets, slow sinking pellets, semi-humid feed, micro-encapsulated feed and powder feed. This is based on the intended fish species and size. Pellets of different sizes can be extruded ranging from 0.2mm-8mm diameter. The pellet length should be 2-3 times its diameter (Jauncey & Ross, 1982). In dry extrusion, the mixture is forced through a die under high pressure. In wet extrusion low pressure steam is injected into mixer.

(vii) Fish feed pellets drying

To prevent the growth of molds on fish feeds, moisture should be reduced to below 11.5%. These can be achieved by drying the feeds in the sun or a drier at a temperature of about 600C. For instance, a drier with 3 or so layers improve on drying space and screen fish pellets and thus separating powder. Anticorrosive measures should be taken to preserve the nutrition composition of feed, PH value and general quality.

(viii) Fish feed pellets cooling

The fish feed pellets, after spraying liquid, are conveyed to the counter-flow cooler. The counter-flow cooler has many advantages in fish feed pellets processing, such as high automation, small air volume, low power consumption and small floor area.

(ix) Oil-spraying

Aqua-feeds are sprayed with edible oil using heat-sensitive components and drum-type sprayers. Fish feed pellets are sprayed with liquid oil ensuring full contact with oil droplets in the air. Oil coating is beneficial because it enhances floatability, creates a shield against absorbing moisture and helps in the adherence of vital additives. Considering the fish's physiological features and environmental issues, the feed should be made in such a way to ensure optimal feed conversion to reduce aquatic environment pollution caused by feeds. Thus, the feed should be easy to digest and absorb.

SUPPLEMENTARY AMINO ACIDS

Protein as an ingredient is so far the most important during feed formulation given its vital role in sustaining the growth of fish. Majorly, protein requirements in aqua-feed have traditionally relied on fishmeal (FM) and other conventional sources such as meat and bone meal (MBM), poultry-by-product (PBP), blood meal (BM), hydrolyzed feather meal (HFM), fish silage (Abowei and Ekubo, 2011); soybean meal, sunflower seed cake, cottonseed meal/cake, rapeseed meal, pea seed meal, groundnut cake, lupin beans, sesame seeds, as well as grain legumes such as Leucaena leaf meal, green gram legume, alfalfa and Jack bean (Gatlin et al., 2007; Hertrampf and Piedad-Pascual, 2012b). Some conventional ingredients such as FM are preferred for aqua-feeds because of the high protein content (65% to 72%), balanced proportions of the essential amino acids that meet the requirements of all fish species (Hu et al., 2013; Jackson, 2012; Tacon et al., 2010) and availability of information about their nutritional profiles and effect on fish growth when included in aqua-feeds.

Nevertheless, use of conventional ingredients as protein sources for aqua-feeds is facing a common problem of competition from human consumption and animal feed industry, hence increasing cost *(Moutinho et al., 2017)* and leading to perennial shortages. Thus, it is necessary to search for less costly and easily available non-conventional proteins aquafeed ingredients of low human use preference. Several studies conducted in KMFRI and elsewhere, by scientists, have explored alternative ingredients which can be used as protein sources for aquafeeds. Such alternative ingredients are presented in two categories: Non-conventional plant protein sources and non-conventional animal protein sources.

4.7.1 NON-CONVENTIONAL PLANT PROTEIN SOURCES

Both terrestrial and aquatic non-conventional plant protein sources have been explored for aquafeeds. Most plant protein ingredients are easily and locally available and can be collected cheaply especially in developing countries, without extra costs *(Ghosh et al., 2018; Lucas et al., 2019).*

Some of the terrestrial plant protein sources include plant tubers such as sweet potato by-products (Soltan, 2002), cocoyam peels (Nwokocha and Nwokocha, 2013); fruits and fruit wastes (Soltan, 2002); leaf meals such as those from sweet potatoes (Munguti et al., 2012); pawpaws (Obwanga, 2010), moringa (Yuangsoi and Masumoto, 2012), amaranth (Ngugi et al., 2017), Turi leaf meal (Dorothy et al., 2018), Leucaena (Sotolu and Faturoti, 2008), cassava (Ng and Wee, 1989) and banana leaves (Dongmeza et al., 2009) among others. Other terrestrial plant protein sources have also been derived from seeds such as ***Prosopis juliflora*** (Ondiba, 2016); nuts such as bambaranut (Onyimonyi & Ugwu 2007) among others. The aquatic sources of plant protein include macrophytes such as Azolla (Dorothy et al., 2018); grasses such as Bermudagrass, Typha and nursery grasses (Sahito ***et al.***, 2015), duckweed (El-Shafai ***et al***., 2004), seagrass among others.

4.7.2 NON-CONVENTIONAL ANIMAL PROTEIN SOURCES

Non-conventional animal protein sources for fish feeds include those from birds (Sabat ***et al.***, 1998); tadpole meal, fly larvae, earthworm meal (Musyoka et al., 2019), insects (Belghit ***et al.***, 2019) etc. The potential use of insect meal in fish diets has recently attracted much attention (Henry ***et al***. 2015). It is therefore reasonable to consider insect meals as potential raw material in fish feeds. Although it is widely practiced in Sub Saharan Africa, few scientific reports were found on the deliberate collection and feeding insects to fish. Rutaisire (2007) reported that 5% of farmers in Uganda use termites for feeding fish. Insects such as white ants (*Macrotermes spp.)* and grasshoppers (*Ruspolia* spp.) have found use as fish food. Most of these non-conventional ingredients have not been fully utilized in aqua-feed production because their chemical composition and nutritional profiles are not well known or understood. Thus, some ingredients are feared that they may be toxic or poisonous. Further, there is insufficient information on processing methods in a view to commercializing them.

4.7.3 SUPPLEMENTARY AMINO ACIDS (AA)

When using alternative or unconventional protein sources in the production of aquafeeds, the levels of indispensable amino acids may be imbalanced and therefore they should be regularly checked to ensure the dietary requirements of amino acids for target fish species are met. In most cases lysine and methionine are limiting upon use of plant-based ingredients in fish diets. Deficiency and imbalance in Essential amino acids (EAA) may impair body metabolism and homeostasis.

Essential AA are important due to their role as building blocks for proteins, suppressing of aggressive behavior in fish, appetite stimulation, growth and development, energy utilization, immunity, osmoregulation, ammonia detoxification, antioxidants, defense, metamorphosis, pigmentation, gut and neuronal development, stress responses and reproduction (Wu ***et al.,*** 2014) Careful use of Essential AA doses may be important in addressing disease resistance, immune response, reproduction, behavior among others. Several functional properties of amino acids for different fish species has been highlighted in a review of different studies (Andersen, Waagbø & Espe, 2016). In cases where plant protein ingredients are used to prepare fish feeds, Supplements of limiting EAA can be incorporated to ensure 100% replacement of FM (Ahmed ***et al.,*** 2019).

A survey conducted by KMFRI 2020 tabulated the active feed producers, their location, production capacity, the feed type and approximated farmers served from each producer. (Table 4.12)

> SOME CONVENTIONAL INGREDIENTS SUCH AS FM ARE PREFERRED FOR AQUA-FEEDS BECAUSE OF THE HIGH PROTEIN CONTENT (65% TO 72%), BALANCED PROPORTIONS OF THE ESSENTIAL AMINO ACIDS THAT MEET THE REQUIREMENTS OF ALL FISH SPECIES AND AVAILABILITY OF INFORMATION ABOUT THEIR NUTRITIONAL PROFILES AND EFFECT ON FISH GROWTH WHEN INCLUDED IN AQUA-FEEDS.

Table 4.12 Detailed List of Aquaculture Fish Feed Manufacturers

Fish Feed Manufacturer	Location	Distribution Location	No. of Staff	Feed Production Level MT/ Month	Production Capacity	Type of Feed	Fish Farmers Served
Jewlet (Feed) Enterprises Ltd	KenduBay	Nationally	5	40	500	Floating and sinking pellets	1,000
Butula Fish Farmers Cooperative	Butula	Busia County	10	Nil		Sinking pellets	Operation Stalled
Dominion Fish Feed Limited	Siaya	Nationally	30	24,000		Sinking pellets	30
Tigoi Fish Feed Company	Kakamega	Vihiga County	4	1		Sinking pellets	200
Matayos Aquafeed SHG	Busia	Busia County	7	2		Sinking pellets	350
Nyawara Animal Feed Plant	Gem, Siaya	Nationally	2	10		Sinking pellets	>50
Deje Farm Products	Sega, Siaya	Siaya & Busia	4	1		Sinking pellets	>100
Awino Fish Feed Limited	Siaya	Siaya	4	1		Sinking pellets	15
Sare Millers	Kisumu	Vihiga County	6	15		Floating and sinking pellets	70
Kenya Marine and Fisheries Research Institute	Sangoro	Nationally	3	4	48	Sinking pellets	200
Nyanjiga Farm	Siaya	Nationally	2	10		Pelletizer, Mixer, Miller	200
Mabro Fish Feed Ent.	Bondo Siaya	Bondo, Siaya	11	6		Hammer, Mixer, pelletizer	70
Aqualife Solutions	Machakos	Nationally	5	20	500	Floating pellets	50
Sigma Feeds Limited	Rongai	Nationally		72	10,000	Floating pellets	>
Javarih Holdings	Nyamonye, Siaya	Nyanza Region	3	Nil		Sinking pellets,	20
Unga fish feeds-Nairobi	Industrial Area Nairobi	Nationally	12	300	5,000	Floating pellets	>200
Lenalia Feeds - Limuru	Limuru Kiambu	Nationally	4	40	1000	Floating and sinking pellets	>100
Bidii Fish Feeds Luanda(not producing)	Emuhaya, Vihiga	Western/ Nyanza- Kenya		5	100	Floating and sinking pellets	>70

Table 4.13 Detailed List of Aquaculture Fish Feed Importers (2019)

	Fish Feed Manufacturer	Local Dealer/ Representative	Distribution Location	Feed Imported In Mt/ pa (As at 2020)	Type Of Feed
1	Aller Aquafeeds - Denmark	Cage farms, Mwea Aqua Fish Farm Kirinyaga, Sare Millers Limited, Kisumu	Siaya, Usenge	250	Extruded feeds
2	Rannan Fish feeds - Israel	Samaki Express Limited, Nairobi	Nationally	156	Extruded feeds
3	Novatech fish feeds- zambia	Victory farms	Homabay	400	
3	Skreting fish feeds – the Netherlands	Victory farms	Homobay	4500	Extruded feeds
		Unga fish - (catfish)	Nationally	27	Extruded feeds
		Starter tilapia	Nationally	130	
		Starter catfish	Nationally	100	
		Kamuthanga – Machakos	Machakos	156	Extruded feeds
		Fresh catch - Athiriver	Athiriver	102	
4	LFL Riche Terre - Mauritius	Africa blue	Bondo	100	Extruded feeds
		Pindu Fish farm	Kiambu	26	
5	Laguna brazil	Jewlet enterprises	Homabay	600	Extruded feeds
6	Prime feeds - Israel	Africa blue	Bondo	100	Extruded feeds
	Biomar - france	Starter diet – Makindi fish farm Thika	Thika		

Table 4.14 Fish feed cost range at farm level

Feed Name	Feed Description	Feed Sizes (mm)	Crude Protein (CP)	Crude Fibre (CF)	Farm Prices (Kshs)
Tilapia and catfish Fry feed	Starter fry	0-1.0	>40		250 - 398/=
	Small crumbles	1.0-1.4	>40		250 - 398/=
	Big crumbles	1.4-2.0	>40		250 - 398/=
Tilapia and catfish	Brood stock feed	4.0	40	8	140-180/=
	Pre-Grower feed	2.0	35	6	110-180/=
Pre-grower, grower and broodstock feeds	Grower feed	4.0	30	5	100-150/=

4.8. STATUS AND PROSPECTS OF LIVE FOOD PRODUCTION

Live food production occupies central position in both freshwater and marine aquaculture, with the latter being more critical. This is because marine larval fishes cannot synthesize specific important fatty acids via de-novo metabolic pathways, hence must feed on live food diets to improve survival ***(Lubzens et al. 1995).*** The major live food resources available in nature include single and multi-cell microorganisms,e.g. bacteria, algae, rotifers, copepods, cladocerans, mysids, Artemia etc. Live food resources are critical for successful fish larviculture. However, the hatchery production of these live foods depends on the availability of high-density microalgae, which is unstable, laborious and costly to produce, thus impedes the development of larviculture, especially in most tropical countries (Ogello et al. 2019, 2020). The copepods and cladocerans are nutritious live foods but are difficult to culture and, are larger than the mouth gap of most larval fishes (Ogello et al. 2020). Artemia nauplii 46 of contain essential nutrients, but the supply depends on the natural ecological conditions, making their availability unpredictable and expensive ***(Ogello et al., 2014)***. Within the rotifers, the demand for Brachionus spp. as first choice diet for larval fishes is overwhelming due to their small size (90–350 µm), capacity for nutritional enrichment, and high reproductive rates. Today, the Kenyan rotifer strain *Brachionus angularis* is so far the smallest (lorica length: 85.6±3.1 µm; width: 75.4±3.6 µm) and, reproduces optimally at 25oC with 2.5×106 algal cells ml-1; thus convenient for feeding small-mouth freshwater fish larvae (Ogello et al., 2016). Because of their favourable reproductive attributes, the demand for rotifers has increased, prompting more investigations into convenient culture techniques to ensure consistent supply in hatcheries. The cost of production is the main factor that determines rotifer availability.

In Kenya, the ESP program triggered an explosive public interest in fish farming, causing critical shortages of fish feeds and seeds, which are so far the most significant bottlenecks to aquaculture development in Kenya. Today, most fish farmers employ inert diets e.g. powdered chicken egg yolk, milk and fish meal ***(Rastrineobola argentea)*** for larval fish rearing. However, these diets quickly compromise water quality and are not easily ingested or digested by the larval fish, unlike the live foods ***(Ogello et al., 2018).***

Despite the existence of ***Artemia franciscana*** at the Kenyan coast, optimizing it for local aquaculture is yet to be achieved as only about 10 kg of poor-quality cysts is harvested each season ***(Ogello, 2013; Ogello et al. 2014b)***. As a result, most Kenyan hatcheries, especially those handling marine fishes, continue to report significantly high larval fish mortalities due to lack of suitable starter diet. Therefore, developing predictable and cost-effective live food production technologies appears to be the key to unlocking aquaculture potential in Kenya.

Over the years, small-scale fish farmers have used animal manures to boost the natural pond productivity mostly in the developing countries. However, the optimal use of animal manure is sometimes poorly understood, leading to stunted fish productivity. Moreover, the direct use of some manure e.g. of pigs, is restricted by the diverse cultural and religious aspects (Ogello et al., 2013). Recent studies by Ogello and Hagiwara (2015) reported that mass production of the Kenyan rotifer B. angularis can be achieved by using 2 m1-1 of chicken manure extract. In order to make fish more accessible and affordable to the local people and, to spur considerable socio-economic benefits in the society, there is need to embrace localized innovative fish production technologies as critical priorities that should start from addressing larval fish feed disparities (Ogello et al. 2018, 2019, 2020). Today, live food production techniques such as biofloc technology that can produce sufficient live food materials to sustain local hatcheries have been documented (Ogello et al. 2018, 2019, 2020). These techniques are applicable for both freshwater and marine aquaculture, and can produce about 2000 – 3000 individuals per millilitre of culture water ***(Ogello 2017; Ogello et al. 2018; Nesta et al. 2019).***

FEEDS IN KENYA

Fish feeds accounts for between 40-60% of the total cost of aquaculture production and are, therefore, an important factor in determining the economic outcome for fish farms. In Kenya, the price of Nile tilapia received by the farmers is relatively low, both due to the limited purchasing power of the local buyers and because of competition with cheap, frozen tilapia imported from China (Awuor, 2019). Notably, the price of commercial fish feeds is expensive and beyond the reach of most farmers ***(Charo-Karisa et al., 2013).*** As a result, profit margins of fish farms are narrow and fish farmers must minimize production costs. To reduce costs of production Most fish farmers in Kenya rely on backyard feeds rather than more expensive factory-made extruded feed (EF) ***(Charo-Karisa et al., 2013; Aura et al., 2018).***

The locally made feeds are prepared by processing and formulating using assorted fish feeds ingredients like fishmeal e.g. Freshwater shrimp meal and/or sardines (omena) as the main protein source combined with agricultural by-products like rice, wheat bran, cottonseed cake, sunflower seed cake, cassava, etc. The pellets are produced using local meat mincers. Although backyard feed formulations are generally accepted as a way of enhancing productivity and cutting costs in semi-intensive aquaculture, no comprehensive evaluation has been carried out to evaluate the costs and benefits of backyard feeds vs the imported/extruded fish feeds in Kenya. Yet, the adoption and sustainability of innovative aquaculture technology in aquaculture will depend on its potential for economic return (Nanyenya et al. 1999; Isyagi 2007). The current chapter highlights the key findings of a case study of the economic benefits of 1-hectare Nile tilapia farm in Kenya using backyard and extruded feeds.

Cost of production

The costs per kg of backyard feed was 25.5% lower than the cost of extruded feed (Table 4.15). However, the cost of producing a kg of fish with extruded feed was 21.7% less expensive than when using backyard feed (Table 1), probably due to better feed conversion (lower FCR) and higher weight gain. Utilizing imported/extruded diets for feeding fish under semi-intensive culture can reduce the cost of producing tilapia significantly compared with using backyard feed formulation in a tropical climate.

Table 4.15. Feed costs in the semi-intensive culture of Nile tilapia in Kenya. USD 1 = Ksh 100.

Parameter		PF		EF
Net cost per kg of feed produced (USD/kg) (Based on ingredients cost)		0.35		0.47
Feed cost per kg of fish produced (USD/kg)	1.57		1.23	

ENTERPRISE BUDGET ANALYSIS

Farmers operating 1-hectare tilapia farm and utilizing backyard feed would only be able to make a profit above variable costs (Table 4.16), implying that the venture would only be profitable in the short term, suggesting lack of economic viability of such ventures. For farmers using the extruded feed, would be able to make profits both above the variable and total costs, suggesting that the operation would be profitable both in the short term and long term (Engle 2005). For farmers using backyard feed, tilapia production will be profitable as long as the price is above $ 3.8/kg, which appears to be higher than tilapia farm gate price in Kenya ($ 3.5/kg), an indication of lack of sustainability of such venture, given the consumers' willingness to pay. On the other hand, the break-even price for farmers utilizing extruded feed ($ 2.5/kg) was lower than the tilapia farm gate price in Kenya, suggesting that the venture would be profitable. The BCR was below 1 for farmers utilizing backyard feed, an indication that backyard feed is not profitable for Nile tilapia culture under semi-intensive farming in Kenya (Oladejo and Ofoezie 2006).

Table 4.16 Enterprise Budget for 1-hectare Tilapia Farm Model For 1 Production Cycle in Kenya. Cost and price information is given in USD

Parameter	PF	EF
Fixed cost		
Amortized pond cost	666.7	666.7
Amortized equipment and tools	150	150
Sub-total variable costs	816.7	816.7
Interest on fixed costs	98.0	98.0
Total Fixed Cost (TFC)	914.7	914.7
Variable cost		
Feeds	11880	21384
T. fingerlings	1500	1500
Fertilizer and lime	800	800
Harvest	100	100
Security personnel (4)	300	300
Sub-total variable costs	2700	2700
Interest on operating costs	324	324
Total variable cost (TVC)	20250.1	29754.1
Total cost (TC)	**21164.8**	**30668.8**
Farm-gate price of fish	3.5	3.5
Gross revenue	20790	42525
Net returns above TVC	539.9	12770.9
Net returns above TC	-374.8	11856.2
Brake even price	3.8	2.5
Benefit-cost ratio	0.7	1.4

CASH FLOW

For farmers using backyard and extruded feed, cash flow for 10 years was calculated as shown in figure 4. For the first two years of operation, there is negative cash flow, while the remaining 8 years there is a positive cash flow for farmers utilizing backyard feed (Fig. 4a), indicating that the enterprise may not have adequate cash available in the first two years to meet its financial obligations e.g. repayment of loans (Engle 2005). It could also be a pointer that the farm may not be realizing profit during the first two years of operation hence need for borrowing during the first two years to stay afloat (Manning and Hishamunda 2001). Negative cash flow would only be realised during the first year of operation for the farmers utilizing extruded feed (Fig. 4b), suggesting that such farms would be able to meet their financial obligations from the second year of operations.

> **THIS CHAPTER DEMONSTRATES THAT ALTHOUGH BACKYARD FEED IS CHEAP, EXTRUDED FED IS THE MOST APPROPRIATE FEED FOR THE CULTURE OF NILE TILAPIA DUE TO FASTER GROWTH AND COST-EFFECTIVENESS.**

RISK ASSESSMENT

The Net Present Value (NPV) for 1-hectare farm using backyard feed was negative for three years after starting the operation. From the fourth year, there was a positive accumulated NPV. For the farmers utilizing extruded feeds, the NPV was only negative for the first year thereafter the accumulated NPV was positive for the rest of the years of operation. The highest NPV would be achieved by farms using extruded feeds and the least NPV in farms utilizing backyard feeds. The payback period (expected number of years required to recover the original investment) for farmers utilizing backyard and extruded feeds would be 9 and 5 years, respectively. The higher number of the payback period for the farms utilizing backyard feed (9 years) implies that the venture is risky.

Utilizing pelleted feed for the culture of Nile tilapia under semi-intensive systems appears not to be feasible and profitable. The highest NPV and IRR would be recorded for farms utilizing extruded feed, suggesting that it is more effective to use extruded diets than backyard diets for Nile tilapia in Kenya. The highest payback period recorded for farms utilizing backyard diets shows that the venture is risky. This chapter demonstrates that although backyard feed is cheap, extruded fed is the most appropriate feed for the culture of Nile tilapia due to faster growth and cost-effectiveness. Future research should be geared towards a comparison of the cost-effectiveness of the various extruded feeds available in Kenya.

4.10. HANDLING AND STORAGE OF FISH FEEDS

Fish feeds formulations usually involves a combination of various ingredients to make a balanced diet that meets most if not all the nutritional requirements of fish. Most of these ingredients have chemical characteristics that make them difficult to be stored as finished fish feed products (Kolapo and Sanni, 2007). For example, formulated feeds are usually fortified with vitamins, and the potency of vitamins decline with storage. Notably, vitamins can easily be denatured by heat, oxygen, moisture and ultraviolet light. On the other hand, fishmeal, the main protein source in fish feed formulation, also contains higher oil content, making them susceptible to oxidative rancidity ***(Kubiriza et al., 2016).*** Hence, the quality of a feed can begins to deteriorate steadily after manufacture.

BEST MANAGEMENT PRACTICES FOR FISH FEED HANDLING AND STORAGE- “DO’S” AND “DON’TS”

1. Handling can result to breakage and fines, hence further reducing the quality of pellets. It is important to consider moving the feed as little as possible and as gently as possible. If movement is necessary, use forklifts and pallets, or hand trucks and mini pallets, as it allows bags to be handled in multiple units. This minimizes the amount of feed movement within each bag and reduces the creation of dust and fines. Feed conveying equipment such as bucket elevators, belt conveyors, and drag conveyors can also be used as they are least destructive.

2. Store feed in a dry, well-ventilated area, preferably in a warehouse, silos or bin, to offer protection from the rapid change of temperature.

3. The farmers should always use the principle of First-In-First-Out (FIFO) to maximise freshness and minimise waste. This ensures that older feed batch is used or bought before new ones, which helps minimise wastage. The oldest materials MUST be used first.

4. When buying feeds, farmers need to check the labels for batch number and dates to buy the freshest feed in the store. Remember the nutritional quality of feed begins to deteriorate steadily after manufacture.

5. The farmer should only purchase the amount of feed that his stock will be able to finish within 1-2 months. The longer the feed stays in storage, the lower the nutritional quality.

6. Protect the feed from rodents, bats, chickens and other animals. The feed can be stored in cages made of coffee wire mesh to keep off such animals (see plate 1a)

7. Feeds must be stored off the floor and walls and preferably on pallets or racks to prevent them from getting damp hence attracting insects and mould growth (see plate 1b)

8. Limit the stacks of feed during storage to avoid dampness and preferably, farmers should limit the number of rows of bags stacked in the pallets to 8-10 to maintain air circulation and most importantly to avoid any crushing of pellets in the lower rows.

9. Feed should be stored under cool and dry conditions with temperatures of < 20 oC and humidity of less than 70%.

10. During transportation and handling, protect the feed from moisture, heat and direct sunlight. Heat and sunlight directly destroy feed nutrients like vitamins.

11. Do not use feed that is moulded. Farmers need to learn what the normal colour of the feed they use looks like (see plate 2).

12. Pesticides and other toxic chemicals should not be kept or used near the fish feeds.

13. The feeds shall be packed and supplied in airtight and suitable weather-resistant material. e.g. laminated bags.

Most organic manufactured products, fish feeds have a limited shelf life. To realize the full economic and nutritional value of fish feeds, proper storage and handling cannot be overemphasized. Deterioration of feed quality can occur at the point of manufacture, transport or farm level, hence, need for a concerted effort to maintain wholesomeness. Finally, it is worth noting that the quality of manufactured feed will never improve during storage but can be maintained at the same level using best management practices described in this chapter.

4.11. FEED CHALLENGES AND OPPORTUNITIES

The Kenyan feed industry has gradually started to move forward. However, it is faced with an array of challenges and constraints including skyrocketing feed prices, unavailability of ingredients, lack of expertise in feed formulation and production, lack of monitoring and evaluation on quality and standard adherence etc.

COST OF FEEDS

Fish feed constitutes at least 60% of the production cost in the fish farming enterprise. The cost of feed is the main challenge faced by the Kenyan fish farmers at small- and large-scale levels. Lack of enough feed manufacturing facilities for quality aquafeed in Kenya contributes to increasing demand for quality feed among fish farmers in Kenya. The few existing fish feed producers in Kenya face the challenge of the high cost of ingredients hence compromising the quality of the final product. Quality feeds imported into the country are expensive and is not affordable by small scale farmers. The current Fish feed prices in Kenya varies from company to company as outlined in the tables below. This is divided into imported feds and locally manufactured fish feeds.

IMPORTED FISH FEED PRODUCTS AND PRICES

1. Aller Aqua price list

Feed type	Particle Sizes	Package SIZE	PRICE /KG (Kshs)
ALLER PARVO EX	0GR	20kgs	360
ALLER PARVO EX	1GR	20kgs	360
ALLER PARVO EX	2GR	20kgs	360
ALLER PARVO EX	3GR	20kgs	360
ALLER SANA FLOAT	2MM	15kgs	140
ALLER SANA FLOAT	3MM	15kgs	135

2. Skreting feed company catfish feed price list

Skreting tilapia feed products and prices

Feed type	Cp%	size	Package	Price per kg
Catfish- 0.2 Gemma Wean (Artemia Replacer) 2.5kg	62	0.2	3	3500
Catfish-0.3 Gemma Wean 20kg	62	0.3	20	2400
Catfish -0.5 Granulate Fish Starter 20kg	57	0.5	5	505
Catfish -1.0Micro - Pellet Fish Starter 20kg	57	1	20	450
Catfish- 1.8 Micro-Pellet Fish Starter 15kg	55	1.8	15	400
Catfish- 8.0 Brood Stock Feed - 15kg	45	8mm	15	360
Catfish 40%Floating 2mm	40	2mm	25	190
Catfish 40% Floating 3mm	40	3mm	25	175

Local Feed Producers

1. KMFRI Sangoro tilapia feed price list

Feed type	Particle size	CP %	Price/kg
Starter	Marsh	40%	120/kg
Starter	2mm	35%	100/kg
Grow out	3mm	30%	80/kg
Finisher	4mm	30%	80/kg

2. Lenalia fish feed products

Feed type	Particle size	CP % (catfish)	CP% (tilapia)	Price/kg
Starter diet	0.5mm	45%	35%	120/kg
Grower	Crumbles	30%	30%	130/kg
Finisher	4mm	25	27%	130/kg

3. Fugo fish feed (tilapia feed price list)

Feed type	C P (%)	sizes	Package size	Price per kg
Tilapia Repro - 20kg	38	4.5mm	20	320
Fugo Tilapia Starter Crumbles	40	Crumble	25	200
Fugo Tilapia Pre-Grower Pellets	35	2mm	25	115
Fugo Tilapia Grower Pellets	32	3mm	25	106
Fugo Tilapia Hi-Pro Finisher Pellets	30	4mm	25	101
Fugo Tilapia Low-Pro Finisher Pellets	25	4mm	25	85

Lack of trained personnel

Lack of trained personnel in areas of aquaculture nutrition, feed formulation and processing, and machine operators is also a major challenge to the aquafeed industry in Kenya.

LACK OF FEED INGREDIENTS

Production of adequate quality feeds require the availability of feedstuff and ingredients. Currently, the protein source for aquafeed production in Kenya is the Omena and freshwater shrimp (FWS). Seasonality in the production of FWS becomes a major bottleneck for consistence production of aquafeed. Current level of raw materials production does not meet the needs of both aquafeeds industry and the non-conventional ingredients which could be used as substitutes have limitation in commercial quantity as well as localized availability.

UNCOORDINATED MONITORING AND EVALUATION OF FISH FEEDS IN KENYA

Monitoring and evaluation of feeds in Kenya are important in ensuring quality feeds are supplied to farmers. This, however, is a challenge because of improper coordination from the different implementing organs. For example, the devolution of fisheries to the counties has led to poor coordination and monitoring of fish feed quality standards. For instance, feed suppliers are selling feed with low crude protein than what appears on the label and yet the feed is sold at high prices

> **QUALITY FEEDS IMPORTED INTO THE COUNTRY ARE EXPENSIVE AND IS NOT AFFORDABLE BY SMALL SCALE FARMERS.**

OPPORTUNITIES FOR AQUA FEED PRODUCTION AND INVESTMENT

HIGH DEMAND FOR FISH FEED

According to (KNBS, 2019), the current aquaculture production stands at 15,120 metric tons (MT) annually. With assumed food conversion ratio of 2, the approximated annual fish feed demand in Kenya is 30,000 MT. The demand for aquafeed in Kenya is expected to further rise as more investors intensify aquaculture production. This is a good opportunity for feed producers and investors to exploit.

THE DEVELOPMENT OF EAST AFRICAN FEED STANDARD

Provision of quality feed is a prerequisite for sustainable aquaculture in Kenya (Munguti et al., 2014). The final draft of the east African feed standard has been developed and validated for use as a guide in feed production. The standard document provides guidelines on general and specific quality measures to consider, Feed additives and provisions related to their use, compliance with the aflatoxin requirements, maximum heavy metals and pesticide residue limits, labelling and packaging. According to the standards, compounded fish feed shall meet the requirements of the nutrients and digestible energy. Through the east African harmonized feed standards feed manufacturers and distributors can now sell their products across the borders hence opening up the market.

TAX WAIVER ON IMPORTED RAW MATERIALS

Removal of VAT on raw material for feed production is expected to lead to a decrease in the selling price of the feeds, making them affordable to the farmers, hence contributing positively to the growth of the agricultural sector.

OPPORTUNITY IN THE BLUE ECONOMY BLUEPRINT

The blue economy initiative focusses to establish and strengthen smallholder business-oriented aquaculture enterprises. This will improve aquaculture production, productivity as well as food security and nutrition of smallholder farmers (Ondimu, et al., 2018). This is an opportunity for feed producers to exploit due to the availability of ready market for the products.

REFERENCES

Asis, R.D., Paola, D.R. and Aldao, A.M. (2002). Determination of aflatoxin B1 in highly contaminated peanut samples using HPLC and ELISA. J. Food Agric. Immunol., 14: pp. 201-208. Brown, D. I. (2001). Aflatoxin: Occurrences and Health Risk in plants poisonous to Livestock. Publication of Department of Animal Science, Cornell University.

Aura, M.C., Musa, S., Yongo, E., Okechi, J., Njiru, J.M., Ogari, Z., Wanyama, R., Charo-Harrison, H., Mbugua, H., Kidera, S., Ombwa, V., Abwao, J., 2018. Integration of mapping and socio-economic status of cage culture: Towards balancing lake-use and culture fisheries in Lake Victoria, Kenya. Aquacult. Resear. 49(1), 532-545. https://doi.org/10.1111/are.13484.

Awuor, J., Obiero, K., Munguti, J., Oginga, J., Kyule, D., Opiyo, M., Odote, P., Yongo, E., Owiti, H and Ochiewo, J., 2019. Market linkages and distribution channels of cultured, captured and imported fish in Kenya. Aquaculture studies. 19(1), 1-11.

Brown, D. I. (2001). Aflatoxin: Occurrences and Health Risk in plants poisonous to Livestock. Publication of Department of Animal Science, Cornell University.

Charo-Karisa, H., Opiyo, M., Munguti, J., Marijani, E., Nzayisenga, L., 2013. Cost-benefit analysis of pelleted and unpelleted on-farm feed on African catfish (Clarias gariepinus Burchell, 1822) in earthen pond. African J. of Food, Agriculture, Nutrition and Development. 13, 8019-8033.

Cheng, Z., Ai, Q., Mai, K., Xu, W., Ma, H., Li, Y., Zhang, J. (2010). Effects of dietary canola meal on growth performance, digeston and metabolism of Japanese seabass, Lateolabrax japonicus. Aquacult. 305, 102–108. doi:10.1016/j. aquaculture.2010.03.031.

Ciceron, M. F. A., Del Parado, J. M. and Carera E. C. (2008). A Comparative Study on the Antimicrobial Resistance of Escherichia coli isolates of chickens and fish grown on agricultural scientist, 91: 3, 28-33.

El-Sayed, A. F. M. (2006). Tilapia culture. Wallingford, GB, England: CABI Publishing.

Engle C, Neira I (2005) Tilapia farm business management and economics. USAID, Pine Bluff p41.

FAO (2001). How should I store my feeds? In feeds and feeding of fish and shrimp. FAO Corporate document repository. Fisheries and aquaculture Department Rome, Italy.

Jauncey, K., & Ross, B. (1982). A guide to tilapia feeds and feeding (No. Va0769). [sn] http://www.feedpelletplants.com/fish-feed-pellets-processing-technology.html

Kolapo, A. L. and Sanni M. O. (2007). Biochemical changes of soyiru (fermented soybean) during storage. Agricultural and Food Science Journal of Ghana, 6: 471 – 483.

Kubiriza, G., Arnason, J., Sigurgeirsson, O., Snorasson, S., Tomasson, T., and Thorarensen, H. (2016). Lipid oxidation of dried silver cyprinid fishmeal as an impediment in the manufacture of aquafeeds. RUFORUM Working Document Series (ISSN 1607-9345) No. 14 (1): 863-869. Available from http://repository.ruforum.org, KNBS. (2019). ECONOMIC SURVEY 2019.

Lubzens E, O. Gibson, O. Zmora, A. Sukenik, Potential advantages of frozen algae (Nannochloropsis sp.) for rotifer (Brachionus plicatilis) culture. Aquaculture, 133, 295–309 (1995).

Manning P, Hishamunda N (2001) Promotion of sustainable commercial aquaculture in sub-Saharan Africa. Volume 2: Investment and economic feasibility. FAO Fisheries Technical Paper No. 408/2. Rome, FAO. 61 pp.

Munguti, J. M., Musa, S., Orina, P. S., Kyule, D. N., Opiyo, M. A., Charo-karisa, H., & Ogello, E. O. (2014). management practices , challenges and opportunities An overview of current status of Kenyan fish feed industry and feed management practices , challenges and. (June).

Nesta K, Ogello EO, Sakakura Y, Hagiwara A. 2019. Fish processing wastes as an alternative diet for culturing the minute rotifer, Proales similis de Beauchamp. Aquaculture Research DOI: 10.1111/are.13707

Oladejo SO, Ofoezie IE (2006) Unabated schistosomiasis transmission in Erinle River Dam, Osun State, Nigeria: evidence of neglect of environmental effects of development projects. Trop Med Int Health 11(6):843–850, 11(6), 843–850

Ondimu, K. I., Chemoiwo, M., & Kemboi, J. (2018). Blue Economy Bankable Projects. 76.

Ogello EO, Wullur S, Sakakura Y, Hagiwara A. 2018. Composting fishwastes as low-cost and stable diet for culturing Brachionus rotundiformis Tschugunoff (Rotifera): influence on water quality and microbiota. Aquaculture, 486: 232–239

Ogello, E.O., Kim, H-J, Suga, K. and Hagiwara, A. 2016. Life table demography and population growth of the rotifer Brachionus angularis in Kenya: influence of temperature and food density, African Journal of Aquatic Science, 41(3):329-336

Ogello EO, Wullur S, Hagiwara A. 2019. Blending fishwastes and chicken manure extract as low-cost and stable diet for mass culture of freshwater zooplankton, optimized for aquaculture. IOP Conf. Series: Materials Science and Engineering 567 (2019) 012022 doi:10.1088/1757 899X/567/1/012022

Ogello EO, Wullur S, Sakakura Y, Hagiwara A. Dietary Value of Waste-Fed Rotifer Brachionus rotundiformis on the Larval Rearing of Japanese Whiting Sillago japonica. E3S Web of Conferences 147, 01005 (2020)

Ogello EO. 2017. Studies on the Development of Low-cost and Stable Live Food Production Technologies for Tropical Aquaculture: A case Study of Rotifera (Family: Brachionidae). PhD Thesis of Graduate School of Fisheries and Environmental Sciences, Nagasaki University, pp 165

Silva, J.M.G., Espe, M., Conceicao, L.E.C., Dias, J., Valente, L.M.P. (2009). Senegalese sole juveniles (Solea senegalensis Kaup, 1858) grow equally well on diets devoid of fish meal provided the amino acids are balanced. Aquacult. 296, 309–317.

Silva, J.M.G., Espe, M., Conceicao, L.E.C., Dias, J., Valente, L.M.P., 2009. Senegalese sole juveniles (Solea senegalensis Kaup, 1858) grow equally well on diets devoid of fish meal provided the amino acids are balanced. Aquacult. 296, 309–317.

Sotolu, A.O., Sule, S.O., Oshinowo, J.A and Ogara I. M. (2014). Implication of Aflatoxin in Fish Feeds and Management Strategies forSustainable Aquaculture. PAT; 10 (1): pp. 38-52

Watanabe, T. (2002). Strategies for further development of aquatic feeds. Fisheries Scie., 68, 242–252. doi:10.1046/j.1444-2906.2002.00418.x. Abowei, J.F.N., Ekubo, A.T., 2011. A review of conventional and unconventional feeds in fish nutrition. British Journal of Pharmacology and Toxicology. 2, 179-191.

Ahmed, M., Liang, H., Chisomo Kasiya, H., Ji, K., Ge, X., Ren, M., ... & Sun, A. (2019). Complete replacement of fish meal by plant protein ingredients with dietary essential amino acids supplementation for juvenile blunt snout bream (Megalobrama amblycephala). Aquaculture nutrition, 25(1), 205-214.

Andersen, S. M., Waagbø, R., & Espe, M. (2016). Functional amino acids in fish health and welfare. Frontiers in Bioscience, 8, 143-169.

Belghit, I., Liland, N. S., Gjesdal, P., Biancarosa, I., Menchetti, E., Li, Y., ... & Lock, E. J. (2019). Black soldier fly larvae meal can replace fish meal in diets of sea-water phase Atlantic salmon (Salmo salar). Aquaculture, 503, 609-619.

Dongmeza, E., Steinbronn, S., Francis, G., Focken, U., & Becker, K. (2009). Investigations on the nutrient and antinutrient content of typical plants used as fish feed in small scale aquaculture in the mountainous regions of Northern Vietnam. Animal Feed Science and Technology, 149(1-2), 162-178.

Dorothy, M. S., Raman, S., Nautiyal, V., Singh, K., Yogananda, T., & Kamei, M. (2018). Use of Potential Plant Leaves as Ingredient in Fish Feed-A Review. Int. J. Curr. Microbiol. App. Sci, 7(7), 112-125.

El-Shafai, S. A., El-Gohary, F. A., Verreth, J. A., Schrama, J. W., & Gijzen, H. J. (2004). Apparent digestibility coefficient of duckweed (Lemna minor), fresh and dry for Nile tilapia (Oreochromis niloticus L.). Aquaculture Research, 35(6), 574-586.

Gatlin III, D.M., Barrows, F.T., Brown, P., Dabrowski, K., Gaylord, T.G., Hardy, R.W., Herman, E., Hu, G., Krogdahl, Å., Nelson, R., 2007. Expanding the utilization of sustainable plant products in aquafeeds: a review. Aquaculture research. 38, 551-579.

Ghosh, K., Ray, A.K., Ringø, E., 2018. Applications of plant ingredients for tropical and subtropical freshwater finfish: possibilities and challenges. Reviews in Aquaculture.

Henry, M., Gasco, L., Piccolo, G., & Fountoulaki, E. (2015). Review on the use of insects in the diet of farmed fish: past and future. Animal Feed Science and Technology, 203, 1-22.

Hertrampf, J.W., Piedad-Pascual, F., 2012b. Handbook on ingredients for aquaculture feeds. Springer Science & Business Media.

Hu, L., Yun, B., Xue, M., Wang, J., Wu, X., Zheng, Y., Han, F., 2013. Effects of fish meal quality and fish meal substitution by animal protein blend on growth performance, flesh quality and liver histology of Japanese seabass (Lateolabrax japonicus). Aquaculture. 372, 52-61.

Lucas, J.S., Southgate, P.C., Tucker, C.S., 2019. Aquaculture: Farming aquatic animals and plants. Wiley-Blackwell.

Moutinho, S., Martínez-Llorens, S., Tomás-Vidal, A., Jover-Cerdá, M., Oliva-Teles, A., Peres, H., 2017. Meat and bone meal as partial replacement for fish meal in diets for gilthead seabream (Sparus aurata) juveniles: Growth, feed efficiency, amino acid utilization, and economic efficiency. Aquaculture. 468, 271-277

Musyoka, S. N., Liti, D. M., Ogello, E., & Waidbacher, H. (2019). Utilization of the earthworm, Eisenia fetida (Savigny, 1826) as an alternative protein source in fish feeds processing: A review. Aquaculture Research, 50(9), 2301-2315.

Munguti, J. ; Charo-Karisa, H. ; Opiyo, M. A. ; Ogello, E. O. ; Marijani, E. ; Nzayisenga, L. ; Liti, D., 2012. Nutritive value and availability of commonly used feed ingredients for farmed Nile tilapia (Oreochromis niloticus L.) and African catfish (Clarias gariepinus, Burchell) in Kenya, Rwanda and Tanzania. Afr. J. Food, Agric., Nutr. Dev., 12 (3): 6136-6155.

Ng, W. K., & Wee, K. L. (1989). The nutritive value of cassava leaf meal in pelleted feed for Nile tilapia. Aquaculture, 83(1-2), 45-58.

Ngugi, C.C., Oyoo-Okoth, E., Manyala, J.O., Fitzsimmons, K., Kimotho, A., 2017. Characterization of the nutritional quality of amaranth leaf protein concentrates and suitability of fish meal replacement in Nile tilapia feeds. Aquaculture Reports. 5, 62-69.

Benson, O. Obwanga. (2010). The efficacy of selected plant materials in formulated diets for nile tilapia, Oreochromis niloticus (L). Egerton University, 23.

Ondiba R., 2016. Effects of substituting cottonseed meal protein with Prosopis juliflora seed meal on Nile tilapia growth. MSc. Thesis, University of Eldoret-Eldoret, Kenya.

Onyimonyi, A. E., & Ugwu, S. O. C. (2007). Performance of laying hens fed varying dietary levels of bambara (Voandzeia subterrenea Thouars) offals. Int. J. Poult. Sci, 6, 223-226.

Sabat, P., Novoa, F., Bozinovic, F., & Martínez del Rio, C. (1998). Dietary flexibility and intestinal plasticity in birds: a field and laboratory study. Physiological Zoology, 71(2), 226-236.

Sahito, M. A., Ansari, I. T., Narejo, N. T., Suheryani, I., Waryani, B., Ansari, Z. A., & Noor-ul-Ain, N. (2015). Comparative study of biochemical properties of non-conventional plant sources to prepare low cost fish feed. Pakistan Journal of Nutrition, 14(7), 431.

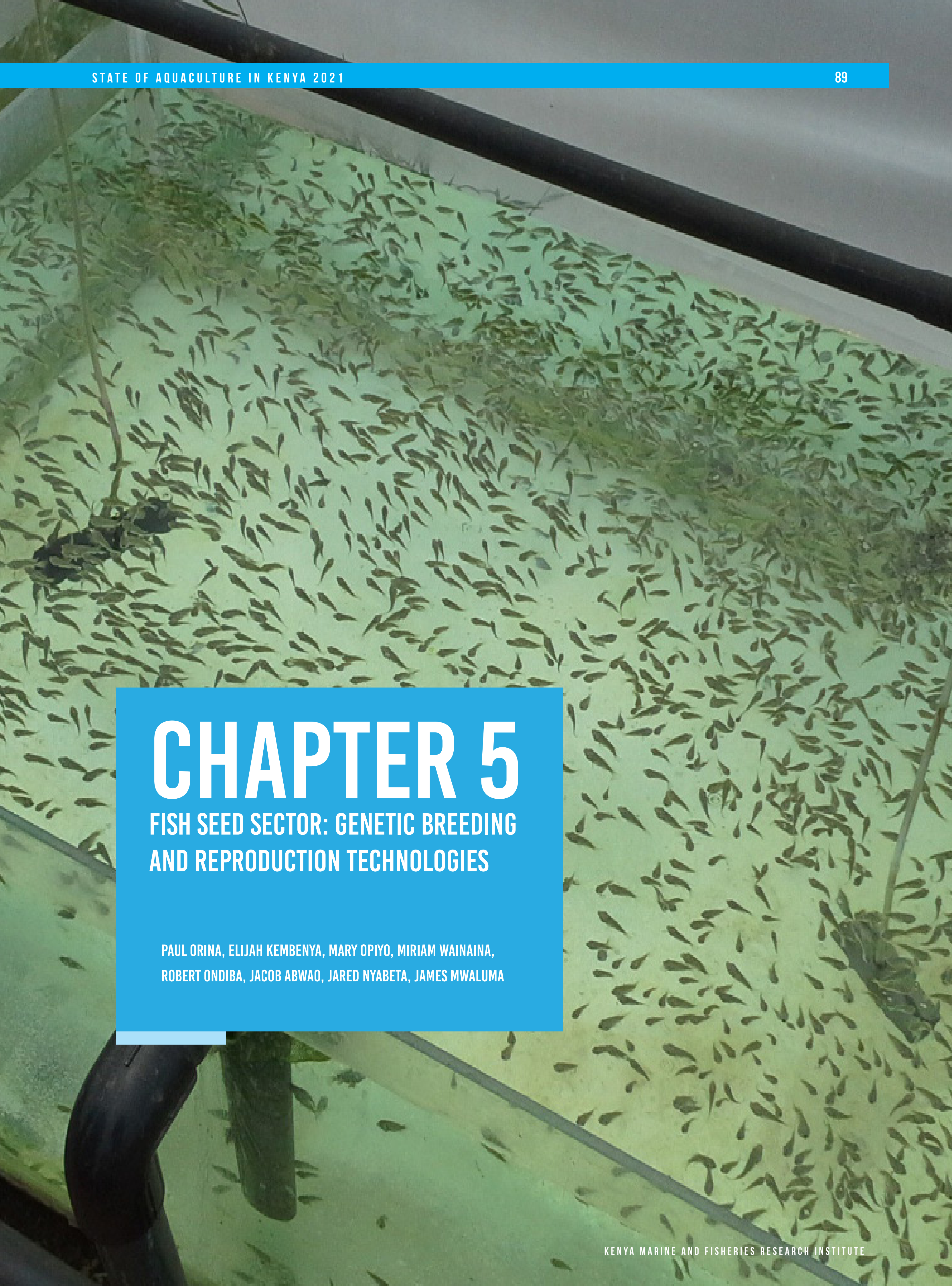
Soltan, M. E., & Sirry, S. M. (2002). Usefulness of Some Plant Flowers as Natural Acid-Base Indicators. Journal of the Chinese Chemical Society, 49(1), 63-68.

Sotolu, A. O., & Faturoti, E. O. (2008). Digestibility and nutritional values of differently processed Leucaena leucocephala (Lam de Wit) seed meals in the diet of African catfish (Clarias gariepinus). Middle East Journal of Scientific Research, 3(4), 190-199.

Spinelli, J. (1980). Unconventional feed ingredients for fish feed. Fish feed technology. Rome, UNDP/FAO, ADCP/REP/80/11, 187-214.

Tacon, A., Hasan, M., Allan, G., El-Sayed, A., Jackson, A., Kaushik, S., Ng, W., Suresh, V., Viana, M., 2010. Aquaculture feeds: addressing the long-term sustainability of the sector, Proceedings of the global conference on aquaculture, pp. 193-232.

Yuangsoi, B., & Masumoto, T. (2012). Replacing moringa leaf (Moringa oleifera) partially by protein replacement in soybean meal of fancy carp (Cyprinus carpio). Songklanakarin Journal of Science & Technology, 34(5).



CHAPTER 5

FISH SEED SECTOR: GENETIC BREEDING AND REPRODUCTION TECHNOLOGIES

PAUL ORINA, ELIJAH KEMBENYA, MARY OPIYO, MIRIAM WAINAINA, ROBERT ONDIBA, JACOB ABWAO, JARED NYABETA, JAMES MWALUMA

Key Messages	Policy Recommendations
• Kenya's aquaculture is predominated by freshwater species mainly Nile tilapia (90%) and African Catfish (8%) a trend mainly driven by consumer preference. • Marine species including Milk fish, Prawns, Mud crabs and Seaweed have gained prominence in the recent past among coastal local communities. Other cultured species include Common carp and Rainbow trout and Artemia. • The freshwater aquatic ecosystem is rich in commercially important fish species with potential for aquaculture including African carp (Labeo victorianus), Ribon barbell (Labeo barbus altianalis), Jipe tilapia (Oreochromis jipe), Baringo tilapia (Oreochromis niloticus baringoensis), Singida tilapia (Tilapia esculenta), Victoria tilapia (Oreochromis variabilis) and Lungfish (Protopterous aethiopicus). • Access to quality fingerlings is often constrained by the distance to fish hatcheries, lack of infrastructure and the cost of inputs. To ensure continued access to high-quality broodstock and seed, hatcheries are significant. • KMFRI is engaged in Nile tilapia and African catfish selective breeding and mass breeding programmes respectively. Nile tilapia involving 2 sires and 1 dam per hapa has seen 200 sires and 100 dams used as filial generation which are screened Sagana and Lake Victoria strains. The Nile tilapia selective breeding programme initiated in 2012 is in the 8th generation and part of its mixed sex population distributed to over 12 multiplication centers across the country for seed production and supply to grow-out farms.	• The present and future of aquaculture development relies heavily and solely on the genetic integrity of the indigenous fish populations. • Demand for fingerlings will rise due to the emerging cage farming in Lake Victoria which requires thousands of fingerlings • The Kenyan government is in the progress of establishing a National Mariculture Resource and Training Centre (NAMARET Centre) 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. • Aquaculture farm due to move aquatic genetic material should ensure disease free genetic material, recipient provide quarantine facility; recipient provide proof of escapee safeguards; risk assessment and management information; and heavy metals and chemicals free fish and fish products • Genetic improvement programs are long term investments which require reliable capacity in terms of infrastructure (laboratories, ponds and equipment) and human capacity who closely monitor fish during the breeding procedures. With this regard genetic improvement required reliable continuous funding for sustainability and structured systems to ensure that the different generations are closely monitored. • Genetic improvement programs require personnel with skills and knowledge in population genetics, molecular genetics and biotechnology. This is required for both the scientists and technologists who are working in fish genetic improvement and breeding programs.

Orina, P., Kembenya E., Opiyo M., Wainaina M., Ondiba R., Abwao J., Nyabeta J., & Mwaluma J. (2021). Seed Industry, Genetic Breeding and Reproduction Technologies. In: Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition -Sensitive Fish Food Production Systems; Chapter 5: pp 89–102

5.0. AQUACULTURE SEED DEVELOPMENT AND GENETIC RESOURCE MANAGEMENT

Aquaculture plays a key role in the global food production, economic development and food security and nutrition, considering the dwindling capture fisheries and, a growing human population. Kenya's aquaculture is predominated by freshwater species mainly Nile tilapia (90%) and African Catfish (8%), a trend mainly driven by consumer preference. Marine species including Milk fish, Prawns, Mud crabs and Seaweed have gained prominence in the recent past among coastal local communities. Other cultured species include Common carp and Rainbow trout and Artemia. Meanwhile the Kenyan marine and freshwater aquatic ecosystem is rich in commercially important fish species with potential for aquaculture including African carp ***(Labeo victorianus*)**, Ribon barbell ***(Labeo barbus altianalis),*** Jipe tilapia ***(Oreochromis jipe),*** Baringo tilapia ***(Oreochromis niloticus baringoensis),*** Singida tilapia ***(Tilapia esculenta),*** Victoria tilapia **(***Oreochromis variabilis)* and Lungfish ***(Protopterous aethiopicus).***

Aquaculture unlike terrestrial livestock has a wide range of species with unique genetic material linked to specific environmental requirements, known as gene by environment (GxE) effect. This gives fish and other aquatic organisms a unique advantage over terrestrial animal despite being a late entrant in human animal husbandry. Unique to potential and cultured fish and other aquatic organisms is their high fecundity and other multiplication approaches depending their biology. Cultured species have over time demonstrated high fecundity with ease of breeding manipulation giving rise to marine fish and freshwater aquaculture hatcheries.

> **MARINE SPECIES INCLUDING MILK FISH, PRAWNS, MUD CRABS AND SEAWEED HAVE GAINED PROMINENCE IN THE RECENT PAST AMONG COASTAL LOCAL COMMUNITIES.**

Breeding programmes whose source of genetic material is local water bodies are at inception in Kenya with the National Aquaculture Research Center, Sagana being the Nile tilapia and African catfish breeding nucleus supported by several multiplication centers across the country. External fertilization gives room for advanced genetic manipulation ranging from chromosome set manipulation, to gene transfer, hybridization, as well as selective crosses. In Kenya, Nile tilapia is at F7 generation while African catfish is at F3 generation both under family selection approach. Despite the fast-growing interest in aquaculture resulting in high genetic material movement, the sub-sector lacks adequate biosafety measures against diseases, hybridization and invasions by alien species on wild stocks. Ultimately, a genetically improved aquatic organism confers certain aquaculture advantages to the producer resulting in high productivity and economic gains at minimal cost. However, engagement in a breeding programme should take cognizance of the cost and time related effects prior to inception.

5.1. AQUACULTURE SPECIES IN KENYA

Kenya's aquaculture dates to the 1920s and has all along had Nile tilapia, African catfish and Rainbow trout as the main culture species, all inland freshwater species. Nile tilapia is the most cultured species (90%) followed by African catfish (8%). Rainbow trout is limited to high altitude areas with free-flowing Mount Kenya Rivers. Common carp, Lung fish, African carp (Ningu) and Ribon barbell are among inland freshwater species currently under domestication trials. Mariculture initiated in the 1970s along the Kenya Coast is equally fast developing due to poor wild catches, growing fish protein demand, population increase and national and county governments support. Milk fish, Grey mullet and Seaweed are the predominating mariculture species (95%), while prawns, mud crabs and artemia are slowly gaining interest.

5.2. KENYA'S FISH HATCHERIES DEVELOPMENT

The continued growth of aquaculture in many parts of Kenya has necessitated a high demand of quality fish seed for the commonly cultured species; including food fish (Nile tilapia and African catfish) and ornamental fish ***(Koi carp and Goldfish).*** Access to quality fingerlings is often constrained by the distance to fish hatcheries, lack of infrastructure and the cost of inputs. To ensure continued access to high-quality broodstock and seed, hatcheries are significant.

The operational hatcheries were 87 in number in 2017 (Figure 5.1). Majority of the hatcheries in Kenya are owned by private fish farmers which constitutes 82% while hatcheries being managed by the government institutions constitutes 82% (Figure 5.2). Some hatcheries closed done due to low demand of fingerings ***(Nyonje et al., 2018***) as compared to the numbers in 2016. However, it is expected that the demand for fingerlings will rise due to the emerging cage farming in Lake Victoria which requires thousands of fingerlings.

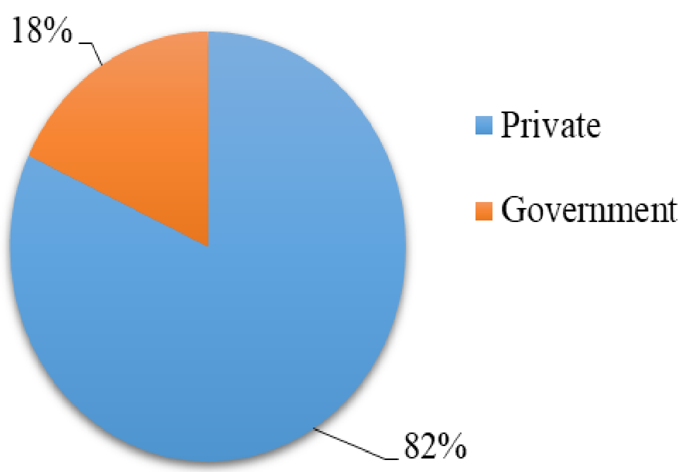


Figure 5.1: Hatchery ownership in Kenya

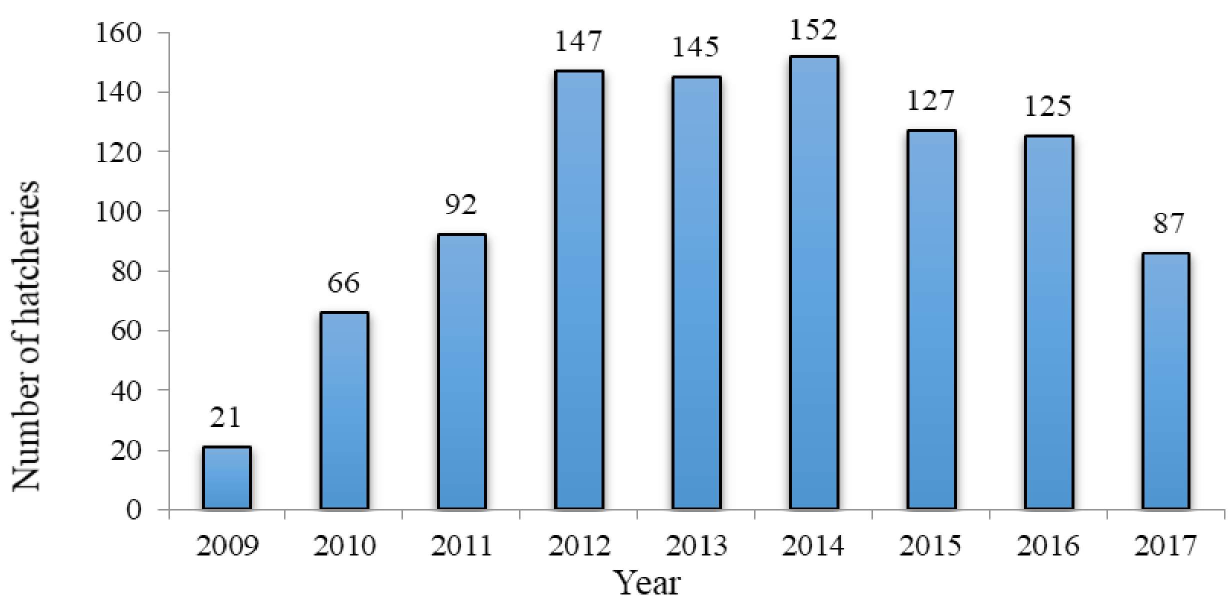


Figure 5.2: Changes in number of hatcheries from 2009 – 2017(Source: Nyonje et al., 2018)

Table 5.1. Number of Authenticated Hatcheries by County, December 2017.

No	County	No. of hatcheries	Species
1	Baringo	1	Nile tilapia
2	Bungoma	2	Nile tilapia, African catfish
3	Busia	3	Nile tilapia, African catfish
4	Embu	1	Nile tilapia
5	Homa-Bay	4	Nile tilapia
6	Isiolo	1	Nile tilapia
7	Kajiado	4	Nile tilapia, African catfish
8	Kakamega	2	Nile tilapia, African catfish
9	Kiambu	5	Nile tilapia, African catfish
10	Kilifi	1	Nile tilapia
11	Kirinyaga	6	Nile tilapia, African catfish, Koi carp, Goldfish
12	Kisii	3	Nile tilapia, African catfish, Koi carp, Goldfish
13	Kisumu	6	Nile tilapia, African catfish
14	Kitui	2	Nile tilapia
15	Laikipia	3	Nile tilapia, African catfish
16	Machakos	1	Nile tilapia, African catfish
17	Makueni	2	Nile tilapia, African catfish
18	Meru	7	Nile tilapia, African catfish
19	Migori	3	Nile tilapia
20	Mombasa	2	Nile tilapia, African catfish
21	Muranga	4	Nile tilapia, African catfish
22	Nairobi	2	Nile tilapia, African catfish
23	Nakuru	3	Nile tilapia, African catfish
24	Nyamira	1	Nile tilapia
25	Nyandarua	1	Nile tilapia
26	Nyeri	2	Nile tilapia, African catfish
27	Siaya	5	Nile tilapia, African catfish
28	Taita Taveta	1	Nile tilapia
29	Tharaka Nithi	4	Nile tilapia, African catfish
30	Uasin Ngishu	2	Nile tilapia, African catfish
31	Vihiga	3	Nile tilapia, African catfish
	Total	**87**	

Fish farmers are advised to obtain fingerlings from authenticated hatcheries. For hatcheries to be authenticated, they are required to have facilities such as a water reservoir, resting tanks, breeding tanks, weighing balance, incubators for hatching eggs, scoop nets, oxygen supply and fish packaging materials *(Nyonje et al 2018).* Depending on the hatchery, the water reservoirs can either be plastic tanks, cemented tanks or consist of lined ponds from which the water is either pumped into breeding ponds or supplied from a tower to the breeding pond and the incubation units. The recommended practice for the hatcheries in Kenya is to keep broodstock for 3 years before bringing in a new stock. This is to ensure high fingerling production since females older than 3 years spawn less frequently.

5.3. MARINE HATCHERY DEVELOPMENT

Kenya Marine and Fisheries Research Institute (KMFRI) and the State Department of Fisheries and aquaculture and the Blue Economy have the mandate to provide the technology, training and policy framework needed to guide mariculture development. Taking advantage of the expertise the proposal is made to establish a National Mariculture Resource and Training Centre (**NAMARET Centre)** at Shimoni that will focus on reducing the key barriers faced by the mariculture sector.

The government is well aware of the aforementioned obstacles and is in the progress of establishing a National Mariculture Resource and Training Centre (NAMARET Centre) which will incorporate a marine hatchery, wet and dry laboratory, training resource center, administration block, accommodation and museum. The most critical component the marine hatchery is intended to provide consistent supply of high quality seed of finfish and shellfish for the growth of the industry. In this effort, KMFRI will work with different stakeholders including SDFA &BE, KeFS, Universities, County Governments and other practitioners to add value to the services.

NAMARET Centre will work consultatively to develop technologies and policies as per the demand of the practitioners and other stakeholders in addition to ensuring environmental integrity. This may include but not limited to technologies in marine hatchery skills in seed production, live feeds, nutrition, culture systems, species diversification, technology transfer and dissemination, extension frameworks, policy frameworks, Marketing and business planning, site selection and value addition.

To produce and supply sufficient quality seeds of finfish and shellfish for promotion of mariculture in Kenya. Therefore, the hatchery will ensure that there is an all year production of seeds as well as open opportunities for entry of more farmers in production. This will be achieved through providing dynamic and competent leadership in the generation and promotion of science-based responsible technologies in order to strengthen stakeholder capacities in mariculture and aquatic resources utilization and management.

Current mariculture growth in Kenya is constrained by the lack of seeds of finfish and shellfish. Several constraints to achieving this goal has been identified including a reliable source of quality seed stock, well trained practitioners and suitable facilities to carry out developmental research (Hecht et al 2019). Now, mariculture production at the cost is low mainly relying of harvesting seeds from the wild hence limiting production to one crop per year with the most cultured candidate species being milkfish and prawns. With conservative estimates of total pond area of between 60-120 ha available for each species, it is estimated that demand for milkfish fingerlings is most likely in the region of 278125 and prawns 2.14 million per annum (Hecht et 2019). If the industry expands from 20 to 160 ha in 5 years then the demand will increase to 4.5 to 34.3 million (Hecht 2019) generating substantial income for the hatchery and profoundly increasing the production of milkfish and prawns.

Currently no finfish hatchery exists, however few private hatcheries exist for mud crabs (mud crab fattening- soft shell) and prawns often compounded with water quality issues and lack of broodstock. A critical first step is to ensure sustained and consistent production is the development of hatchery facilities to provide farmers with reliable source of seed. It is estimated that there are about 66 communities engaged in prawn/milkfish farming in which 59% are active (Hecht et al 2019) and one of the main reasons cited for their failure to move from subsistence level being lack of seeds. Currently, the NAMARET center in Shimoni intends to serve as first government hatchery facility to bridge this gap.

With the marine hatchery at Shimoni potential also exists to produce other high value species such as groupers, sea cucumbers, and pearl oysters which can generate much income. The proposed multispecies hatchery facility will in the first instance serve the development of the small scale mariculture sector from its current and largely donor dependent state to a medium size commercial state. This will require amongst others a comprehensive hatchery to provide the required seed for the sector. The future emerging commercial sector would, in all likelihood, also be dependent on the hatchery for seed.

> **"THE MOST CRITICAL COMPONENT THE MARINE HATCHERY IS INTENDED TO PROVIDE CONSISTENT SUPPLY OF HIGH QUALITY SEED OF FINFISH AND SHELLFISH FOR THE GROWTH OF THE INDUSTRY.**

5.4. ECONOMIC CONSIDERATIONS IN FISH GENETIC IMPROVEMENT

Profitability of breeding programs is the main factor in the implementation of fish genetic improvement. In Kenya significant contribution of genetic improvement have been realized in livestock. On the other hand, the genetic resource in aquaculture is either similar or inferior to the wild stock since most hatcheries are still receiving brooders from the wild (FAO 2008; Nyonje et al., 2018). The genetic improvements efforts in Atlantic salmon ***(Salmon salar)*** (Housto and Macqueen, 2019), GIFT Nile tilapia ***(Oreochromis niloticus)*** in Egypt and South East Asian countries (Ponzoni et al., 2011; Asian Development Bank, 2005) and common carp ***(Cyprinus carpio)*** in India (Nguyen and Ponzoni 2008) have demonstrated that genetic improvement can increases farm income, either via increased production, cost reduction or a combination of both. Genetic improvement in aquaculture is occasioned by a series of experimentation with plentiful and efficient record keeping for years and thus the desired results (biological trait improvement) may take long to be realized. Challenges in genetic improvement programs is the cost implication making these breeding programs mainly operated by private firms with minimal involvement from government as observed in developing and developed countries (FAO, 2008). As such specific species of animals of economic importance are normally earmarked for genetic improvement. For successful fish genetic improvement, the following considerations are supposed to be made: -

1. Human Resource capacity and skills

Genetic improvement programs require personnel with skills and knowledge in population genetics, molecular genetics and biotechnology. This is required for both the scientists and technologists who are working in fish genetic improvement and breeding programs.

2. Reliable capacity

Genetic improvement programs are long term investments which require reliable capacity in terms of infrastructure (laboratories, ponds and equipment) and human capacity who closely monitor fish during the breeding procedures. With this regard genetic improvement required reliable continuous funding for sustainability and structured systems to ensure that the different generations are closely monitored.

3. Market demand for production and survival traits

Demand of a particular trait in the market determines the improvement to be done in a particular fish species, for example high fillet yield has been the drive towards selective breeding for fast growth and high yields; Breakout of diseases has also led to selection for disease resistance in tilapia, rainbow trout; flesh colour for selection in Salmon; and tolerance to a given climatic condition like cold tolerance for tilapia and high temperature tolerance to rainbow trout.

Cost-benefit analysis

To assess the effectiveness of a genetic improvement investment, cost-benefit analysis can be used. The rule of thumb is to express the gains (benefits) and expenditure (cost) of any breeding program to the current situation (baseline data of that trait). Benefits will be based on the increased output/production of the desired trait(s). Costs include investments for experiment infrastructure, rearing facilities, feed input, trait recording, infrastructure and genetic analysis. The net present value for a given time horizon is equated to the measure of the profitability of the breeding program. For instance, economic values for Nile tilapia *(O. niloticus*) and common carp *(C. carpio)* have been estimated from profit equations (Ponzoni et al., 2007, 2008).

However, profit equations results may not be reliable where the production systems have a high degree of complexity e.g. effect of seasonality such as cold and warm weather conditions instead bio-economic models are used (Rewe and Kahi 2012). Aquaculture farms are complex production systems; when fish are reared outdoors, they are exposed to changing environmental conditions such as temperature which has a direct effect to fish growth rate. Harvesting of terrestrial animals is associated to age on the other the hand fish are harvested at a certain weight thus the length of a production cycle in not dependent on the stocking date, additionally, other factors e.g. dissolved oxygen and stocking density may limit the productivity of the a farm system. In such scenario the performance of the biological trait will be assessed using the bio-economic models. The common choice of biological traits for genetic improvement include survival and growth rate.

Survival/mortality:

A farmer needs to be able to harvest as many fish as possible, mortality will affect feed costs and juvenile/table size fish costs. But other factors such overcrowding and environmental changes will affect performance of this trait. Fish mortalities associated with these factors may thus increase the expenditure and lower the revenues affecting the bio-economic model.

Growth/FCR: For most selection programs, growth enhancement is the priority, as it is easily quantified and highly heritable. Selection for rapid growth improves the efficiency in which fish use feed since feed intake rate affects feed cost. Selection directly targeting the improvement of the FCR would be even more useful. To directly select for FCR, feed intake needs to be recorded verses the weight output. It is important though to note that the plankton that is actively eaten by fish should be catered for in the feed conversion ratio calculations. The complexity in fish growth where growth rate changes during different developmental phase. To overcome this complexity, selection is based on harvest weight at a specific time period. For economic consideration, the harvest weight is targeted for improvement for a specific growth period. Notably in bio-economic models the improved biological trait does not affect fixed costs, hence change in profit due to genetic change equals change in gross margin (Figure 5.1).

In breeding programs for aquaculture species, improvement in a biological trait will therefore be weighted based on the economic gain. It is therefore crucial to include all inputs affecting the traits (expenses and income) to avoid underestimation (more expenses than income inputs) or overestimating the profit (more income than expenses inputs) in the model. The whole economic consideration theory is based on profit, economic efficiency, or return on investment. However, if far reaching societal gains from a genetic improvement program are to be realized e.g. providing safer fish or environment protection, the program may depart from economic gain concept.

5.5. AQUACULTURE GENETIC IMPROVEMENT IN KENYA

Aquaculture though a recent entrant into agricultural breeding strategies is aimed at increased productivity at minimal cost. These is achieved through selection of traits from parent stock that confer an advantage to the fish, producer, marketer and consumer. The preferred traits selection in aquaculture is more advanced in countries with structured aquaculture value chains. Unlike Asia and Europe, Africa, Kenya included have largely depended on unimproved fish strains as their broodstock.

Due to the increasing demand for fish protein coupled with capture fisheries decline, aquaculture has gained prominence and more precisely the culture of Nile tilapia in Kenya. Further to this, the intensity and diversity of efforts to improve the genetic baseline of these species have seen significant development. In the same breath, there has been increased demand by hatcheries and grow-out farms for importation of super YY males, GIFT and Abbassa strains. In addition, Dutch and Indonesian strains of African catfish have been imported to enhance the species productivity. However, this comes with little knowledge by the value chain actors on the genetic by environment effects associated with any fish breeding programme, thus the need for demand driven local breeding programmes. Other than the traditional and science-based quantitative genetic approaches in Nile tilapia breeding, chromosomal manipulations, physiological alteration of sex determination, gene transfer, and genetic marker-assisted breeding are also in practice across the globe.

However, traditional tilapia breeding approaches taking advantage of additive and non-additive gene effects are still the most practical means of improving broodstock for small scale breeders globally.

In Kenya, KMFRI is engaged in Nile tilapia and African catfish selective breeding and mass breeding programmes respectively. Nile tilapia involving 2 sires and 1 dam per hapa has seen 200 sires and 100 dams used as filial generation which are screened Sagana and Lake Victoria strains. The Nile tilapia selective breeding programme initiated in 2012 is in the 8^{th} generation and part of its mixed sex population distributed to over 12 multiplication centers across the country for seed production and supply to grow-out farms.

Though mass selection is fast and cost effective, it has been documented to fast regress to homozygosity unless the number of parents is large (Gjerde et al., 1996; Villanueva et al., 1996), worse still, the breeding programme may have negative effects. This has slowed down the breeding programme with Bentsen and Olesen (2002) approach of structured parent identification and their contribution to the next generation documented. Even though, strain comparison already carried out has demonstrated that the Kenyan African catfish strain is equally superior albeit limited breeding programme. Thus, this demands that increased breeding programme efforts to be put in place for all aquaculture species to develop strains that are resilient to the prevailing environmental conditions in Kenya.

> "THE COMPLEXITY IN FISH GROWTH WHERE GROWTH RATE CHANGES DURING DIFFERENT DEVELOPMENTAL PHASE. TO OVERCOME THIS COMPLEXITY, SELECTION IS BASED ON HARVEST WEIGHT AT A SPECIFIC TIME PERIOD.

5.6. INDIGENOUS SPECIES BREEDING TECHNOLOGIES

There is need for diversification of fish species for culture and conservation of those on a verge of extinction. Currently, the only method of achieving this is through captive breeding of indigenous fish species. This ensures availability of fingerlings for aquaculture and stocking into the natural waters. KMFRI has taken lead in breeding of some indigenous species. The indigenous fish whose captive breeding trials have been successfully achieved include: ***Labeo victorianus, Oreochromis jipe*** and ***Oreochromis niloticus baringoensis.*** The efforts of breeding ***L. victorianus*** are for the purpose of its conservation. This species appears in the International Union for Conservation of Nature (IUCN) red list as a critically endangered species. The other two species; ***O. jipe*** and ***O. n. Baringoensis*** have been tested and found suitable for culture. Therefore, selected farmers in Taita Taveta have been supplied with fingerlings of ***O. jipe*** after a successful captive breeding programme. Further, ***O. n. baringoensis*** a species endemic to Lake Baringo has been successfully propagated and plans are underway to supply fingerlings to farmers in Baringo County.

Domestication and breeding trials of indigenous species at KMFRI is a continuous activity and currently the potential of ***Protopterus aethiopicus*** for aquaculture is being tested. Breeding of ***L. victorianus*** is done by inducing females with reproductive hormones (gonadotropins) to hasten the process of ovulation (Orina et al., 2014; Kembenya et al., 2016). Broodstockof ***L. victorianus*** is collected from their natural environments, especially rivers within the Lake Victoria basin, for seed production. The species requires proper timing of their reproduction to coincide with their breeding season in the wild. Broodstock of ***O. jipe*** are collected from Lake Jipe while those of ***O. n. baringoensis*** are obtained from Lake Baringo. Unlike ***L. victorianus,*** breeding of ***O. jipe***, and ***O. n. baringoensis*** in captivity do not pose any challenge as they don't require the use of exogenous reproductive hormones. Once broodstock are obtained from the wild they are transported to holding facilities where they get acclimatized and then paired at a ratio of 1 male to 3 females. With proper feeding the fish can reproduce naturally and then fingerlings are harvested and nursed separately till they are ready for stocking.

5.7. GENETIC MATERIAL TRANSFER

The transfer of germplasm from one habitat to another is common in Kenya and many other Africa countries. This is driven by the need to improve food security and nutrition by engaging in aquaculture as an economic activity. The most transferred species is Nile tilapia; *Oreochromis niloticus* considering it's the most important species for fisheries and aquaculture (Shechonge et al., 2019). The fish which is native to Africa and middle east, has been widely introduced into tropical and subtropical regions.

As a result of the expanding aquaculture sector coupled with the ballooning cage culture in Lake Victoria, the demand for fast growing tilapia strains has seen several hatcheries introducing genetically improved tilapia mainly from Asian countries. Some of the known imported tilapia strains into Kenya include: the super YY strain from TilAqua, Netherlands and the chitralada from Thailand. Other improved strains though still not confirmed to have been imported in to Kenya include: the genetically improved farmed tilapia (GIFT), the GenoMar strains, amongst many more (Moses et al., 2019).

The super YY was first brought into Kenya by the Jambo fish project in 2012, since then, other hatcheries have also imported and adopted the Dutch super YY strain. Such hatcheries include: Kamuthanga fish farm, Jewlet fish farm and Makindi fish farm. The transfer of the tilapia germplasm for optimization of aquaculture in Kenya has both socio economic and ecological impacts;

Benefits of socio economic impacts

These include:

- higher incomes for farmers and private investors,
- better nutrition (more protein),
- reduced poverty,
- improved health and welfare.
- Also, since women are traditionally involved more in processing and marketing of fish, they too will benefit from the adoption of improved strains.

ECOLOGICAL IMPACTS ON GENETIC TRANSFERS AND IMPLICATIONS ON AQUACULTURE

The present and future of aquaculture development relies heavily and solely on the genetic integrity of the indigenous fish populations. However, there are fundamental ecological risks and negative aspects associated with such transfer of fish. Gene flow from introduced strains could replace the existing germplasm with hybrids hence face the danger of reduced growth rate and low resilience as a result of inbreeding depression. In Kenya, most of the ponds are not isolated from streams and wetlands thus farmed fish can easily escape and hybridize with native tilapia (Ndiwa, 2017). This scenario is typical for cage culture of tilapia in Lake Victoria. As reported by Orina et al., (2018), most of the materials for cage culture easily allow for fish escape and interbreeding with the wild tilapia population. This causes genetic erosion of the wild population which are the very source of germplasm for broodstock.

GENETIC MATERIAL BIOSAFETY

Wild and cultured genetic material is imported or exported across boundaries for breeding, training and research. As aquaculture grows across the globe, cultures fish and other aquatic organisms have similarly experienced growing movements with Nile tilapia and African catfish among the topmost widely spread cultured species. However, this movements need to take cognizant of environmental integrity. There have been numerous documented cases of competition, predation, disease transfer and habitat damage resulting from the introduction of alien species and this should be treated with utmost caution. It is thus imperative that genetic material movement as well as genetic improvement programmes should not undermine the goals of conserving genetic diversity in wild aquatic species and protecting the integrity of aquatic communities and ecosystems.

Aquaculture farm due to move aquatic genetic material should meet the following criteria;

(a) Disease free genetic material
(b) Recipient provide quarantine facility
(c) Recipient provide proof of escapee safeguards
(d) Risk assessment and management information
(e) Heavy metals and chemicals free fish and fish products

Farmed aquatic materials are prone to contamination as living or processed products. This may arise from contaminated waters in production or dressing and product processing areas. Poor agricultural practice resulting in emission of chemicals and other soil impurities including heavy metals. Use of water from quarries or mining points and application of chemicals in aquaculture should be cognizant of associated fish and human health associated complications. Aquatic organisms are known to be efficient water filters and bio-accumulators of their intake (heavy metals and chemicals). This is eventually likely to be passed on to humans at aquatic organisms' consumption resulting to a myriad of health complications. This implies that all aquaculture genetic material are subjected a risk assessment and subsequently a management plan put in place. This entails confinement measures and management programmes aimed at ensuring reduced risks to acceptable levels.

REFERENCES

Kembenya, E. M., Marcial, H. S., Outa, N. O., Sakakura, Y. and Hagiwara, A. (2016). Captive Breeding of Threatened African Carp, Labeovictorianus, of Lake Victoria. Journal of the World Aquaculture Society.doi: 10.1111/jwas.12328.

Moses, M., Mtolera, M. S. P., Chauka, L. J., Lopes, F. A., de Koning, D. J., Houston, R. D., & Palaiokostas, C. (2019). Characterizing the genetic structure of introduced Nile tilapia (Oreochromis niloticus) strains in Tanzania using double digest RAD sequencing. *Aquaculture International*. https://doi.org/10.1007/s10499-019-00472-5

Ndiwa, T. C. (2017). Contribution to the knowledge of the populations of Nile tilapia (Oreochromis niloticus) inhabiting extreme conditions of temperature and alkalinity To cite this version : HAL Id : tel-01542402.

Nyonje, B. M., Opiyo, M. A., Orina, P. S., Abwao, J., Wainaina, M., & Charo-Karisa, H. (2018). Current status of freshwater fish hatcheries, broodstock management and fingerling production in the Kenya aquaculture sector. Livestock Research for Rural Development 30: Article #6.

Orina, S., Ogello, E. O., Kembenya, E. M., & Muthoni, C. (2018). *State of Cage Culture in Lake Victoria , Kenya.*

Orina, P. S., Rasowo, J., Gichana, E., Maranga, B. &Karisa, H.C. (2014). Artificial Breeding Protocol and Optimal Breeding Environment for *Labeovictorianus*(Boulenger, 1901).*International Journal of Fisheries and Aquatic Studies* 1(6): 138-143

Shechonge, A., Ngatunga, B. P., Bradbeer, S. J., Day, J. J., Freer, J. J., Ford, A. G. P., … Genner, M. J. (2019). Widespread colonisation of Tanzanian catchments by introduced Oreochromis tilapia fishes: the legacy from decades of deliberate introduction. Hydrobiologia, 832(1), 235–253. https://doi.org/10.1007/s10750-018-3597-9

Rege, J. E. O. (1991). Genetic Analysis of reproductive and productive: performance of Friesian cattle in Kenya. II Genetic and phenotypic trends. *Journal of Animal Breeding and Genetics*, 108 (1-6), 424-433. https://doi.org/10.1111/j.1439-0388.1991.tb00204.x

Kosgey, I. S., and Okeyo, A. M. (2007). Genetic improvement of small ruminants in low-input, smallholder production systems: Technical and infrastructural issues. Small Ruminant Research, 70 (1): 76-88. https://doi.org/10.1016/j.smallrumres.2007.01.007

Ntombizakhe, M., and Rege, J. E. O. (2002). Monitoring of Sahiwal and Friesian cattle genetic improvement programmes in Kenya. AGTR Case Study. Nairobi, Kenya: ILRI. https://cgspace.cgiar.org/handle/10568/3579

Rewe, T. O., Indetie, D., Ojango, J. M., and Kahi, A. K. (2006). Economic values for production and functional traits and assessment of their influence on genetic improvement in the Boran cattle in Kenya. Journal of Animal Breeding and Genetics, 123 (1): 23-36. https://doi.org/10.1111/j.1439-0388.2006.00558.x

Bett, R. C., Kosgey, I. S., Bebe, B. O., and Kahi, A.K. (2007). Genetic improvement of the Kenya Dual Purpose Goat: Influence of economic values and prospects for a practical breeding programme. *Tropical Science*, 47 (3): 105-119. https://doi.org/10.1002/ts.204

FAO. 2008. *Aquaculture development. 3. Genetic resource management.* FAO Technical Guidelines for Responsible Fisheries. No. 5, Suppl. 3. Rome, FAO. 2008. 125p.

Nyonje, B. M., Opiyo, M. A., Orina, P. S., Abwao, J., Wainaina, M., & Charo-Karisa, H. (2018). Current status of freshwater fish hatcheries, broodstock management and fingerling production in the Kenya aquaculture sector. *Livestock Research for Rural Development,* 30(1).

Ponzoni, R.W., Nguyen, N. H., Khaw, H.L., Hamzah, A., Bakar, K.R.A., Yee, H.Y. (2011). Genetic improvement of Nile tilapia *(Oreochromis niloticus)* with special reference to the work conducted by the Worldfish Center with the GIFT strain. *Reviews in Aquaculture,* 3:27–41. doi: 10.1111/j.1753-5131.2010.01041.x

Ponzoni, R. W., Nguyen, N. H., and Khaw, H.L (2007). Investment appraisal of genetic improvement programs in Nile tilapia *(Oreochromis niloticus). Aquaculture, 269:* 187–99.

Ponzoni, R.W., Nguyen, N. H., Khaw, H.L., and Ninh, N. H. (2008). Accounting for genotype by environment interaction in economic appraisal of genetic improvement programs in common carp *Cyprinus carpio. Aquaculture* 285: 47–55.

Asian Development Bank. (2005). An Impact Evaluation of the Development of Genetically Improved Farmed Tilapia and Their Dissemination in Selected Countries. *Asian Development Bank*. http://hdl.handle.net/11540/3321.

Houston, R. D., & Macqueen, D. J. (2019). Atlantic salmon (Salmo salar L.) genetics in the 21st century: taking leaps forward in aquaculture and biological understanding. *Animal Genetics, 50(1),* 3–14. https://doi.org/10.1111/age.12748

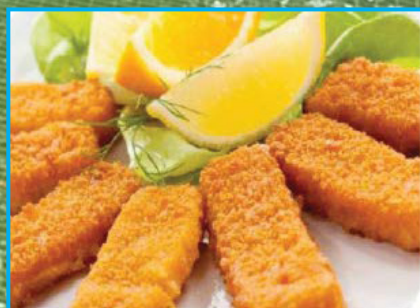
Janssen, K., J,Berentsen, P., Besson, M and Komen, H. (2017). Derivation of economic values for production traits in aquaculture species. *Genetics Selection Evolution, 49:*5. doi:10.1186/s12711-016-0278-x

Rewe T. O., and Kahi A. K. (2012). Design and Application of Bio-economic Modelling in Livestock Genetic Improvement in Kenya: A Review. *Egerton Journal of Science and Technology* 12: 113-119

Nguyen,H. N., and Ponzoni, R. W., (2008). Genetic improvement of carp reduces poverty, hunger in Asia. https://www.aquaculturealliance.org/advocate/genetic-improvement-carp-reduces-poverty-hunger-asia/



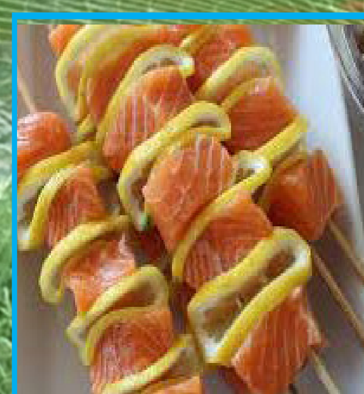





CHAPTER 6

FISH POST-HARVEST MANAGEMENT, VALUE ADDITION AND MARKETING

DOMITILA KYULE-MUENDO, FONDA JANE AWUOR, CECILIA GITHUKIA, JOSYLINE KENDI, VENNY MZIRI, KEVIN OBIERO, PAUL ORINA




Key Messages	Policy Recommendations
• The Kenyan aquaculture production contributes to only 10% percent of Kenyan fish consumption; while its climate is ideal for fish farming. The demand for fish is rapidly rising due to population growth and rising incomes. • The aquaculture sector in Kenya has the potential to become a significant source of affordable, high-quality protein; to reduce poverty, provide employment and contribute to gross domestic product. • Currently, prices are getting even better than those in the world market for whole tilapia in almost all major towns in Kenya where aquaculture is practiced. • Given that fish is a highly perishable product, the expansion and advancement of fish handling techniques for fish processing, harvesting, handling and storage are key at a time when aquaculture enjoys its development in a fast paced and vibrant economy. • The technologies employed to curb physical and quality losses in Kenya include: Temperature management, quality packages, fish handling, level of education on those who handle, safety measures, sizes, levels of breakages, Discarding of by-catches. • To increase aquaculture products market value, expanding consumer preference and longer shelf life, aquaculture value chain actors at different chain nodes are both adopting and adapting product development technologies	• Fish farmers needs to embrace value addition in order to add value to their products and improve shelf life of the products. • The local, regional and international markets are still unexploited. The ever rising local and regional demand for fish creates an avenue for production of more fish. • The prospect of the fish market in Kenya is high, attributed to the country's fast-growing population, the stature prescribed to aquaculture, the dynamic promotion of fish consumption by the Kenyan government and the heightened demand for fish. • To tap into market opportunities successfully, innovative research on domestic, regional and international markets is critical. • To make profits, efficient handling and processing of fish and fish products, as well as skillful risk management is key. Weak and inefficient value chains obstruct market signals between producers and consumers whereas strong and stable market signals, primarily price has the potential to revitalize supply and investment in improved quality. • Intensive culture of fish in ponds, raceways, tanks and other facilities results in effluents with high levels of nutrients which when released in the natural water body can cause eutrophication and conflicts with other water users. • Therefore, implementation of the Ecosystem Approach to Aquaculture (EAA) could facilitate sustainable utilization of water resources in cage culture and hence overcoming constraints in facing the above-mentioned challenges.

Kyule-Muendo, D, Awuor, F. J., Githukia, C., Kendi, J., Mziri, V., Obiero, K., & Orina, P. (2021). Post-Harvest Management, Value Addition and Fish Marketing. In: Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition -Sensitive Fish Food Production Systems; Chapter 6: pp 103–112.

6.1 INTRODUCTION

The Kenyan aquaculture production contributes to only 10% percent of Kenyan fish consumption; while its climate is ideal for fish farming. The demand for fish is rapidly rising due to population growth and rising incomes (Obiero et al., 2020). The aquaculture sector in Kenya has the potential to become a significant source of affordable, high-quality protein; to reduce poverty, provide employment and contribute to gross domestic product.

The country's per capita annual fish consumption is around 5 kg/per/yr and is expected to increase with the government's effort to promote fish through the "Kuza, Kula na Kuuza" campaign – which translates to "Farm, Eat and Sell" throughout the country. The domestic market for farmed fish is promising partly due to product scarcity, consumer awareness of the health benefits of eating fish as well as quality assurance of farmed fish (Githukia et al., 2014; Obiero et al., 2014) This combination of good prices and high demand becomes a real boost for aquaculture.

The African aquaculture sector has become an even more appealing investment proposition considering the COVID-19 pandemic. When coronavirus first spread throughout China, the availability and price of products like frozen tilapia—an important import for Sub-Saharan Africa — dropped/rose respectively. Some 90% of Africa's farmed fish consumption is imported from Asia, with Sub-Saharan Africa producing less than 1% of the global total (Corsin, 2020). Currently, the retail price for fillets in Nairobi now is retailing between USD 350 per kilogram which is almost double the normal price

Currently, prices are getting even better than those in the world market for whole tilapia in almost all major towns in Kenya where aquaculture is practiced. Given that fish is a highly perishable product, the expansion and advancement of fish handling techniques for fish processing, harvesting, handling and storage are key at a time when aquaculture enjoys its development in a fast paced and vibrant economy. Aquaculture value chain actors have engaged various marketing strategies and technological approaches with significant success aimed at enhancing product shelf life, diversification and profits. Proper handling and processing of fish continue to play an increasingly important role in the production of value-added products, which promotes profitable enterprises and reduce post-harvest losses (Kyule-Muendo et al., 2017). Again, it ensures that high quality products reach the markets.

Fish provide a rich source of high-quality proteins containing all essential amino acids, minerals, and micronutrients such as iron, zinc, omega-3 fatty acids, omega-6 fatty acids and vitamins, often in highly bioavailable form. However, micronutrient deficiencies affect hundreds of millions, particularly women and children in developing countries. The associated burdens of micronutrient deficiencies include increased risks of perinatal and maternal mortality, growth retardation, child mortality, cognitive deficits and reduced immune function. Value addition is the most popular word in the food-processing industry, particularly in enhancing the value and profit margins of products. Value addition promotes safety, increases shelf-life, helps maintain a high level of quality, opens new market opportunities and increases fish trade. The need to develop superior farmed fish products niche is therefore inevitable. This is possible through the development of value addition technologies for aquaculture products that meet consumer preferences and needs.

> "THE AFRICAN AQUACULTURE SECTOR HAS BECOME AN EVEN MORE APPEALING INVESTMENT PROPOSITION CONSIDERING THE COVID-19 PANDEMIC..

6.2 POST-HARVEST TECHNOLOGIES

The main aim of post-harvest technologies is to reduce losses in both quality and quantity and to maintain safety between harvest and consumption sites. These losses are encountered at the stages of harvesting, packaging, transportation and delays at different stages of handling.

However, introduction of new technologies in fisheries production in Kenya highly face challenges emanating from public finance for infrastructure such as all-weather roads and electricity and unavailability of necessary supplies, tools or equipment. The process of developing post- harvest technology and its purposeful use needs an interdisciplinary and multi-dimensional approach, which must include, scientific creativity and technological innovations (Majumdar, 2019). The technologies employed to curb physical and quality losses in Kenya have considered of the following:

Temperature management, Quality packages, Fish handling, Level of education on those who handle, Safety measures, Sizes, Levels of breakages, Discarding of by-catches among others.

The technologies currently used in fish preservation in Kenya include: Sun-drying, Smoking, Salting/brining/pickling, Gutting, Fermentation, Canning, Chilling and freezing, development of Value-added products. Most common techniques in Kenya are smoking and sun-drying which are rudimentary all over the country depending on the area's geographical conditions. In the low humidity areas especially those in forest zones employ smoking.

A few fish farmers in South coast like Kwale County have employed some drying machines to generate hot air especially during the South Easterly monsoons and North Easterly monsoons when the sunshine hours have been reduced by rains.

6.2.1 SMOKING AND SUN-DRYING

Most fishermen and a few farmers apply this technique using traditional smoking kilns. The most commonly used fuel is wood free from timber preservative, paint, gum or any other added substances. The fish is exposed to temperatures of 70°C.

Sun-drying is practiced in the northern and coastal Kenya where the climatic conditions are of hot weather in nature. Others employ slow refrigeration where the fishermen and farmers store fresh fish in ice boxes with ice blocks for 2 to 3 days. Additionally, there is the combined technology for Solar-wind dryer. For instance, in Vanga and Kipini at the coast employ a solar-wind dryer as shown in plate 2 above. Most traders practice drip drying as shown in plate 4 before deep frying.

Plate 4: Drip drying prior to deep frying in Lake Victoria

6.2.2 CHILLING AND FREEZING

The technology of chilling at between 7℃ and 16℃ and freezing at -18℃ has been used to increase the shelf life of fish. Freezing is the most common used method.

Plate 5: Fish in a freezer

6.3 VALUE ADDITION METHODS AND TECHNOLOGIES

Value addition in fish is an important strategy that will add economic value and possibly widen the market performance while reducing a problem of post-harvest losses in sub-Saharan Africa (Kyule et al., 2014, Mohamad et al., 2011). To increase aquaculture products market value, expanding consumer preference and longer shelf life, aquaculture value chain actors at different chain nodes are both adopting and adapting product development technologies. This is by utilizing mostly minced fish to develop diversified fish products. In Kenya, some of the products sold in most fish markets include; fish fillets, samosas, balls, sausages, pie, burger, fingers, smoked catfish and tilapia, dried fish, fish oil, gel, chapati and skewers among other products and their recipes are available (Kyule et al., 2017). Currently some fish processors and traders are engaged in product development as shown in Table 6.1 below.

Table 6.1: Operational Fish outlets in Kenya

No.	Fish outlet	Locality
	Fish Carnivore Centre	Meru
	Fish Market in near old harbor of Mombasa	Mombasa
	AFIPEK-peak industry body for Kenya fish processors and exporters	Mombasa
	Pwani seafood	Mombasa
	South Africa Shoprite	Mombasa
	Kenya Tropical Sealife Ltd	Nairobi
	Takaungu fish shop	Mombasa
	Enozipora Entreprises-Dried fish clearing agents and supplier	Nairobi
	Lencare General Merchants-frozen nile perch fish maw	Nairobi
	Meru Fish Centre	Meru
	Biointensive Training Centre	Meru
	Davstar Fish Cafe	Kirinyaga
	High-End Fishes	Kirinyaga
	Embu Fish Den	Embu
	Zonic Hotel	Kisii

6.4 ECONOMIC ANALYSIS OF VALUE-ADDED PRODUCTS

An economic analysis entails an investigation of the existing economic climate which is vital for business survival. It is a decision-making method that is based on comparing a detailed analysis of costs to a detailed analysis of expected benefits. This helps the investor in determining the selling price of the products to ensure the business is making profits. In addition, the investor will be able to decide on the value-added products to concentrate on taking in to account the profit margins and demand of products from his consumers. This evaluation greatly helps the investor to know whether he is making a profit or a loss.

One of the most effective types of economic evaluation is the cost-benefit analysis, it deals solely in monetary terms and endeavors to ascertain whether the business is making profit or loss. In preparation of value-added products, an economic analysis helps an investor in adjusting their ingredients used in formulating the recipes to maximise profits (Kyule-Muendo, 2017). A cost-benefit analysis will always compare the cost of the effort against the benefits that result from that effort. Value-addition refers to any action that helps to raise the value of a product enabling the investor to realise better profits. In addition to increasing the shelf-life of fish and avoiding unnecessary losses associated with spoilage, value addition also increases consumption since there are more varieties in the market for consumers to choose from. A summary of costing and percentage profit for fish value-added products is included in Table 6.2 *(adopted from Kyule-Muendo, 2017).*

Table 6.2: Cost and percentage profit of value-added products

Production type	Cost of production/piece	Selling price/ piece	Profit/piece	% profit
Catfish samosa	32	40	8	25
Fish finger	15	30	15	100
Fish ball	28	30	2	7
Deep fried catfish	50	100	50	100
Smoked catfish	130	200	70	54
Fish burger	150	200	50	33
Fish pie	150	200	50	33
Fish sausage	18	30	12	67
Fish soup	10	20	10	100
Fish skewer	20	50	30	100

6.5 PROMOTING CONSUMPTION OF NUTRIENT-RICH FISH SPECIES AND PRODUCTS

According to FAO (2015), the world's supply of fish for human consumption has ultimately outpaced population growth in the last five decades, with the global per capita fish consumption ranging from about 10 kg in the 1960s to 20 kg currently. In Kenya, the per capita annual consumption of fish is around 5 kg and is expected to increase with the government's effort to promote fish consumption especially in areas where fish consumption has not reached.

The Kenyan government has in the recent past conducted programmes/events to promote fish consumption country world which include;

6.5.1 FISH EATING CAMPAIGNS AND FISH FAIR EVENTS

Through the "Kuza, Kula na Kuuza" campaign - meaning "Farm, Eat and Sell" – promotion throughout the country, the government has sensitized communities on appropriate post-harvest handling technologies, created market and information exchange mechanisms for farmed tilapia and catfish value chain. In such campaigns, fish farmers and traders get an opportunity to sell their fish and other aquaculture inputs to members of the public as indicated in the Table 6.3.

Table 6.3: Aquaculture products retail prices by region

Region	Tilapia Ksh/Kg	Catfish Ksh/ Kg	Milk Fish Ksh/ Kg	Prawns	Seaweed Ksh/Kg	
					Cottonii	Spinossm
Coast	300	350.	200.- 250	400-600	40.	30.00
Western	300.	300				
Nairobi	350	300				
Central	300	350				
Eastern	300	350				
Nyanza	400	350				
Rift Valley	300	250				

The fish fair events may involve awareness-raising messages using television and radio programmes, interactive drama during a fish fair event in a school or community and/or an "Eat more fish campaign". The primary target locations are normally the nontraditional fish-eating communities. Farmers are usually engaged in the identification of "fish champions" within the community to facilitate the promotion of fish consumption. For instance, identification of a well-known fish cook from a restaurant/fish eatery to promote improved fish recipes and value-added fish products, such as fish samosas (prepared with minced fish and catfish eggs), fish fingers, fish balls, fish oil and fish soup serve with cornmeal and green vegetables.

6.5.2 SCHOOL FISH FEEDING PROGRAMME

This build on positive experiences with school fishponds, including some ponds developed under the Economic Stimulus Programme. The government focus was in public institution and schools whose purpose was to contribute to school meals and raise awareness on the nutritional benefits of fish. Moreover, this programme was deemed to have a spillover effect on the promotion of fish consumption from school children to family members at home. For instance, In Kirinyaga, a private school is feeding about 200 students from the fish pond within the school premises and the pond water and fish waste are used for growing vegetables in complementing the school meals.

6.6 MARKETING AND SUPPLY OF FISH AND FISH PRODUCTS

The prospect of the fish market in Kenya is high, attributed to the country's fast-growing population, the stature prescribed to aquaculture, the dynamic promotion of fish consumption by the Kenyan government and the heightened demand for fish. For aquaculture to be a profitable and sustainable enterprise, expansion of fish production will need a market-oriented private sector engagement with the government being a market enabler, permitting the private sector to thrive. To tap into market opportunities successfully, innovative research on domestic, regional and international markets is critical. Market research, product development and data analysis on primary information like fish and fish products production volumes and consumption and processed data on market trends and forecast is vital for market expansion of these products. Market research will inform consumers and producers' needs by isolating dietary gaps, mapping consumption patterns and the relationships with production trade analysis and regulation impacts. Further, the development of a fish market infrastructure is fundamental to widening market access, lowering post-harvest losses thereby increasing farmer income. Similarly, enhancing the development of infrastructure and harmonized policies will allow free flow of fish and fish products mainly driven by market forces.

The market for fish in Kenya is available and accessible and need a regular supply of fish but actors are faced with the challenge of attaining the prerequisites for supplying various market segments. The fish commodity market is intrinsically competitive and unpredictable, associated with shortages and linked to tight margins along the entire fish value chain. To make profits, efficient handling and processing of fish and fish products, as well as skillful risk management is key. Weak and inefficient value chains obstruct market signals between producers and consumers whereas strong and stable market signals, primarily price has the potential to revitalize supply and investment in improved quality.

With regards to market differentiation, three key segments can be differentiated. (i) Low-income group typified by a great proportion living in urban areas who have a preference for small-sized whole fish or chunks from a whole fish. Given prevailing market prices of fish, this category can purchase a single fish or a piece for each person in that household; (ii) The middle-income group typified by having a preference for small or medium-sized whole fish and (iii) the high-income group typified by having a preference for big fish. Fish farmers can leverage on this market differentiation to identify their niche markets and target consumers.

Improving consumer markets through the sanitary and phytosanitary measures (SPS), market information, logistics, market infrastructure, trade regulations and market access are vital for enabling the flow of fish and fish products from the producers to processors, consumers and export markets. Fish product standard certification and compliance are anticipated to play a vital role in the lean but growing market for higher-value niche fish products in urban supermarkets. Improving the branding and quality of these products can equally enable them to fetch higher prices in the regional and global markets.

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MARKET RESEARCH, PRODUCT DEVELOPMENT AND DATA ANALYSIS ON PRIMARY INFORMATION LIKE FISH AND FISH PRODUCTS PRODUCTION VOLUMES AND CONSUMPTION AND PROCESSED DATA ON MARKET TRENDS AND FORECAST IS VITAL FOR MARKET EXPANSION OF THESE PRODUCTS.

REFERENCES

FAO, (2015). FAO Global Aquaculture Production database updated to 2013 – Summary information.

Githukia C.M, Obiero K.O, Manyala J.O, Ngugi C.C. and Quagrainie K.K. (2014). Consumer perceptions and preferences of wild and farmed Nile tilapia (Oreochromis niloticus L.) and African catfish (Clarias gariepinus) in urban centres in Kenya. International Journal, 2(7), 694705

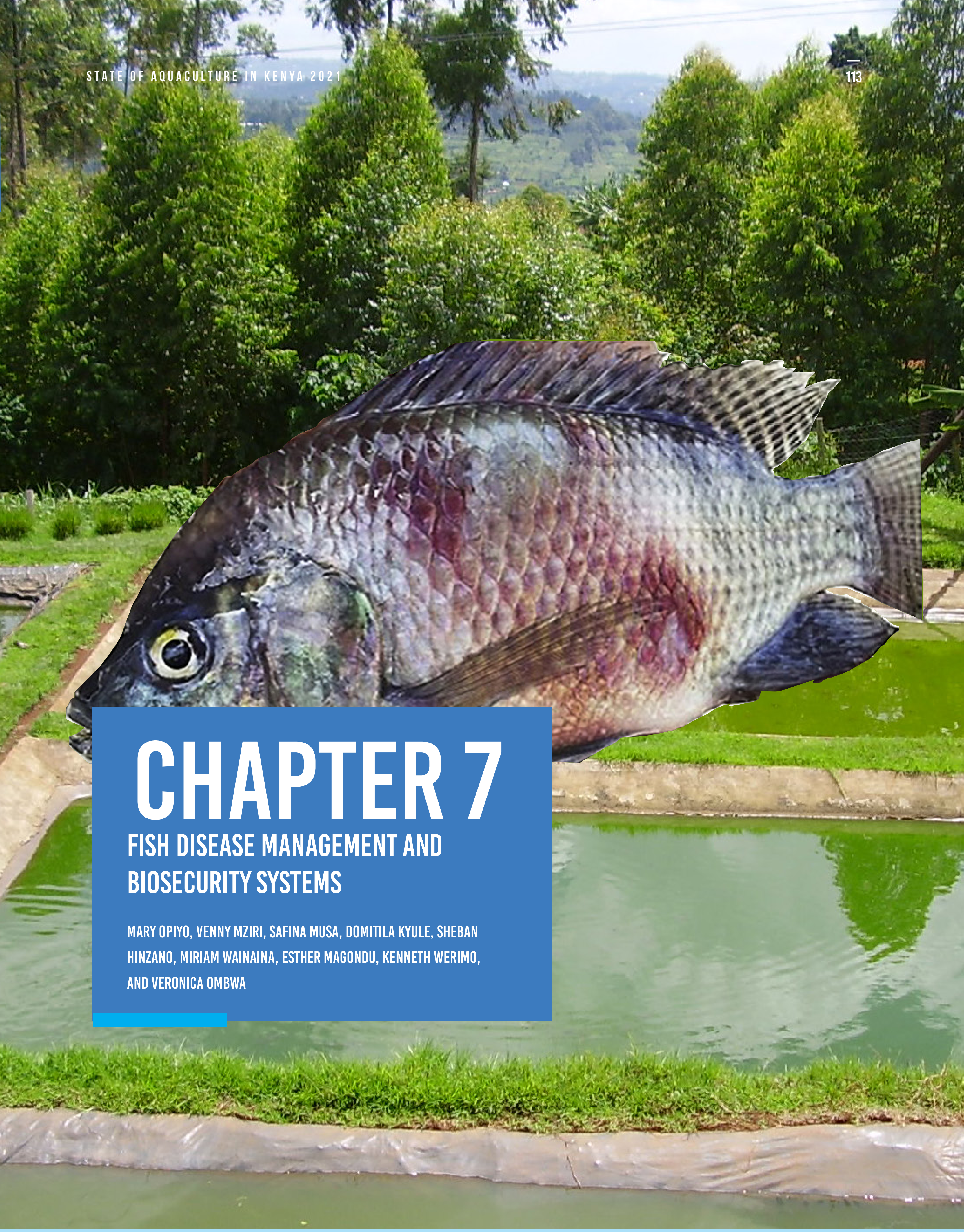
Kyule-Muendo, D., Munguti J.M., Opiyo M.A., Obiero K.O., Githukia C.M., Orina P.S., Njiru J.M., Charo-Karisa H. (2017). ***Fish Recipe Book,*** Volume 1. Kenya Literature Bureau. P. ISBN: 978-9966-103-63-6.

Kyule, D.N., Yongo, E., Opiyo, M.A., Obiero, K., Munguti, J.M., and Charo- Karisa, H., (2014), "Fish product development and market trials of fish and fish products in Kenya: a case study of Kirinyaga and Meru Counties", ***Livestock Research for Rural Development*** 26 (6): 1-9.

Majumdar, R. K. (2019). ***Advances in Fish Processing Technology.*** In Technologies for Value Addition in Food Products and Processes (pp. 163–190).

Mohamad, R., Ahmad, M. F., Abidin, A.Z.Z., and Mohamad, R., (2011), "Consumers acceptance and purchase intent of fresh water fish products developed by MARDI", ***Economic and Technology Management Review,*** 6: 77-82.

Obiero K.O, Opiyo MA, Yongo E, Kyule D, Githukia CM, Munguti JM, Charo-Karisa H (2014). Consumer preference and marketing of farmed Nile Tilapia (Oreochromisniloticus) and African Catfish (Clarias gariepinus) in Kenya: Case Study of Kirinyaga and Vihiga Counties. Int. J. Fish. Aquat. Stud. 1 (5): 67-76.



CHAPTER 7

FISH DISEASE MANAGEMENT AND BIOSECURITY SYSTEMS

MARY OPIYO, VENNY MZIRI, SAFINA MUSA, DOMITILA KYULE, SHEBAN HINZANO, MIRIAM WAINAINA, ESTHER MAGONDU, KENNETH WERIMO, AND VERONICA OMBWA

Key Messages

- The rapid growth of aquaculture in Kenya has boosted fish trade and movement of fish leading to high risks of introduction of fish with unknown health information.
- On average almost 50% of the loss in production is a result of disease and parasitic attacks in aquaculture farms.
- In Kenya, besides having policies and measures in place addressing fish health, there has been a lack of expertise in fish disease diagnostics, laboratories, and quarantine facilities.
- Viral diseases are most significant due to lack of anti-viral therapeutics, high susceptibility of fish in the early stages of their life cycle, difficulties in developing effective vaccines in the early stages of the fish, and lack of information on transmission mechanisms of viral diseases.
- Bacterial infections arise from gram-positive and gram-negative bacteria, for example, Edwardisiella tarda, Vibrio paraaemolyticus, Vibrio aglinolyticus, Aeromonas liquefaciens, Aeromonas hydrophila, Streptococcus iniae, Flavobacterium, Mycobacterium fortuitum and many strains of Pseudomonas.
- Fungal spores are commonly found in fish culture water without causing any disease to fish. The fungi genera normally isolated from fish are Saprolegnia, Achlya, Aphanomyces, and Branchiomyces.
- Good water quality in culture system results in higher production and profits while poor water quality induces stress on fish, adversely affecting growth and in extreme cases cause mortality and lower the profits of a fish farm

Policy Recommendations

- Most hatcheries in Kenya lack quarantine facilities and this could be attributed to poor fish disease reporting in the country.
- Biosecurity refers to measures that prevent the introduction of infectious agents into defined geographical locations or facilities.
- The prospect of the fish market in Kenya is high, attributed to the country's fast-growing population, the stature prescribed to aquaculture, the dynamic promotion of fish consumption by the Kenyan government and the heightened demand for fish.
- To ensure biosafety in aquaculture, biosecurity measures should be implemented at all stages of the aquaculture production cycle, which include broodstock-stations, individual farms, national and international organizations responsible for aquaculture exports and imports.
- Physical disease control measures to prevent infectious agents from entering the farm include quarantine, vaccination, regulation of temperature, use of recommended stocking densities, and filtration and irradiation of inflow water using ultraviolet light.
- Development of standardized cleaning and disinfection protocols backed with proper records keeping would be key to effective management and control of commercial important diseases that could potentially cripple the sector.
- Investments to improve aquatic animal health and disease prevention include investment in skilled personnel/ researchers; Investments in research on the development of relevant biotherapeutics and chemotherapeutics; well-equipped laboratories; institutional capacity governing aquatic health issues, routine surveillance, quarantine facilities; and improving the linkages between various stakeholders in the aquatic animal health issues nationally and beyond

Opiyo, M., Mziri, V., Musa, S., Kyule, D., Hinzano, S., Wainaina, M., Magondu, E., Werimo, K., & Ombwa, V. (2021). Fish Disease Management and Biosecurity Systems in Kenya. In: Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition -Sensitive Fish Food Production Systems; Chapter 7: pp 113–126.

7.1 INTRODUCTION

Fisheries and aquaculture play a great role in food security and the creation of alternative livelihoods in developing countries (FAO, 2016). Demand for an affordable rich protein diet is set to increase with human population growth projections set to reach 10 billion people by 2050 (World population prospects, 2015). Aquaculture development has thus been on the rise with most of the production destined for human consumption (FAO, 2016). Technological advancements and expansion of the aquaculture industry have made culture methods to become more intensive to increase yields that can satisfy the existing demand (Rico et al., 2012).

Synonymous with this growth is the risk of aquatic animal disease proliferation due to a rise in intensification leading to increased stress levels in the cultured animal and their environment (Mohapatra et al., 2012). On the other hand, the growth of aquaculture has boosted fish trade and movement of fish leading to high risks of introduction of fish with unknown health information ***(Opiyo et al., 2018).*** This is a result of the translocation of diseases across countries and continents through live fish transportation of broodstock *(Bondad- Reantaso, 2005*). Risks of endemic, emerging, and re-emerging fish diseases could impact livelihoods, and in cases of zoonotic infections, human health could be impacted thus affecting future markets. On average almost 50% of the loss in production is a result of disease and parasitic attacks in aquaculture farms (Assefa and Abunna, 2018). The situation is severe in developing countries and calls for urgent disease prevention and management measures. Fish diseases arise from an interplay of three key factors; a poor/ compromised environment, the existence of a virulent pathogen, and a susceptible host. They are categorized based on their causative agents as bacterial, viral, fungal, or parasitic diseases.

Limited information exists on fish disease outbreaks in Kenya with most studies having been done on Nile tilapia and African catfish most of which is on parasitic diseases. However, there is a gradual shift in attention to the other disease categories with the advancement in aquaculture and the rise in commercialization and intensification. In Kenya, besides having policies and measures in place addressing fish health, there has been a lack of expertise in fish disease diagnostics, laboratories, and quarantine facilities (Akoll and Mwanja, 2012). The rise of cage fish farming in Lake Victoria and the concerns being raised on the health status of the lake possess potential risks that would warrant investigations. With the advancement in global fish farming, there is a need to develop comprehensive health management practices that would encompass; identification of the etiological agent of a disease, improvement of disease surveillance, advancement in the disease diagnostic methods, development of novel & effective vaccines and anti-viral therapeutics and finally, the deployment of existing modern technologies to disease management ***(Dhar et al., 2014).***

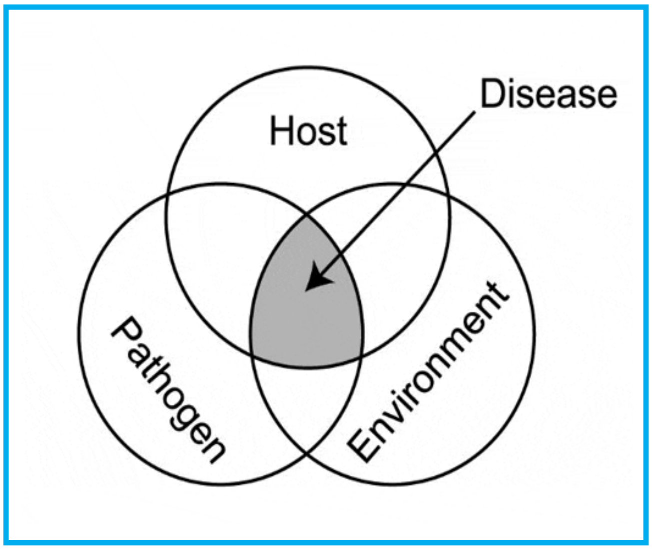


Figure 7.1: Interaction between the host, pathogen, and environment to cause fish diseases

It is important to note that disease is rarely a simple association between a pathogen and a host fish. Usually, other circumstances must be present for the active disease to develop in a population. These circumstances are generally grouped under the umbrella term "Stress" caused by environmental problems. Fish become vulnerable to pathogenic infections when there are stressors (environmental abnormalities, water quality deterioration, unbalanced nutrition, or bodily injuries) that weaken fish natural resistance (immune system).

7.2 VIRAL DISEASES AND PATHOGENS IN CULTURED SPECIES

Viral diseases are most significant due to; lack of anti-viral therapeutics, high susceptibility of fish in the early stages of their life cycle, challenges in the development of vaccines that are effective in the early stages of the fish and lack of information on the mechanisms in which viral vaccines develop ***(Dhar et al., 2014).*** Additionally, viral infections are often difficult to detect, are untreatable, difficult/impossible to eradicate, and can cause massive mortalities resulting in significant losses (***Kibenge et al., 2012).*** The spread of viral diseases via international trade is a major threat to aquaculture. Translocation of animals with no obvious clinical signs or carrying subclinical infections, asymptomatic carrier hosts, and the shipment of infected eggs are some of the threats that affect the sustainability of finfish farming ***(Rodgers et al., 2011).***

Mortality from viral infections can either be age-dependent or temperature-dependent. Viruses are transmitted by either horizontal or vertical transmission. Horizontal transmission is via shedding into faeces, urine, body fluids, semen, or ovarian fluids and released into the water. Vertical transmission, on the other hand, is where the viruses present in the broodstock (in ovary or testes) are passed on to the offspring.

Among the viruses affecting aquatic animals are; Lymphocystis, Infectious Pancreatic Necrosis Virus (IPNV), Infectious Hematopoietic Necrosis Virus (IHNV), Infectious Salmonid Anemia Virus (ISAV), Nervous Necrosis Virus (NNV), Epizootic Hematopoietic Necrosis Virus (EHNV), Viral Hemorrhagic Septicaemia (VHS), Spring Viremia of Carp (SVC), Infectious Spleen and Kidney Virus (ISKNV) and Koi Herpes Virus (KHV).

Among the World Organisation for Animal Health (OIE) listed fish diseases, viral infections are the highest in the list at 9 out of the 12 listed diseases, thus indicating their significance in aquatic animal health. Nationally, there have been cases of viral infections, though to a limited extent affecting the cultured species. With the case of communal resource use, chances of translocating a disease to an aquaculture facility thrive due to the possibility of either vertical or horizontal transmission. The following are potential viral infections that are of significance in Kenya.

Disease	Causes/conditions for susceptibility	Symptoms	Control/Treatment
1. *Infectious Pancreatic Necrosis Virus (IPNV)* Infectious Pancreatic Necrosis Virus *(IPNV)* Genus Aquabirnavirus and family *Birnaviridae.* It affects both freshwater and marine species and has a wide host range, causing massive mortalities under high temperatures.	• High temperatures • Infects all salmonids; brook trout and rainbow trout are most susceptible. • Transmission can be both horizontal and vertical nodes. Surviving fish from this infection become carriers.	• Necrosis of the exocrine pancreas in salmonids. • Intestinal and liver lesions. • In contrast, the virus has only been reported to cause subclinical infections in tilapia where no clinical signs are apparent • High mortalities in the juveniles (up to 95%); which reduces in older fish • Swirling, swimming at the surface and aggregating at the water inlet • Deformities such as vertebral scoliosis • Dorsal darkening • Hemorrhage in the ventral part	• Can be inactivated by chlorine, formalin, iodine, ozone, high pH (pH 12) • Vaccination; Administered by intraperitoneal injection (Birnagen Forte, Alpha Jects 1000, Norvax Minova-6, SRS/IPNV/Vibrio and AquaVac IPN Oral) according to the manufacturer's prescriptions. • Quarantining newly acquired stocks • Application of the recommended stocking densities • Screening of parental stocks and eggs

Disease	Causes/conditions for susceptibility	Symptoms	Control/Treatment
2. *Infectious Hematopoietic Necrosis Virus (IHNV)* This virus is in the Rhabdoviridae family and affects salmon and trout fishes.	• Widely distributed; causing high mortalities in cold temperatures • It has peak mortality (100%) at 10 ˚C and no disease at >15 ˚C. • High mortality in young fish; while the older fish are asymptomatic carriers • Transmission is by both vertical and horizontal modes.	• Swirling/whirling swimming patterns • Fry swimming on the surface and aggregating at the pond inlet • Pale gills and viscera • The presence of milky fluid in the stomach and intestines, white, thick, faecal strings trailing from the rectum • Lethargy; extensive hemorrhages on the abdomen and in the eyes around the pupil • High mortalities; and deformities e.g. vertebral scoliosis in some adults	• Using IHNV-free stock; • Disinfecting eggs (25 ppm iodine for 5 min) • Quarantine • Disinfect water with UV, ozone, • Test and slaughter (broodstock culling) • Elevate culture temperature (>15oC) for IHNV infected fish, with smaller operating facilities (hatchery producing eggs, fry) • Vaccination; via intramuscular injection using a commercial vaccine (APEX-IHN) according to the manufacturer's prescription.
3. *Viral Nervous Necrosis Disease (VNND)* It is caused by a Nervous Necrosis Virus (NNV) of the family Nodaviridae with a wide host range; affecting around 40 marine species and freshwater fish (e.g. catfish and Tilapia; *Oreochromis niloticus).* Transmission is by both horizontal and vertical nodes.	• VNND shows no clinical sign at 16oC but an increase in temperature to 22oC results in elevated viral loads and consequently leads to mortality.	• Abnormal swimming behaviours (e.g., corkscrew swimming and abrupt darting) from the damage of the nervous system; dark colouration in body • Loss of appetite and lethargic • Fish float near the edge of the pond	• Good husbandry and biosecurity; the use of virus-free spawners and reducing the spawning frequency, egg washing, disinfecting seawater with ozone • Vaccination; immersion immunization, oral immunization and vaccination of broodstock by intramuscular injection 1 month before breeding season to lower the risk of vertical transmission; Quarantining newly acquired stocks; and application of the recommended stocking densities

Disease	Causes/conditions for susceptibility	Symptoms	Control/Treatment
4. *Viral Hemorrhagic Septicaemia (VHS)* This virus is in the family Rhabdoviridae, primarily found in marine species and has a wide host range. It is widely distributed in the Pacific region, but with a rise in international trade of live aquatic animals, chances of translocating the disease are high.	• Exists in high temperatures; 22 ˚C.	• Exophthalmia and haemorrhages at the base of the fins, in the gill covers, on the gills, and in the liver, spleen, kidney, and intestine	• Apply on-farm prophylactic measures e.g. disinfection of eggs by iodophore treatment, hemical disinfection of ponds and equipment; careful handling of fish to minimize stress; safe and sterile disposal of dead fish; avoiding crowding of fish during the cold seasons and purchasing fish from virus-free farms. • Quarantining newly acquired stocks • Application of the recommended stocking densities • Screening of parental stocks and eggs
5. *Infectious Spleen and Kidney Virus (ISKV)* Caused by an Iridovirus of the family Iridoviridae. It has a wide host range; affecting a wide variety of freshwater fish including Tilapia. It is vertically transmitted.	• Effects of this disease are more severe in juvenile fish, though mortality can also occur in market sized fish.	• Mortality is typically between 20% and 60% and sometimes reaches 100% of fish in intensive culture conditions. • Lethargy; loss of appetite; pale gills • Hemorrhages in fins and operculum	• Good husbandry and biosecurity • Immunization of fry • Use of previously exposed individuals could represent a practical disease management strategy. • Vaccination as a control strategy • Quarantining newly acquired stocks • Application of the recommended stocking densities • Screening of the parental stocks and eggs

Disease	Causes/conditions for susceptibility	Symptoms	Control/Treatment
6. *Koi Herpes Virus (KHV)* Koi herpesvirus disease (KHVD) is caused by Koi Herpes Virus, also known as Cyprinid herpesvirus3 (CyHV3). It is in the Alloherpesviridae family and affects freshwater species. It has a narrow host range and results to high mortalities in temperatures between <13oC or >23oC.It is restricted to the common carp (Cyprinus carpio) and Koi × crucian carp (Carasius carasius) hybrids.	• High mortality at 18–26 °C • Affects all ages	• Appetite loss • High mortality in all strains of common carp, at all ages. In the field, adults are more susceptible. • Lethargic and enophthalmia (sunken eyes) • White patches on the skin and gills • Increased mucus secretion • Secondary bacterial infection, such as Flavobacterium columnare, is common in affected fish. • Gill inflammation, hyperplasia, and necrosis, hematopoietic tissue necrosis • Gasping movements in shallow water suffering from suffocation	• Vaccination; by immersion or injection using a commercial vaccine KV-3 (also known as Cavoy) using the prescribed dosages indicated by the manufacturer. • Avoidance, vigilant screening for KHV-free stock • Biosecurity • Elimination of vectors

Disease	Causes/conditions for susceptibility	Symptoms	Control/Treatment
7. *Goldfish Hematopoetic Necrosis Virus* It is also referred to as Cyprinid herpesvirus 2 (CyHV2) and is distributed worldwide. It belongs to the family Rhabdoviridae. The virus exhibits high latency; healthy goldfish retain the CyHV2 DNA for lengthy periods.	• High temperatures (15 ˚C -25 ˚C). • All life stages are susceptible	• Large scale hemorrhages on the body, fins and gills • Pale and necrotic gills; Protruded anus • Shrunken eyes; Anorexia • High mortality at all ages • Necrosis of hematopoietic tissue, spleen, pancreas, intestine • Liver, spleen, and kidneys may appear pale and enlarged • Spleen and other tissues often display white granular nodules	• Quarantining newly acquired stocks • Application of the recommended stocking densities • Screening of the parental stocks and eggs
8. *Tilapia Lake Virus (TiLV)* Tilapia lake virus (TiLV), also known as syncytial hepatitis of tilapia—SHT. Classification by the International Committee of Virus Taxonomy (ICVT) puts TiLV as a single new species known as Tilapia tilapinevirus in the new genus Tilapinevirus	• High stocking density • Increased water temperatures (≤ 25 ˚C) • Stressful conditions; e.g. transfer of fingerlings to grow out ponds.	• Dermal lesions/ulcers; Skin hemorrhage; Scale protrusion • Abdominal distension (ascites) • Ocular abnormalities (in severe cases rupture of the lens) • Loss of appetite; Slow movement • Reduced schooling behavior.	• Strict biosecurity on farm • Screening of new stock • Quarantine of new stock before introduction into the system • No vaccine yet; prevention is key
9. *Lymphocystis* This is caused by the Lymphocystis disease virus (LCDV) in the family *Iridoviridae.*	• Numerous fish species in fish farming are susceptible to this disease.	• External lesions • Ocular lesions	• Quarantining newly acquired stocks • Application of the recommended stocking densities • Screening of the parental stocks and eggs

Plate 7.2: Koi Herpes virus disease; a) relatively mild clinical signs on the gills of a common carp b) necrotic changes on the gills of common carp

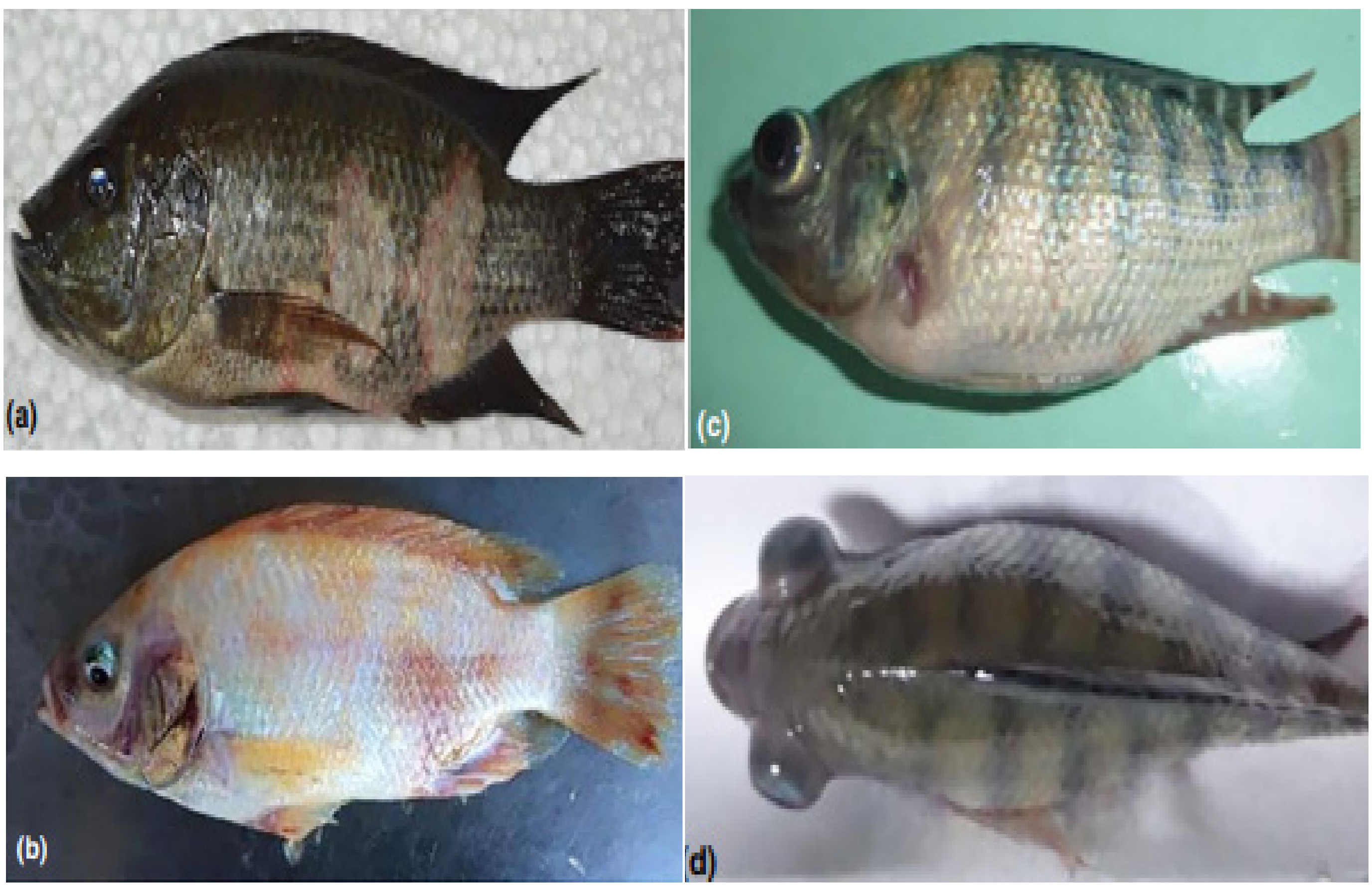


Plate 7.3: Clinical signs that are representative of TiLV infected Nile Tilapia and Red tilapia. (a) Skin hemorrhage and lesions, (b), (c) and (d) exophthalmia and distended abdomen. (Photos adopted from Jansen et al., 2018)

7.3 PREVENTION AND CONTROL OF VIRAL DISEASES IN AQUACULTURE

The global aquaculture industry has increased tremendously in the past few decades. This has led to the corresponding increase in the emerging and discovery of aquaculture viruses. Given that some viruses have had a shattering impact on the aquaculture industry worldwide, meanwhile preventive and control measures should be taken to avert the introduction of a disease in a susceptible population to reduce infection to tolerable levels in already infected populations respectively. Thus, the old axiom "prevention is better than cure," is highly applicable in aquaculture virology.

7.3.1. DISEASE PREVENTION AND CONTROL USING BIOSECURITY MEASURES

Biosecurity refers to measures that prevent the introduction of infectious agents into defined geographical locations or facilities. It also includes biocontainment referring to control of diseases already present in an area to prevent transmission to other areas. The major concerns in biosecurity are the potential carriers of infectious agents, which include infected hosts, nonhost biological carriers, and contaminated inorganic objects. To ensure biosafety in aquaculture, biosecurity measures should be implemented at all stages of the aquaculture production cycle, which include broodstock-stations, individual farms, national and international organizations responsible for aquaculture exports and imports.

(i) Implementation of Biosecurity on Brood Stock Stations

Brood stock-stations serve as starting points because of their role in the supply of eggs and live fish for fish farming. Some of the routine biosecurity measures carried out on broodstock stations for the control and prevention of infectious diseases are as discussed below;

(ii) Routine Screening of Parent-stock and Eggs

Parent stocks should be screened routinely using laboratory tests for the identification and removal of infected fish so that only disease-free fish are used to produce eggs for fish farming, this is done to prevent vertical transfer of pathogens. Individual fish from parent-stock should be tagged and screened for viral infections using sperms, ovarian fluid and other materials for virus isolation and identification using cell culture and/or reverse transcription polymerase chain reaction (RT-PCR) (Watanabe et al., 2000). Infected eggs should be removed from the breeding program and only eggs certified free of disease infections should be dispatched for fish farming. It is reported that some viral diseases such as white-spot syndrome virus (WSSV), Taura-syndrome virus (TSV), infectious hematopoietic and hemorrhagic necrosis virus (IHHNV) and infectious myonecrosis virus (IMNV) have contributed to the significant reduction of disease outbreaks on fish farms (Moss et al., 2012).

(iii) Manuals of Standard Operating Procedures for Brood Stock Stations

To ensure consistency in the implementation of biosecurity measures on broodstock stations, it is important that manuals for standard operating procedures (SOPs) are prepared and that these SOPs include biosecurity control measures as part of routine operations on broodstock stations. The SOPs should include; details on facility design, facility flow for both personnel and stock, showing restricted and non-restricted areas, equipment and personnel disinfection procedures, inflow water and wastewater management, feeding regimes, and other management procedures. Besides, SOPs should provide protocols for sample collection used in routine screening of viral diseases, guidelines for handling disease outbreak, and reporting of notifiable diseases to regulatory national veterinary institutions. Standard data entry forms must be prepared and filled in routinely, showing records on the health status, disinfection of equipment and facilities, quantity of fish-eggs, diseases screened per batch, diagnostic tests carried out, immunostimulants used or vaccinations, sources of feed, feed consumption, weight gain, and other relevant biosecurity and management practices used on the broodstock station.

7.3.2. PHYSICAL DISEASE CONTROL MEASURES

This refers to physical activities carried out to prevent infectious agents from encountering reared fish.

(i) Quarantining

All newly acquired stock should be quarantined before they can be put in the same facility as resident stock. The quarantine facility should be built away/physically separated from the resident stock. A period of 4–6 weeks is ideal for viral diseases. There should be no exchange of equipment and personnel between the quarantined and resident stock.

(ii) Vaccination

It is recommended that all acquired fish be vaccinated before they are put in the mainstream facility with the resident fish.

(iii) Regulation of temperature

This plays a pivotal role in reducing the occurrence of several viral diseases when applied accurately as shown in Table 7.1 below;

Table 7.1: Inactivation Temperatures and pH for Selected Fish Viruses

Method	Virus	Viral Disease	Virus Family	Temperature/ pH	Duration
Heat	Infectious hematopoietic necrosis virus	IHNV	Rhabdoviridae	55°C	30 s
				45°C	10 min
	Epizootic hematopoietic necrosis virus	EHNV	Rhabdoviridae	40°C	24 h
				60°C	15 min
	Viral hemorrhagic septicemia virus	VHSV	Rhabdoviridae	70°C	1 min
				50°C	10 min
	Spring viremia of carp virus	SVCV	Rhabdoviridae	45°C	20 min
				50°C	5 min
	Infectious salmon anemia virus	ISAV	Orthomyxoviridae	50°C	2 min
				55°C	1–10 min
	Infectious pancreatic necrosis virus	IPNV	Birnaviridae	70°C	2 h
				80°C	10 min
	Nervous necrosis virus	NNV	Nodaviridae	37°C	4 days
				60°C	1 h
				70°C	10 min
Acid (pH)	Infectious hematopoietic necrosis virus	IHNV	Rhabdoviridae	pH 3.8–4.3	30 s
	Epizootic hematopoietic necrosis virus	EHNV	Rhabdoviridae	pH 4.0	1 h
				pH 12.0	1 h
	Viral hemorrhagic septicemia virus	VHSV	Rhabdoviridae	pH 3.0	3 h
				pH 12.2	5–10 min
	Spring viremia of carp virus	SVCV	Rhabdoviridae	pH 3.0	3 h
				pH 12.0	5–10 min
	Infectious pancreatic necrosis virus	IPNV	Birnaviridae	pH 11.9	5 min
				pH 12.2	10 min
	Nervous necrosis virus	NNV	Nodaviridae	pH 2.0	42 days

(i) Use of recommended stocking densities

This is important because high stocking densities increase the transmission of viral diseases between fish and tend to introduce stress, which exacerbates disease transmission.

(ii) Filtration and irradiation of inflow water using ultraviolet (UV) light

The following UV range can be applied to reduce the chances of introducing viral infections as shown in Table 7.2 below;

Table 7.2: UV Sensitivity Range for Selected Fish Viruses

Virus	Viral Disease	Viral Family	UV Dose (mJ/cm²)
Infectious pancreatic necrosis virus	IPNV	Birnaviridae	100–337
Sea bass neuropathy nodavirus	SBNV	Nodaviridae	211
Atlantic halibut nodavirus	AHN	Nodaviridae	105
Japanese flounder lymphocytic virus	JFLV	Iridoviridae	100
Infectious salmon anemia virus	ISAV	Orthomyxoviridae	3.3–7.5
Viral hemorrhagic septicemia virus	VHSV	Rhabdoviridae	3.1–7.9
Hiramine rhabdovirus	HR	Rhabdoviridae	1.0
Infectious hematopoietic necrosis virus	IHNV	Rhabdoviridae	1.0–10.0
Spring viremia of carp virus	SVCV	Rhabdoviridae	1.0
Channel catfish herpesvirus	CCH	Herpesviridae	1.0–3.0
Koi herpes virus	KHV	Herpesviridae	4.0

7.3.3. CHEMICAL VIRAL CONTROL

This involves the use of chemical substances to inactivate viral pathogens in aquaculture farms. Table 7.3 below shows the concentration and duration of exposure required to inactivate different fish viruses using common disinfectants utilized in aquaculture. It is mandatory that all equipment, personnel, and all facilities be disinfected routinely.

Table 7.3: Dosages of Different chemical compounds for treating fish diseases

Chemical Compound	Application	Viral Disease	Concentration; Duration
Chlorine	Equipment, pumps, vehicles, buckets, nets, foot baths and other equipment	IHNV	0.1–1.0 mg/L; 30 s
		VHSV	25–54 mg/L; 5 min
			98 mg/L; 2 min
		SVCV	7.6 mg/L; 20 min
			36–55 mg/L; 2 min
		ISAV	50–100 mg/L; 15–30 min
		EHNV	200 ppm; 2 h
		VNNV	25–100 ppm; 5–30 min
		IPNV	4–40 mg/L; 2–30 min
Formalin	Fumigation of enclosed facilities	VHSV	3%; 5 min
		ISAV	pH 3.5–4.0
		VNNV	2%; 6 h
		IPNV	2–3%; 5 min
Iodophor	Disinfection of eggs, equipment, boots, nets, vehicles	IHNV	12–25 ppm; 15–30 s
		VHSV	100 ppm; 4 min
		VNNV	25–100 ppm; 10–30 min
		IPNV	2.5–35 ppm; 5–60 min
Quaternary ammonia	Disinfection of aquaculture ponds, hand sanitation and disinfection of plastic surfaces	VHSV	1 mL/L; 5–30 min
		SVCV	100 ppm; 4 min
		VNNV	50 ppm; 10 min
Ozone	Sterilization of waterborne pathogens, disinfection of surfaces and equipment	IHNV	0.01–70 mg/L;10 s to 10 min
		VNNV	0.1–5.3 ppm; 30 s to 2.5 min
		IPNV	70–90 mg/L; 10 min
Phenol	Disinfection of surfaces and equipment	IPNV	5%; 5 min
		VHSV	2.5%; 5 min
Cresol	Disinfection of surfaces and equipment	IPNV	5%; 5 min
		VHSV	0.1–0.25%; 5–25 min
Methanol	Hands and working surfaces	IPNV	80%; 30 min
Ethanol	Hands and working surfaces	EHNV	70%; 2 h
Isopropanol	Hands and working surfaces	VHSV	20–30%; 30 s to 2 min
Formic acid	Fumigation of facilities	ISAV	pH 3.5–4.0; 8–24 h
Sodium hypochlorite	Disinfection of nets, clothing and boots	VHSV	50–100 ppm; 1–5 min

7.3.4. BIOLOGICAL CONTROL MEASURES

This involves the use of biological processes to protect fish from viral infections. They include; vaccination to prevent infection in immunized fish, purchase of certified disease-free eggs or live fish as well as the use of disease-resistant strains of aquatic organisms used for fish farming.

(i) Prevention of viral diseases by Vaccination

Vaccination in aquaculture has emerged as one of the most effective disease preventive strategies, evidenced by the fact that vaccinated fish are less at risk of contracting viral infections compared with unvaccinated fish. However, for the vaccine to be preventive, it requires antigen identification on the surface of the pathogen's immune system to induce protection (Munang'andu et al., 2013).

Vaccine types

Vaccines used in aquaculture for fish viral diseases can be classified into two broad categories; replicative and non-replicative vaccines.

(A) NON- REPLICATIVE VACCINES COMPRISING;

- **IWV (Inactivated Whole Virus) Vaccines**

These account for the largest proportion of vaccines currently used in aquaculture. Inactivation is by using chemical compounds that alter the intracellular replication capacity of the virus (Tafalla et al., 2014).

- **Subunit vaccines**

Here, the gene encoding the immunogenic protein is isolated from the native virus and transferred into a heterologous vector for replication. Genes encoding antigenic proteins for viral antigens are structural proteins that form the outer capsids, while the choice of heterologous vectors used to express these proteins is highly governed by their efficiency in expressing the conformational structure of the antigenic proteins. For example, nodavirus structural proteins expressed in *Escherichia coli* spontaneous self-assemble into a non-enveloped T = 3 quasi symmetrical capsid resembling the native virus structural protein (Lin et al., 2001; Tang et al., 2002), while the VP2 structural proteins of IPNV expressed in yeast cells have also been shown to spontaneously self-assemble into virus-like particles (VLPs) that form the outer capsid resembling the capsid of the native virus (Allnutt et al., 2007; Shivappa et al., 2005).

Given the similarity of these protein structures to their native capsid, these subunit vaccines create a good basis for displaying the immunogenic epitopes encoded in the virus genome. Structural proteins for different fish viruses used to produce subunit vaccines and the heterologous vectors used to express the different immunogenic proteins have recently been reviewed by different scientists (Gomez-Casado et al., 2011; Munang'andu et al., 2014). In general subunit vaccines do not induce cellular immune responses (in general) and are confined to humoral immune responses because they are non-replicative and are delivered by the exogenous route to the antigen presenting cell.

- **Peptide Vaccines**

These use short fragments of amino acid sequences encoding the immunogenic component of the native virus and, because of their limited size, they are not potent enough to require coupling to carrier molecules. This mode of vaccine production is not widely used in the production of fish vaccines apart from one study (Emmenegger and Kurath, 2008) that made a synthetic peptide vaccine for Infectious Hemapoetic Necrosis Virus (IHNV) by coupling the immunogenic protein to bovine serum albumin.

(B) REPLICATIVE VACCINES

Replicative vaccines with the capacity to replicate in host cells with altered pathogenicity, lacking the ability to cause disease. Replicative vaccines can be classified into live vaccines derived from variant strains of the pathogenic native virus or DNA vaccines encoding the immunogenic protein of the native virus.

- **DNA vaccines**

This mode of vaccination is based on the principle that the plasmid DNA, which encodes the immunogenic protein, is injected into host tissues where it enters the cells and is transcribed in vivo to direct the synthesis of its polyprotein antigen from the plasmid vector. So far only Fish DNA vaccine against IHNV has been licensed for use in aquaculture (Novartis, Canada).

- **Live virus vaccines**

These are derived from attenuated pathogenic virus with altered pathogenicity that replicate in host cells without causing disease. These viruses replicate inside host cells and induce cellular and humoral immune responses, immune responses comparable to the native virus. However, only a few live viral vaccines have been licensed in aquaculture so far.

For instance, a live vaccine against VHSV was licensed in Germany, but this vaccine is no longer available in the market. In Israel, a live vaccine obtained by natural selection of a virulent strain for Koi herpesvirus has been licensed and is currently available on the market (Enzmann et al., 1998).

7.4 BACTERIAL AND FUNGAL DISEASES IN AQUACULTURE AND THEIR CONTROL

7.4.1. BACTERIAL DISEASES OF FISH

Bacterial infections arise from gram-positive and gram-negative bacteria, for example, Edwardisiella tarda, Vibrio paraaemolyticus, Vibrio aglinolyticus, Aeromonas liquefaciens, Aeromonas hydrophila, Streptococcus iniae, Flavobacterium, Mycobacterium fortuitum and many strains of Pseudomonas.

1. **Columnaris (Cotton Wool Disease, Saddleback Disease or Cotton Mouth)**

- A bacterial disease affecting freshwater fish especially in warm conditions. Though infections of columnaris as a resuts of *Flavobacterium columnarE* have been reported in rainbow trout which are usually cultured in cold water. It does not affect fish kept in salty water conditions. Cases of columnaris in tilapia are mainly due to *Flexibacter columnaris*. Outbreaks result from temperature fluctuations, trauma and poor water quality.

Symptoms

- Infected fish generally show lethargy; anorexia; weak swimming
- Raised white patches appear on the skin or fins
- Ulcerations due to severe infection

Diagnosis

- Microscopic examination of wet mounts of materials scraped from lesions of infected fish to observe the characteristic haystack colonies of *Flavobacteria columnare*
- Presence of characteristic saddleback lesion which appears as a discolourised grey patch on skin and yellow to orange in gills
- Running standard tests which include Congo red dye, nitrates reduction, catalase and oxidase tests.
- PCR primers targeting chondroitin AC lyase and 16S rRNA genes

Control and treatment

- Maintenance of good water quality
- Reduce stress factors (avoid low dissolve oxygen, high temperature, overcrowding)
- Proper diet and maintenance of good water quality
- Putting new fish in quarantine and prompt isolation of sick fish
- Treating fish with terramycin
- Treating fish with prophylactics such as Sodium chloride, acriflavine, copper sulphate and salt
- Vaccinating fish against *Flavobacteria columnare.*
- Isolating infected fish from healthy ones
- Prophylactic treatment by non-iodized salt, hydrogen peroxide, copper sulfate or potassium permanganate
- Severe conditions can be treated by antibiotics such as florfenicol, sulfadimethoxine and Oxytetraclyline dihydrate

2. Fin and tail rot

- It is caused by *Aeromonas, Pseudomonas* and *Flavobacterium spp.* and occurs in poor environmental conditions in high temperatures.

Diagnosis

- Presence of fin and gill erosion
- Microscopic examination of a squash prepared from infected skin or gills to observe the long rod-shaped bacteria (0.5 × 2.5 µm) gliding slowly without flagella
- Biochemical isolating bacterial colonies by API20E
- Isolation of the bacteria using *Cytophaga* agar medium prepared with seawater where the bacteria produces yellowish colonies
- Run standard tests such as Congo red dye, gliding motility, catalase, indole, oxidation-fermentation, hydrogen sulphide production and catalase tests

Symptoms

- Reddening of the fin that develops to white eroded areas on tips of fins and tail
- Damaged, split or ragged looking fins (fin rot) with fin edges turning black / brown
- Fins will have white dots in cases of *Ichthyophthirius multifilis* infection
- Cotton wool like tufts around the mouth.
- May cause loss of appetite and restlessness
- When chronic fish may develop ulcers on the body

Control and treatment

- Maintaining good water quality
- Gentle handling to avoid inflicting injuries
- Feeding fresh food in small portions
- Maintaining constant water temperature
- Treatment using non-iodized salt and antibiotics
- Use of Chloramine-T

3. Hemorrhagic septicaemia

- The disease is caused by a few different bacteria including *Aeromonas s*pp. and *Pseudomonas* spp. It is mainly spread from one fish to another and is triggered by poor water quality. It is common in tilapia and catfish.

Symptoms

- Open sores and ulcers,
- Reddening of fins and vent
- Loss of appetite
- Change in body colour

Diagnosis

- API-20E test strip
- Standard tests such as aesculin hydrolysis, lysine decarboxylation, acetoin production, and gas production from glucose
- PCR protocol with primers made from the 16S rRNA gene of E. coli for specific identification of *Aeromonas hydrophila*

Control and treatment

- Good hygiene
- Avoid overcrowding of cultured fish
- Avoid excessive handling
- Treating fish with antibiotics such as oxytetracycline HCL, amoxicillin, gentamicin, ofloxacin and sulfadimethoxine
- Isolating infected fish from healthy ones

4. Furunculosis

- It is caused by ***Aeromonas spp.*** and is common in salmonids e.g. rainbow trout

Symptoms

- Boil like lesions
- Excessive mucus on the body
- White patches on the skin
- Ulcerations
- Pop eye (exophthalmia)

Diagnosis

- Isolating the bacteria on Coomassie Brilliant Blue (CBB) agar (Trypticase soy agar (TSA) supplemented with Coomassie Brilliant Blue) and observe the characteristic blue colonies of *Aeromonas salmonicida.*
- Running standard test which include urease, gluconate, ornithine decarboxylase and dyhydrolase tests.
- Elisa test as described by Adams and Thomson (1990).
- PCR protocol of fish tissue e.g. (gill/skin lesion/fin) with primers targeting the 16S rRNA genes and plasmids

Control and Treatment

- Disinfection for superficial infections
- Disinfection of all equipment used
- Vaccination of fish against *Aeromonas salmoncida*
- Use only stocks certified free of Furunclosis
- Isolating infected fish from healthy ones
- Treating infected fish with antibiotics such as oxytetracyline, sulfadiazine, sulfamerazine or sulfadimethoxine and streptomycin sulfate

5. Bacterial gill disease

- This is caused by *Flavoacterium* and is secondary infection to gills which were previously irritated by high ammonia levels of solids in water. It is common in poor water quality conditions

Symptoms

- Destruction of the gill tissue
- Visible bacterial mass on the gills

Diagnosis

- Microscopic examination of wet mounts of gills reveals the bacteria in slow gliding movement
- Isolation of the bacteria in selective media such as cytophaga agar and Hsu-Shotts media produces pigmented yellow colonies with rhizoids or root like appearance
- Indirect fluorescent antibody and enzyme linked immunoassay (ELISA)
- PCR protocol with primers targeting the 16S rRNA gene of *Flavobacterium branchiophilum*

Control and treatment

- Good water quality and sanitation
- Avoid overcrowding
- Prompt isolating of dead or weak fish
- Use of non-iodized salt at 1kg/ 1000 liters
- Use of chloramines-T or Hyamine
- Treat with disinfectants e.g. potassium permanganate 00mg/l for 30 second
- Treat with oxollioic acid mixed with feed at 20mg/kg fish or acriflavin dip at 100ppm for 1 minute

6. Streptococcosis

- Streptococcosis is caused by *Streptococcus iniae* and *S. agalactiae*. It affects tilapia and other fish species in most countries and occurs in both freshwater and marine environments.

Symptoms

- Hemorrhagic eyes
- Corneal opacity in one or both eyes,
- Exophthalmia (protruding eyes),
- Red discoloration at the anus and base of fins,
- Swollen kidney, spleen, and liver.
- Meningoencephalitis
- Dark pigmentation
- Abdominal distention
- Erratic and spiral swimming,
- Curved body, indicating central nervous system impairment

Diagnosis

- API 20 strip test producing the expected profile 4563117
- PCR protocols with primers targeting 16S rRNA gene
- Restriction fragment length polymorphism (RFLP) with Eco III produces 5 restriction fragments of 5 to 14 bp and Hind III produce 7 restriction fragments
- Random Amplified Polymorphic DNA (RAPD) with 14bp primers produce 5 DNA fragments
- Nested PCR protocol with two sets of primers targeting amplification of the ITS rDNA region
- Multiplex PCR protocol that target the ICT O gene

Control and treatment

- Use of prophylactics like non-iodized salt or potassium permanganate, during or after handling,
- Systemic clinical bacterial infections are treated by antibiotics such as oxytetracycline Sulfadimethoxine and amoxicillin.
- Vaccinating fish at the right time. Vaccine not available for tilapia at the moment
- Disinfecting equipment
- Isolating infected fish from healthy ones
- Decrease feed and stocking densities
- Lower water temperatures
- Treat fish with antibiotics in the early stages of an outbreak

7.4.2. FUNGAL DISEASES OF FISH

Under normal conditions, fungal spores are commonly found in fish culture water without causing any disease to fish. Healthy fish have protective mucus covering which can prevent infection by fungal spores. Under poor aquatic environment, through bad water quality, rough handling, fighting or physical injury, the protective mucus is damaged leading to outbreak of fungal infections. Fungal infections are generally a secondary infection to other factors and pathogens as a result of poor aquatic environmental conditions. The fungi genera normally isolated from fish are *Saprolegnia, Achlya, Aphanomyces* and *Branchiomyces.*

1. **Saprolegniasis (Cotton wool disease)**

This is caused by the fungi called *'Saprolegnia'*which is normally present in water and only becomes problematic when there is high organic matter in the water, and on fish which are bruised or injured. It is common in both fresh and brackish water fishes. It also affects eggs during incubation.

Symptoms

- Grey white or brown cotton wool like growths on the skin, gills, fins or eggs.
- The fungi can spread and cover the whole body or all the eggs being incubated

Diagnosis

- Microscopic examination of wet mounts of mycelium from lesions to observe the large branching non-septate hyphae
- Isolation of the fungus and identification of sexual or asexual reproduction stages
- PCR protocol targeting the amplification of the ITS region between 18S and 5.8S Rrna genes of *Saprolegnia spp*

Control and treatment

- Maintain good water quality
- Quarantine new fish
- Avoid overfeeding and overcrowding of fish
- Disinfect equipment used to prevent cross-contamination
- Isolating infected fish from healthy ones
- Prophylactic treatment of eggs during hatching can control infection of eggs
- Limit stress and physical damage of fish during fishing,

handling and transportation

- Use of un-iodized salt and hydrogen peroxide
  - For ornamental fish (non-food) fish use of antifungal ointments can increase survival, if only one or a small number of fish are affected

2. Aphanomyces invadans

It is the primary agent associated with epizootics of ulcerative disease in cultured fish. It has been reported as mycotic granulomatosis (MG) in Japan, red spot disease (RSD) in Australia, epizootic ulcerative syndrome (EUS) in Asia, and ulcerative mycosis in the United States (Yanong, 2003). It affects brackish water and freshwater fish including gold fish ***(Carassius auratus)***, trout, tilapia and common carp. Outbreaks occur in lower temperature below 25°C and reduced salinity in brackish waters.

Symptoms

- Haemorrhage
- Ascites
- Scale loss
- Ulcerations
- Skin and muscle nekrosis

Diagnosis

- Microscopic examination of infected tissue to observe the non-septate hyphae of A. *invadans* (12-25 µm)
- Monoclonal antibodies detection of *A. invadans* hyphae
- PCR protocols targeting amplification of the internally transcribed spacer (ITS) between 18S and 5.8S rRNA genes of A. *invadans*

Control and treatment

- Improving water quality and prompt removal of infected fish
- Treatment with prophylactics such as sodium chloride and agricultural lime
- Routine disinfection of eggs and larvae
- Isolating infected fish from healthy ones
- Treatment can be done by hydrogen peroxide (100-500 ppm) ,
- Treatment by Sodium chloride (10-20 ppm)

3. Branchiomycosis

It is caused by *Branchiomyces* spp. It affects tilapia, common carp and catfish. Infections are usually confined to the gills, colonizing gill vessels and capillaries. Branchiomycosis occurs in eutrophic environments with lot of organic matter and temperature above 20°C.

Symptoms

- Infected areas become necrotic and brownish-grey (gill rot)
- Lesions and gill erosion
- Haemostasis and thromboses by the hyphae
- Proliferation of filaments and the presence of hyphae loaded with sporonts.

Diagnosis

- Macroscopic observation of the typical gill rot lesions
- Microscopic examination of wet mounts of infected gills to observe the non-septate branching oomycetes with spores within gill vasculature or other gill tissue
- Staining of infected gill samples using special stains for fungi (periodic acid schiffs (PAS) or silver stains) where the hyphae and spores stain red

Control and treatment

- Avoid excess decomposing organic matter in culture units during warm months
- Addition of quicklime (150-200kg/ha) at an interval of two weeks which is changed to daily application during an outbreak
- Disinfecting equipment
- Stop feeding fish during an outbreak
- Prompt removal of dead fish and burying them in lime pits
  - Draining, drying and disinfection of culture units with quicklime
  - Reduce stress factors (avoid low dissolve oxygen, high temperature, overcrowding)

There is no known treatment for the disease but some protocols may be beneficial with formalin baths, copper sulphate and benzalkonium chloride dips, and oral methylene blue**.**

7.5 QUARANTINE AND DISINFECTION OF FISH EGGS, FRY AND FINGERLINGS

7.5.1. QUARANTINE

Quarantine has been described as a management action conducted to prevent the introduction of disease-causing agents to an aquaculture facility (Phu et al., 2016). The procedure involves isolation of fish brought to a culture facility from the rest to be monitored for a period ranging from 15 to 90 days depending on how soon pathogens of concern can be detected (AZA, 2007, Arthur et al 2008, Jia et al., 2017). During quarantine, fish are observed for symptoms of infection such as loss of equilibrium, anorexia, lethargy, changes in skin colour, and changes in respiration rates as well as the presence of fin and skin erosions. During quarantine strict observation of the organisms is done and appropriate diagnostic tests done. Besides, proper documentation of all daily activities undertaken in the quarantine room which include feeding, water quality monitoring, inspection and prophylactics administration.

Diagnosis of any disease and culling of fish in question should be done correctly and treatment with efficacious agents administered within an appropriate period. Further, staff should be trained on the importance of controlling diseases and be guided through the development of standard operation procedures (SOP) reviewed regularly to reflect what is being done (Arthur 2008). Where appropriate prophylactics should be administered accordingly (Kent et al. 2009). It has been observed that prophylactic treatments can inhibit developing clinical signs and inappropriate use of antibiotics can lead to the development of antibacterial resistance (Adams and Thompson, 2006).

Most hatcheries in Kenya lack quarantine facilities and this could be attributed to poor fish disease reporting in the country partly due to lack of fish pathology expertise in fisheries research institutions and the absence of veterinarians with a good understanding of aquaculture practices and fish biology. Consequently, most hatchery investors have failed to realize the need for investing in elaborate biosecurity measures. Presence of quarantine facilities would be key to preventing introduction of pathogens from brooders that sourced from the wild from time to time and brought to hatcheries to expand the gene pool of existing broodstock (Opiyo et al. 2018).

Besides, increase of importations of broodstocks and non-indigenous species can lead to introductions of diseases and parasites (Njagi, 2016). Going forward, the sector needs not only quarantine facilities but a comprehensive biosecurity procedure with detailed guidelines on broodstock collection, transportation, acclamation, quarantine as well as a standardized fish hatchery and farm operational procedures including cleaning and disinfecting of hatchery products and live feed. In addition, a survey to characterize the fish diseases in wild and farmed fish would provide critical information for defining the scope and length of quarantine procedures in the country.

7.5.2. DISINFECTION

Disinfection involves the use of physical or chemical agents to remove micro-organisms on animate or inanimate objects (Assefa and Abunna, 2018). In aquaculture, disinfectants include compounds used to destroy micro-organisms living on the surface of fish eggs, hatchery culture facilities, and equipment used in handling juveniles and fish as part of biosecurity protocols to control spread of aquatic animal pathogens. Decomposing uneaten feed and unfertilized eggs in spawning units form a substrate for proliferation of aquatic bacteria and fungi which readily colonize viable spawned eggs affecting their hatching rates. On the other hand, fecal wastes released by brooders during spawning sessions provides an avenue for horizontal transmission of most fish viral pathogens from the brooders to hatched larvae once exogenous feeding begins (Rasowo et al., 2007).

In Kenya, most hatcheries use standardized preventive

> **“DURING QUARANTINE, FISH ARE OBSERVED FOR SYMPTOMS OF INFECTION SUCH AS LOSS OF EQUILIBRIUM, ANOREXIA, LETHARGY, CHANGES IN SKIN COLOUR, AND CHANGES IN RESPIRATION RATES AS WELL AS THE PRESENCE OF FIN AND SKIN EROSIONS.**

management measures to lower chances of disease occurrence whereby routine cleaning and disinfection of facilities is done. Small (2006) noted that prevention strategies such as disinfection of hatchery incoming water, spawned eggs and equipment form first line of defense against egg diseases, enhance optimal embryo development and survival of hatched larvae. Several disinfectants are available and the choice on which one to use depends on the size, type and nature of materials to be disinfected, and the legality of the product in the country in question (IOE 2009). The most common disinfectants used in aquaculture are ammonium compounds, formaldehyde, hydrogen peroxide, chlorine iodine and iodophors (Assefa and Abunna, 2018).

Most disinfectants are inactivated by organic matter except peroxygen compounds, phenolic compounds and reducing agents such as formaldehyde hence water used should be filtered and surfaces thoroughly cleaned before disinfection (Porter and Johnson 2010, Yanong and Erlacher 2012). A typical disinfection protocol for fish eggs and larvae entails pre-washing with purified water, disinfectant application, and thorough rinsing with purified water (Torgersen and Håstein, 1995). In Kenya, commonly used drugs and chemicals in aquaculture are sodium chloride, potassium permanganate and formaldehyde which are meant to eliminate bacterial and fungal infections and improve survival (Opiyo et al. 2018). Treatments in the hatchery are done at egg incubation stage and fry stages to increase survival of hatched fry and fingerling stages of development (Rasowo et al., 2007).

As the country is moving towards intensive production systems, intensive incubation of egg is inevitable which is associated with proliferation of opportunistic bacteria (Skjermo and Vadstein 1999). In light of this, development of standardized cleaning and disinfection protocols backed with proper records keeping would be key towards effective management and control of commercial important diseases that could potentially cripple the sector. In addition, elaborate guidelines on responsible application of prophylactics in the Kenyan aquaculture sector are key since currently the use of prophylactics are based on farmer's knowledge and experience (Magondu et al. 2011). The current guidelines document by the Ministry of Agriculture, Livestock, Fisheries and Irrigation (MALFI 2018) is not elaborate on the issue of anti-microbial compounds use in aquaculture

BIOSECURITY

7.6 BIOSECURITY MEASURES TO CONTROL FISH DISEASES AT THE FARM LEVEL

- Only introduce healthy fish to your farm free from parasites or diseases.
- Quarantine any new fish to the farm for at least four weeks and cold-water fish for eight weeks to ensure they are healthy before introducing them to other culture facilities.
- Wash your hands before and after maintenance of each fish culture facility and using separate equipment to prevent cross-contamination.
- Control movement of water, people and equipment to the farm.
- Empty infected culture facility, clean, disinfect and allow them to stay idle for 4 days.
- Disinfect ponds regularly to kill both the disease organisms and their intermediate hosts
- Prevent the entry of disease organisms by preventing the entry of wild fish by using screens
- Always use good quality feeds
- Prevent the spread of disease within the farm by controlling predators, particularly birds and mammals
- Sanitation by routine sterilization of nets, buckets, and other equipment reduces accidental cross contamination of culture units.
- Ensure quality and sufficient water supply, with adequate dissolved oxygen and free of pollution.
- Maintain clean pond environment by controlling silting, plants and proper phytoplankton and zooplankton balance. Regular pond disinfection is recommended.
- Keep the fish in stress free conditions by controlling stocking density, keeping different sizes separate to reduce fighting, providing proper food supply and handling the fish properly
- House only suitable species together, make sure they are compatible and not likely to bully or eat each other.
- Avoid water sharing among ponds
- In case of disease outbreak, remove sick and dead fish from the ponds immediately
- Bury diseased fish with quicklime away from the ponds
- Ponds with infections should be drained and badly infected fish culled.
- Dry the pond under the sun for about seven days.
- Dampen the pond bottom.
- Spread Lime (Calcium carbonate) evenly over entire surface of pond bottom at the rate of 1500 kg/Ha.
- Wait for 15 days then restock the pond with healthy stock.

7.7 INVESTMENTS TO IMPROVE AQUATIC ANIMAL HEALTH AND DISEASE PREVENTION

Aquatic animal health issues in Kenya have in recent times come to the fore due to rise in the focus in aquaculture as a supplement to wild fish capture fisheries. As a result, the risks of exotic, endemic, emerging and re-emerging diseases are real in our country. However, lack of capacity in various aspects is a hindrance to keeping aquatic animal diseases away. Capacity can be in form of inadequate skilled human capacity, inadequate equipped laboratories for disease diagnostics, lack of routine aquatic disease surveillance activities and lack of quarantine facilities.

Required investment interventions

(a) Investment in skilled personnel/ researchers

Until recently, there has been limited focus and documentation on fish health issues in Kenya with most focusing on parasitic infections. A review by Akoll and Mwanja (2012) found that there was very limited research on bacterial, fungal and viral diseases in the region, which still stands to date, though baby steps have been taken in that direction. This was attributed to the lack of diagnostic infrastructure, the high cost of diagnosing and identifying such pathogens and the absence of outbreak reports owing to poor record keeping. There is a need to invest in educating and training of fish health specialists to deal with both disease diagnostics, treatments and on the correct drugs for use in the industry.

(b) Investments in research on development of relevant biotherapeutants and chemotherapeutants

In Kenyan aquaculture, chemotherapeutants are widely applied in pond culture for the treatment of various diseases. In as much as various trials have been done in the laboratories on biotherapy, application of such on a wide scale (in the culture systems) is not practical in Kenya as yet. This therefore calls for more investment in the development of biotherapy for large scale application on the field. Further on, a look into some of the drugs applied for instance formalin (which is carcinogenic but applied for a variety of ectoparasite infections) points to the urgency in development of safer options for the farmer and the consumer.

(c) Investment in well-equipped laboratories

The need for well designated and equipped laboratories cannot be re-emphasized, coming against the rising investments in aquaculture. Presently, Kenya is yet to have specialized fish diagnostic laboratories recognized by the OIE. However, diagnoses of aquatic disease outbreaks are performed at local universities and public research institutes that research fisheries and aquaculture (Opiyo et al., 2018). Nevertheless, commendable steps have been taken to address AAH (Aquatic Animal Health) issues by Kenya Marine and Fisheries Research Institute through their investment in state-of-the-art equipment that would assist in aquatic animal disease research. This has been done in their various stations spread across the country.

Additionally, the State Department for Fisheries and the Blue Economy has three well-equipped laboratories in Nairobi, Kisumu and Mombasa, respectively which are not yet operational, since they must be commissioned first. However, a recent training to 6 African states (Kenya, Uganda, Nigeria, Ghana, Egypt, and Angola) by global fish health experts on Tilapia Lake Virus was undertaken at the Kisumu laboratory. In November and December 2019, a national TiLV surveillance team utilised the laboratory during their surveillance of the emerging viral disease.

(d) Investments in the institutional capacity governing aquatic animal health issues

Statutory and policy instruments need to be realigned considering aquaculture development, in which issues on aquatic animal health come in (Akoll and Mwanja, 2012). Issues of drug application in aquaculture need to be regulated to prevent problems of residues in the environment and consequent drug resistance (Defoirdt et al., 2011). Additionally, the lack of legislation on the prohibition of certain drugs leads to indiscriminate use with a negative impact in the long run.

(e) Investment in routine surveillance

Development and implementation of routine monitoring and surveillance for aquatic animal diseases are vital in the control and prevention of such diseases. This is because, through surveillance, it is possible to detect diseases way before they can result in massive losses (Matolla, G. 2019). There is a need to strengthen the biosecurity governance, knowledge and capacities in fish disease pathology, diagnostics, surveillance, emergency preparedness and provision of networking support to aquatic animal health management (Kenya national action plan-TiLV).

(f) Investment in quarantine facilities

Lately, the world is said to have become a global village, with a lot of trade taking place the world over. According to Opiyo et al. (2018), quarantine facilities are non-existent in Kenya, with minimal biosecurity being practiced on monitoring of new introductions. Translocation of brooders and fry from other countries into Kenya (for instance the exotic strains of Nile tilapia which are preferred over the indigenous one) poses a risk of introduction of Trans Aquatic animal Diseases (TAADs).

Exotic diseases can be introduced into our system resulting to proliferation of diseases and infections via live fish transport. Lack of quarantine facilities and the fact that the risk analysis processes are rarely conducted on trade in live aquatic animals, and the continuation of such practices may result to the rapid spread of disease pathogens within and between countries (Subasinghe et al. 2001, Bondad-Reantaso 2004, Akoll and Mwanja, 2012).

(g) Investments in improving the linkages between various stakeholders in the aquatic animal health issues nationally and beyond

Most research findings are not available to the fish farmers due to the weak linkages between them (Aloo et al., 2017). Investing in the betterment of linkages between various sectors working in the animal health aspects can go a long way in building capacities, creation of bodies/ cooperatives that can be useful in tackling aquatic animal health issues. Moreover, investing in trainings/ capacity building of local officers from others abroad who have more experience/ exposure to aquatic animal diseases can go a long way in awareness creation of how to handle issues on aquatic health.

7.8 WATER QUALITY REQUIREMENTS AND MANAGEMENT STRATEGIES FOR FISH FARMING

In aquaculture, any characteristic of water that affects the survival, reproduction, growth, production or management of fish or other aquatic creatures in any way is a water quality variable (Boyd, 2003). Fish performs all their life functions in water. Accordingly, the success or failure of any aquaculture system will likely depend on water quality (Alam and Al-Hafedh, 2006).

Good water quality in culture system will result into higher production and profits while poor water quality induces stress on fish, adversely affecting growth of fish and in extreme cases cause mortality and lower the profits of a fish farm (Iwama et al., 2000). Therefore, monitoring and regulating (if possible) water quality should be part of daily routine in a fish farm and farmers are encouraged to keep records of water quality.

Many water quality variables determine water quality in aquaculture and farmers need to monitor and keep records of regularly. These include Temperature, oxygen, carbon dioxide, pH, alkalinity, ammonia and suspended solids. Out of these, oxygen and ammonia are the most critical water quality parameters and farmers need to give close attention to the two variables by management techniques. Fish have tolerable limits of water quality parameters in which they perform optimally. For a fish farmer to monitor these water quality parameters, use of water quality analysis kits is recommended. The kits vary in complexity of operation from single water quality kits to multi-parameter ones. Due to the high cost of these meters, it's recommended that farmers form groups to procure compact, portable and field-based meters with ready to use reagents and data forms for monitoring the water quality parameters.

A sharp drop or an increase within these limits has adverse effects on their body functions and survival (Davenport, 1993: Kiran, 2010). Hence successful aquaculture management requires an understanding of water quality. Hence, this chapter attempts to provide some basic guidelines for the fish farmer on the water quality requirements and management for high fish yield and the sustainability of aquaculture.

> **"DURING QUARANTINE, FISH ARE OBSERVED FOR SYMPTOMS OF INFECTION SUCH AS LOSS OF EQUILIBRIUM, ANOREXIA, LETHARGY, CHANGES IN SKIN COLOUR, AND CHANGES IN RESPIRATION RATES AS WELL AS THE PRESENCE OF FIN AND SKIN EROSIONS.**

clearing drainage system to improve water flow for biosecurity

CONCLUSION

The success or failure of any fish farming operations will depend partly on water quality. The quantity and quality of natural food available in a pond determine the water quality and mass per unit area of fish that a pond can support. These may be improved by the application of fertilizers and /or supplementary feeding. For maximum benefits water quality parameters must be closely monitored and regularly monitored to prevent sudden mass fish mortalities. For ponds with high number of stocked fish, closer monitoring of water quality is essential.

REFERENCES

Adams, A., Thompson, K. D. 2006. "Biotechnology offers revolution to fish health management," Trends in Biotechnology, vol. 24, no. 5, pp. 201–205.

Akoll, P., Mwanja, W. 2012. Fish health status, research and management in East Africa: past and present. African Journal of Aquatic Science 37: 117–29. https://doi.org/10.2989/ 6085914.2012.694628

Alam, A., Al-Hafedh, Y.S. (2006). Diurnal dynamics of water quality parameters in an aquaculture system based on recirculating green water technology. Journal of Applied Science and Enviroment Management, 10,19–21.

Allnutt, F.C., Bowers, R.M., Rowe, C.G., Vakharia, V.N., LaPatra, S.E., Dhar, A.K., 2007. Antigenicity of infectious pancreatic necrosis virus VP2 subviral particles expressed in yeast. Vaccine 25, 4880–4888.

Arthur, J.R., Bondad-Reantaso, M.G., Subasinghe, R.P. 2008. Procedures for the quarantine of live aquatic animals: a manual. FAO Fisheries Technical Paper. No. 502. Rome, 74p.

Assefa, A., Abunna, F. 2018. Maintenance of Fish Health in Aquaculture: Review of epidemiological approaches for prevention and control of Infectious diseases of fish. Veterinary Medicine International, Vol 2018, Article ID 5432497, https://doi.org/10.1155/2018/5432497

AZA, 2007. Recommended Quarantine Procedures, IN: 2007 Guide to Accreditation of Zoological Parks and Aquariums pp 16-22, http://www.aza.org/Accreditation/Accred_Cert_Info/

Bader, J. A., Shoemaker, C. A., & Klesius, P. H. (2003). Rapid detection of columnaris disease in channel catfish (Ictalurus punctatus) with a new species-specific 16-S rRNA gene-based PCR primer for Flavobacterium columnare. Journal of Microbiological Methods, 52(2), 209-220.

Benbrook, C.M. (2002). Antibiotic Drug Use in Aquaculture, The Northwest Science and Environmental Policy Center, Sandpoint, Idaho, USA. 18pp

Bondad-Reantaso MG, Subasinghe RP, Arthur JR, Ogawa K, Chinabut S, Adlard R, Tan Z, Shariff M. 2005. Disease and health management in Asian aquaculture. Vet. Parasitol. 132:249–272pp.

Boyd, C.E. (2003). Guidelines for aquaculture effluent management at the farm-level. Aquaculture 226:101–112.

Davenport, Y. (1993). Responses of the Blennius pholis to fluctuating salinities. Marine Ecology Progress Series, 1, pp 101 – 107.

Dhar AK, Manna SK, Allnutt FCT. 2014. Viral vaccines for farmed finfish. Virus Dis. 25(1): 1–17pp. https://doi.org/10.1007/s13337-013-0186-4
Dhar AK, Manna SK, Allnutt FCT. 2014. Viral vaccines for farmed finfish. Virus Dis. 25(1): 1–17pp. https://doi.org/10.1007/s13337-013-0186-4
Emmenegger, E.J., Kurath, G., 2008. DNA vaccine protects ornamental koi (Cyprinus carpio) against North American spring viremia of carp virus. Vaccine 26, 6415–6421.

Enzmann, P.J., Fichtner, D., Schutze, H., Walliser, G., 1998. Development of vaccines against VHS and IHN: oral application, molecular marker and discrimination of vaccinated fish from infected populations. J. Appl. Ichthyol-Zeitschrift fur Angewandte Ichthyologie 14, 179–183.

FAO, 2016. The State of World Fisheries and Aquaculture, Contributing to food security and nutrition for all, Food and Agriculture Organization of the United Nations, Rome, Italy.

Francis-Floyd, R., Watson, C., Petty, D., Pouder, D.B. (2009). Ammonia in aquatic systems. UF/IFAS University of Florida (UF)/ Institute of Food and Agricultural Sciences (IFAS), FA 16, p 5.

Gomez-Casado, E., Estepa, A., Coll, J.M., 2011. A comparative review on European-farmed finfish RNA viruses and their vaccines. Vaccine 29, 2657–2671.

Hecht, T. and Endemann, F. 1998. The impact of parasites, infections and diseases on the development of aquaculture in sub-Saharan Africa. J. Appl. Ichthyol. 14: 213-221pp.

Iwama, G.K., Vijayan, M.M., Morgan, J.D. (2000). The stress response in fish. Ichthyology, recent research advances. Oxford and IBH Publishing Co, Pvt. Ltd, New Delhi

Jansen, DM., Dong, TH. And Mohan, VC. 2018. Tilapia Lake Virus: a threat to the global tilapia industry? Reviews in Aquaculture. 1-15pp.

Jia, B., St-Hilaire, S., Singh, K., Gardner, I. A. 2017. "Biosecurity knowledge, attitudes and practices of farmers culturing yellow catfish (Pelteobagrus fulvidraco) in Guangdong and Zhejiang provinces, China," Aquaculture, vol. 471, pp. 146–156.

Kent, M. L., Feist, S. W., Harper, C., Hoogstraten-Miller, S., Mac Law, J., Sanchez-Morgado, J. M and Whipps, C. M. 2009. Recommendations for control of pathogens and infectious diseases in fish research facilities. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 149(2), 240-248.

Kibenge FS, Godoy MG, Fast M, Workenhe S, Kibenge MJ. 2012. Countermeasures against viral diseases of farmed fish. Antivir Res. 95:257–81pp. Hanson, L., Dishon, A. and Kotler, M. 2011. Viruses (3) 2160-2191pp.; doi:10.3390/v3112160

Kiran, B. R., (2010). Physico-chemical characteristics of fish ponds of Bhadra project at Karnataka, RASĀYAN. Journal of Chemistry, 3(4), 671-676.

Lin, C.S., Lu, M.W., Tang, L., Liu, W.T., Chao, C.B., Lin, C.J., et al., 2001. Characterization of virus-like particles assembled in a recombinant baculovirus system expressing the capsid protein of a fish nodavirus. Virology 290, 50–58.

Mabrok, M., Chokmangmeepisarn, P., LaFrentz, B. R., Kayansamruaj, P., Dong, H. T., & Rodkhum, C. (2019). Development of a species-specific polymerase chain reaction for highly sensitive detection of Flavobacterium columnare targeting chondroitin AC lyase gene. Aquaculture, 734597.

Magondu, E.W., Rasowo, J., Oyoo-Okoth,E., Charo-Karisa, H., 2011. Evaluation of sodium chloride (NaCl) for potential prophylactic treatment and its short-term toxicity to African catfish Clarias gariepinus (Burchell, 1822) yolk-sac and swim-up fry. Aquaculture 319:307–10. https://doi.org/10.1016/j.aquaculture.06. 038.

McLoughlin MF, Graham DA. 2007. Alphavirus infections in salmonids—a review. J Fish Dis. 30:511–31pp.

Ministry of Agriculture, Livestock, Fisheries and Irrigation (MALFI). 2018. Guidelines for the prudent use of antimicrobials in animals, Ministry of Agriculture, Livestock, Fisheries and Irrigation, Directorate of veterinary services, Nairobi.

Munang'andu, H.M., Mutoloki, S., Evensen, O., 2014a. Acquired immunity and vaccination against infectious pancreatic necrosis virus of salmon. Dev. Comp. Immunology. 43, 184–196.

Munang'andu, H.M., Mutoloki, S., Evensen, O., 2014b. Non-replicating vaccines. Gudding, R. Evensen, O. Lillehaug, A. (Eds.). In: Fish Vaccination, vol. 2. Wiley-Blackwell, London, pp. 22–32.

Njagi, I. 2016. Overcoming Challenges to Export in Kenyan. Aquaculture. https://thefishsite.com/articles/overcoming-challenges-to-export-in-kenyan-aquaculture

Opiyo, M.A., Marijani, E., Muendo, P., Odede, R., Leschen,W., Karisa, H.C., 2018. A review of aquaculture production and health management practices of farmed fish in Kenya. International Journal of Veterinary Science and Medicine 6:141-148

Panyawachira, V., Lilley, J. H., Hart, D., & Kanchanakhan, S. (1999, November). A PCR-based technique for the identification of Aphanomyces invadans. In Fourth Symposium on Diseases in Asian Aquaculture, Cebu City, Phillipines (pp. 22-26).

Paperna, I., 1996: Parasites, infections and diseases of fishes in Africa ~ an update, FAo CIFA Technical Paper. 31: 220pp.

Perera, R. P., Johnson, S. K., Collins, M. D., & Lewis, D. H. (1994). Streptococcus iniae associated with mortality of Tilapia nilotica × T. aurea hybrids. Journal of Aquatic Animal Health, 6(4), 335-340.

Phu, T. M., Phuong, N. T., Dung, T. T. et al. 2016 "An evaluation of fish health-management practices and occupational health hazards associated with Pangasius catfish (Pangasianodon hypophthalmus) aquaculture in the Mekong Delta, Vietnam," Aquaculture Research, vol. 47, no. 9, pp. 2778–2794

Pilarski, F., Rossini, A. J., & Ceccarelli, P. S. (2008). Isolation and characterization of Flavobacterium columnare (Bernardet et al. 2002) from four tropical fish species in Brazil. Brazilian Journal of Biology, 68(2), 409-414.

Rahman, M. M., Ferdowsy, H., Kashem, M. A., & Foysal, M. J. (2010). Tail and fin rot disease of Indian major carp and climbing perch in Bangladesh. Journal of Biological Sciences, 10(8), 800-804.

Rasowo, J., Okoth, O.E., Ngugi, C.C. 2007. Effects of formaldehyde, sodium chloride, potassium permanganate and hydrogen peroxide on hatch rate of African catfish Clarias gariepinus eggs. Aquaculture 269: 271–7. https://doi.org/10.1016/j.aquaculture.

Rico, A., Satapornvani. K. T., Haque, M. M. et al. 2012 "Use of chemicals and biological products in Asian aquaculture and their potential environmental risks: A critical review," Reviews in Aquaculture, vol. 4, no. 2, pp. 75–93.

Rodgers CJ, Mohan CV, Peeler EJ. 2011. The spread of pathogens through trade in aquatic animals and their products. Rev Sci Tech. (30):241–56.

Roque, A., Soto-Rodríguez, S. A., & Gomez-Gil, B. (2009). Bacterial fish diseases and molecular tools for bacterial fish pathogens detection. Aquaculture Microbiology and Biotechnology, 1, 73-99.

Shivappa, R.B., McAllister, P.E., Edwards, G.H., Santi, N., Evensen, O., Vakharia, V.N., 2005. Development of a subunit vaccine for infectious pancreatic necrosis virus using a baculovirus insect/larvae system. Dev. Biol. (Basel) 121, 165–174.

Skjermo, J., Vadstein, O. 1999. Techniques for microbial control in the intensive rearing of marine larvae. Aquaculture, 177, 333– 343.

Small, B., C. 2006. Managing Hatch Rate and Diseases in Catfish Eggs. SRAC Publication No. 1804

Speare, D. J., Markham, R. J. F., Despres, B., Whitman, K., & MacNair, N. (1995). Examination of gills from salmonids with bacterial gill disease using monoclonal antibody probes for Flavobacterium branchiophilum and Cytophaga columnaris. Journal of Veterinary Diagnostic Investigation, 7(4), 500-505.

Swingle,R.V.(1969) Relationship of pH of pond water to their suitability for fish culture.Proc.Pacific Sci.Congres 9 (1957) 10:72-75

Tang, L., Lin, C.S., Krishna, N.K., Yeager, M., Schneemann, A., Johnson, J.E., 2002. Virus-like particles of a fish nodavirus display a capsid subunit domain organization different from that of insect nodaviruses. J. Virol. 76, 6370–6375.

Torgersen, Y., Håstein, T. 1995. Disinfection in aquaculture. Revue scientifique et technique (International Office of Epizootics), 14(2), 419-434.

Vandersea, M. W., Litaker, R. W., Yonnish, B., Sosa, E., Landsberg, J. H., Pullinger, C., ... & Noga, E. J. (2006). Molecular assays for detecting Aphanomyces invadans in ulcerative mycotic fish lesions. Appl. Environ. Microbiol., 72(2), 1551-1557.

Watanabe, K., Nishizawa, T., Yoshimizu, M., 2000. Selection of brood stock candidates of barfin flounder using an ELISA system with recombinant protein of barfin flounder nervous necrosis virus. Dis. Aquatic. Org. 41, 219–223.

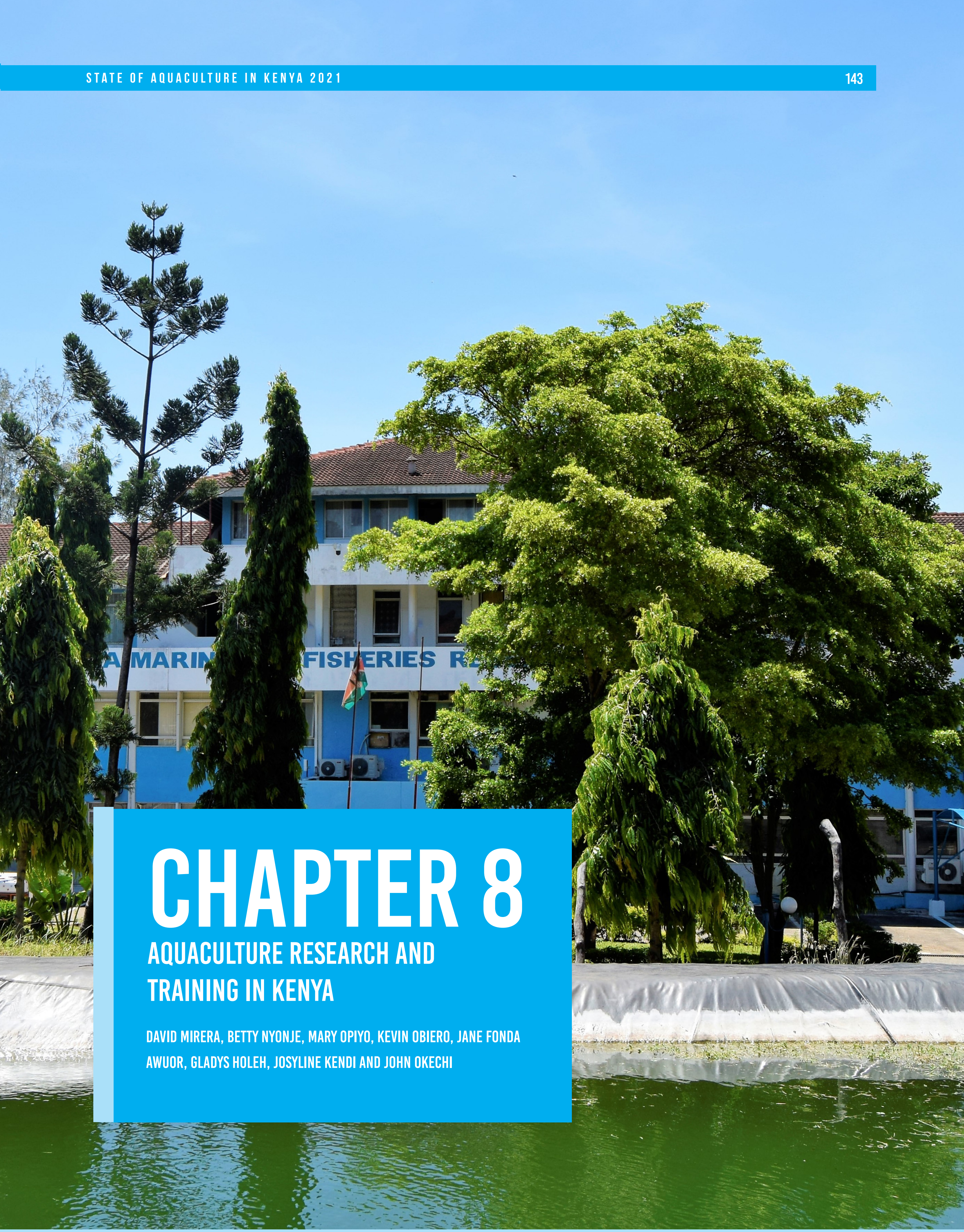
Woo, PTK and Bruno, DW, eds, (1999). Fish diseases and disorders, Volume 3: Viral, bacterial and fungal infections. Wallingford, UK: CAB International. https://www.cabi.org/isc/datasheet/94998

World Organization for Animal Health (OIE). 2009. Methods for disinfection of aquaculture establishments. In Manual of diagnostic tests for aquatic animals.

World Population Prospects 2015. The 2015 Revision, Key Findings, and Advance Tables. United Nations Department of Economic and Social Affairs, 2015.

Yanong, R. P. (2003). Fungal diseases of fish. Veterinary Clinics: Exotic Animal Practice, 6(2), 377-400.

Yanong, R.P.E., Erlacher-Reid, C. 2012. Biosecurity in Aquaculture part I: An Overview, SRAC Publication No. 4707



CHAPTER 8
AQUACULTURE RESEARCH AND TRAINING IN KENYA

DAVID MIRERA, BETTY NYONJE, MARY OPIYO, KEVIN OBIERO, JANE FONDA AWUOR, GLADYS HOLEH, JOSYLINE KENDI AND JOHN OKECHI

Key Messages	Policy Recommendations
• Kenya has made progress in recent years with enrolment numbers for primary education • Despite recent efforts and initiatives in this regard, TVET and labour-market-adapted university education still leave major room for improvement to appropriately equip Kenya's youth. Little or misdirected preparedness for the labour market is one of the major complaints from employers • The development of skilled manpower and its organization to effectively disseminate aquaculture information to farmers is one of the most important components of aquaculture development. • Aquaculture training has attracted investments by the national government in Kenya, with a considerable provision in higher education and vocational training at different institutions. • The technologies existing for adoption in Kenya include Recirculatory aquaculture system for both hatcheries and grow-out farms, Sex reversal technology for seed production, YY technology for all-male tilapia productions, use of raised ponds for intensive production of African catfish and cages for grow-out production of Nile tilapia in dams and lake	• Aquaculture Training in Kenya for farmers can be promoted through: • Agricultural shows by the Agricultural Society of Kenya shows, various farmers get to interact with other prospective consumers from the community as well as fellow farmers. Such interactions create awareness of the existing aquaculture technologies and markets. • Local market days: Institutions that deal with aquaculture products such as the fish value-added products sensitize people in the local markets especially on the market days by availing the products in the market at a cheaper price. • Responding to community needs: Most farmers venturing in aquaculture expects immediate outcomes from it. The scientist in research institutes has always devised new ways of meeting the community needs. For instance, KMFRI has been able to provide F7 broodstock generation through selective breeding where it has distributed fingerlings of F7 generation to many farmers. The general characteristics of this generation are better improved than the previous generations thus increased fish yields and lower feed ratio. • Social networking and ICTs: Social media networks such as TV stations, radio stations and magazine have imparted the community with so much information on aquaculture. • Farmers field schools: In FFS meetings the farmers are sensitized on various farming activities including aquaculture and how they can do integrated farming

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8.0. INTRODUCTION

Education is considered a key element for better employment opportunities. Kenya has made progress in recent years with enrolment numbers for primary education. In contrast, however, with only 3.3% of women and 4.7% of men enrolled in tertiary education, Kenya is falling behind many other African nations and the education provided/ obtained often lacks the necessary skillsets the job market requires. Despite recent efforts and initiatives in this regard, TVET and labour-market-adapted university education still leave major room for improvement to appropriately equip Kenya's youth. Little or misdirected preparedness for the labour market is one of the major complaints from employers. Whereas career success of individuals in relation with the organization has been investigated in previous studies in other sectors, the relationship between students' satisfaction with their training and career satisfaction in the aquaculture industry has not been examined. Therefore, this study investigated the impact of aquaculture alumni's satisfaction with academic training on their job satisfaction and performance in the job market in Kenya

Fish farming was popularized through the "Eat more fish" campaign in the 1960s. However, the number of productive ponds declined in the 1970s, mainly because of inadequate extension services and insufficient training for extension workers (FAO, 1996; Mwamuye et al., 2012). Since then the government has taken significant strides to minimize the anomaly. Nationally, the National aquaculture strategy and development plan 2010-2015 underscores the significance of research innovations, training and provision of extension services for improved aquaculture development. Similarly, the oceans and fisheries policy of 2008 categorically isolates the weak linkages between research, extension and management in the aquaculture sector.

8.1 AQUACULTURE TRAINING AND EDUCATIONAL INSTITUTIONS

The development of skilled manpower and its organization to effectively disseminate aquaculture information to farmers is one of the most important components of aquaculture development. Aquaculture training in Kenya is done at different levels since different categories have different training capacity requirements i.e. Senior and middle-level staff could require specialized post-graduate training of a practical nature, students may need graduate training with practical fieldwork while farmers may require certificate level training with more practical skills. Thus, different approaches in the training institutions are required to cater for increased demand in skills development.

Aquaculture training has attracted investments by the national government in Kenya, with a considerable provision in higher education and vocational training at different institutions. The institutions are aimed at addressing the rapidly increasing demand for skilled human resource need for the aquaculture sector. However, these institutions are also impacted by limited practical capacity in different production systems that have not been established by farmers in the country. Currently, there are many universities and middle-level learning institutions offering fisheries and aquaculture at Certificate, Diploma and Degrees to meet the needs of the industry (Table 8.1) currently there are 14 universities offering degrees in aquaculture related courses in the country.

> AQUACULTURE TRAINING IN KENYA IS DONE AT DIFFERENT LEVELS SINCE DIFFERENT CATEGORIES HAVE DIFFERENT TRAINING CAPACITY REQUIREMENTS

Table 8.1. Aquaculture Training and Educational Institutions in Kenya

No.	Name	Status	Training level	Website
UNIVERSITIES				
1	The University of Nairobi	University	BSc, MSc, PhD	https://www.uonbi.ac.ke/
2	University of Eldoret	University	BSc, MSc, PhD	https://www.uoeld.ac.ke/
3	Technical University of Mombasa	University	BSc, MSc, PhD	https://www.tum.ac.ke/
4	Karatina University	University	BSc, MSc, PhD	https://www.karu.ac.ke
5	Maseno University	University	BSc, MSc, PhD	https://www.maseno.ac.ke
6	Kisii University	University	BSc, MSc, PhD	https://www.kisiiuniversity.ac.ke/
7	Kenyatta University	University	Diploma, MSc, PhD	https://www.ku.ac.ke
8	Egerton University	University	BSc, MSc, PhD	http://www.egerton.ac.ke/
9	Pwani University	University	BSc, MSc, PhD	www.pu.ac.ke
10	Masinde Muliro University of Science and Technology	University	BSc, MSc, PhD	https://www.mmust.ac.ke
11	Jaramogi Oginga Odinga University of Science and Technology	University	BSc, MSc, PhD	https://www.jooust.ac.ke/
12	Jomo Kenyatta University of Agriculture and Technology	University	BSc, MSc, PhD	https://www.jkuat.ac.ke/
13	Masinde Muliro University of Science and Technology	University	BSc, MSc, PhD	https://www.mmust.ac.ke/
14	South Eastern Kenya University	University	BSc, MSc, PhD	www.seku.ac.ke/
TVET INSTITUTIONS				
1	Kenya Wildlife Service Training Institute (KWSTI)	Middle-level college	Certificate, Diploma	http://www.kws.go.ke/content/kenya-wildlife-service-training-institute
2	Ramogi Institute of Advanced Technology	Middle-level college	Craft, Certificate, Diploma	www.ramogiinstitute.ac.ke
3	National Aquaculture Research Development and Training Center (NARDTC), Sagana;	Middle-level college	Tailor-made courses of fish farmers and extension services Student attachment, Diploma Degree, Masters and PhD.	http://www.nardtc.org/

8.2 AQUACULTURE RESEARCH AND TECHNOLOGICAL INNOVATIONS

Over the years, the production from aquaculture has been hampered by a lack of appropriate technologies including on fish breeding and genetics, fish feeds and nutrition, fish health management and biosecurity, as well as post-harvest management, marketing and value addition. Thus there is limited diversity on the species farmed in fresh and marine waters in Kenya. Currently, they are limited to tilapia, catfish, trout, common carp, prawns, crabs, milkfish, Artemia and seaweeds. However, there is enormous potential for inclusion of other species and expansion of farms in addition to diversification of the culture systems like the introduction of cages and utilization of the expansive Indian Ocean for Mariculture (KMFRI, 2017).

The rapids growth of aquaculture in Kenya growth is attributed to the adoption of new technologies and systematic improvement of existing technologies that play a key role in making aquaculture production more efficient, economical, and environmentally sustainable.

The technologies existing for adoption in Kenya are both in the areas of seed production and grow out management and include Recirculatory aquaculture system for both hatcheries and grow-out farms, Sex reversal technology for seed production, YY technology for all-male tilapia productions, use of raised ponds for intensive production of African catfish and cages for grow-out production of Nile tilapia in dams and lakes. In mariculture use of cages have been adopted for crab farming in the sheltered areas.

1. RECIRCULATORY AQUACULTURE SYSTEMS

Recirculatory aquaculture systems are mainly used in hatcheries for the hatching of tilapia eggs in MacDonald's hatching jars and intensive catfish fingerling production. The hatcheries include; Makindi fish farm, Jewlett enterprises, Jafi fish farm, Kamuthanga fish farm, Emmick fish farm, Kutus fish farm, East Africa fish company, KMFRI Sagana and Samaki Tu fish farm. The adoption of technology is still very low in the country due to the high capital requirement. The cost of installation requires a capital of not less than Ksh 500,000 for 4 units of tanks with the cost of the greenhouse approximately Ksh 300,000. The running cost of the recirculating systems in Kenya is expensive and is a challenge to the farmers who have to pay high electricity bills.

RAS Incubation units with MacDonalds hatching jars at Jewlet Enterprises (Photo by Mary Opiyo)

2. SEX REVERSAL TECHNOLOGY

There has been a rise in demand for all-male tilapia fingerlings for grow-out farmers. Experiences from other countries indicate the need to test and optimize all-male tilapia production technologies to ensure higher successes in sex reversal (FAO, 2013). Hormonal sex reversal of tilapia is a very effective method for producing 95-98% male population in tilapia. Young tilapia readily consumes artificial, hormone-treated feeds. 9-11mm fry is often trained to feed within 3-4 days of hatching even where natural food is available. Fry held at high densities in small nursery ponds, hapa nets or tanks and fed on androgen treated feeds for 28-30days and are successfully sex-reversed. Large quantities of fry of the required age/size are usually produced in hapa nets, tanks or open ponds for sex reversal. Depending on water temperatures, brood-stock ponds are drained and completely harvested every 14-18 days after stocking brooders. The fry is graded through a 3.2 mm (1/8 inch) mesh size grader to allow only fry less than 13mm to pass through. More than 50 %of hatcheries in Kenya are practising sex reversal. The success rates are different due to experience and inadequate knowledge of how it is done. More than 40 hatchery managers have been trained on sex reversal but the monitoring and assessment are being carried out to ensure the farmers practice good aquaculture practices to ensure proper handling of the hormones and higher success rates in the process.

Breeding hapas in ponds at Jewlet Enterprises (Photo by Mary Opiyo)

3. SUPER YY TECHNOLOGY

This is a technology whereby YY-males are mated with functional females (XY), their progenies (approximately 50% of them are genetically YY-males) are changed to functional females by diethylstilbestrol enriched feed (male-to-female fish). To produce YY males, diethylstilbestrol at a rate of 500 mg/kg of feed is orally administered for 40 days to first feeding progenies of mitotic gynogenetic males (YY), known to produce only all-male offspring and normal females (XX). By mating YY-males with YY-females YY-male offspring are produced in large quantities. The all-male groups are 14.1% larger when compared with the whole mixed-sex groups. The progeny of YY male with a normal XX female is essentially all XY fry or genetically male tilapia.

The advantage of using YY male technology over hormonal manipulation is that the genetically male (XY) progeny produced contain no traces of hormone at spawning and remain so when reared to the table size. The YY male was introduced in Kenya in 2013 by Jambo fish limited. The brooders have been acquired by some hatcheries including, Kamuthanga Fish farm in Machakos County, Green Algae highland farm in Kirinyaga County and Makindi fish farm in Muranga County. Research on the feasibility of using YY male tilapia in tilapia fingerling production in Kenya has not been conducted and the production of the YY males is only being done at TilAqua in the Netherlands where broodstock are imported to. However due to the outbreak of Tilapia lake virus in 2017. The importation of live fish has been banned to avoid the spread of the disease.

4. AQUAPONIC TECHNOLOGY

Aquaponics is the integration of hydroponics (production of plants without soil) with aquaculture It can reduce nutrient discharges from aquaculture and improve income from the production of both fish and crops (Gichana **ET AL.,** 2019). In aquaponic systems, the nutrient-rich aquaculture wastewater provides nutrients for plants grown in the hydroponic subsystem. Nutrient removal through plant and bacteria assimilation as well as microbial transformation processes reduce the dissolved nutrient concentrations which in turn improves overall water quality parameters for fish production. This symbiotic relationship between fish, microbes and plants conserves water compared to conventional aquaculture systems where water is exchanged.

Fish from aquaponic systems are grown in an environmentally sound manner without using antibiotics and the crops are free of pesticides and chemical residues since no fertilizer or pesticides are used. Aquaponic systems can be found at Gilaqua Fish farm in Nakuru County and other farms in Kiambu and Kikaboni Commercial Aquaponics Farm in Kajiado counties. A demonstration site has been set up at NARDTC Sagana.

8.3 EXTENSION SERVICES AND COMMUNITY OUTREACH PROGRAMS

Efficient extension services are required to support farmers in practice and the new entrants into the sector for effectively promoting sustainable and equitable development of aquaculture that will contribute to overall improved livelihoods and socio-economic life. Extension describes all organized communication efforts by which an agency or individual tries to bring about changes in the knowledge, attitudes, skills and behaviour of a client population, to reach one or more objectives that have been established within the framework of overall development policy (Jungeling, 1993). In precise terms, an extension is an organized, collective effort; it works with, and for, a client population; and it serves a development policy.

Kenya Marine and Fisheries Research Institute (KMFRI), is the main research institute that formulates and implements fisheries/aquaculture national research plans and programmes. The institute implements its programmes through its research stations and sub-stations strategically spread across the country.

Some of the entrants' farmers into the aquaculture sector have no pre-aquaculture knowledge and training. Occasionally training is organized for them at the KMFRI Centers or stations or on-farm training. Farmers training is also provided at several places established through development collaborators.

As a way of improving aquaculture production and assisting aquaculture farmers, KMFRI offers extension services through various methods.

INDIVIDUAL METHODS

i. **Service to office visits/callers**: Aquaculture researchers and technical staff at the research centres/stations offer technical advice to those individuals who personally visit/call at the offices.

ii. **Farm visits:** Aquaculture researchers and technical staff, on a farmer's specific request, or on routinely sampling, visit the farm for any specific investigations and advice.

iii. **Email/mail service:** Farmers may receive advice on email/mail service. This is proving useful especially to the youthful farmers who make use of information technology (IT) tools and internet to access information on fish farming. Farmers, also using apps like WhatsApp share time situations/ or cases of issues in their farms with aquaculture researchers who advise them appropriately.

GROUP METHODS

Workshops and Training: Workshops and training are regularly organized for target fish farmers at KMFRI Centers and the Department of Fisheries Offices (DoF) at the County or sub-county level as per need and request.

Fig. YY. FAO fish disease trainers, participants from African Fisheries Institutions and Dunga cage fish farmers on board KMFRI MV Uvumbuzi learning on how to identify fish diseases at Dunga cage site on 7th December 2018. Photo credit: Owned by John Okechi.

DEMONSTRATIONS, TRAINING AND VISITS:

Demonstrations of innovative or improved culture or hatchery techniques are provided either at KMFRI research centers and stations or in a suitably located private or Government-owned farm. In either case the demonstrations are open to any interested persons. In the case of private farms, KMFRI researchers and technical staff provide the farm owner with repeated training and advice. The fish farm owner is expected to extend the new knowledge and techniques to fellow farmers who, in turn, are expected to disseminate the knowledge to more farmers. The expectation is, the new information trickles down to a large number of farmers in a short time.

MASS MEDIA

Mass media (Newspapers, television, radio, posters, *barazas,* etc.) are used to disseminate basic information and simple technologies on aquaculture.

PRINT PUBLICATIONS

Brochures, booklets, bulletins, pamphlets, manuals, hand-outs, and other forms are prepared by aquaculture division at KMFRI and distributed to the farmers.

EXTENSION SERVICES SOUGHT MOST

Diverse services are sought by fish farmers and include: Hatchery operations and induced breeding of fish, nursery rearing of hatchlings and fingerlings of Nile tilapia and African catfish, rearing of grow-out fish in ponds and cages. Others seeks services on brood and nursery ponds management, on farm feed formulation and use, fish diseases, and best aquaculture practices for better fish growth and yields.

Research and extension linkage

The direct approach of extension services is used by KMFRI because there is a gap in the extension system. It is expected that the Department of Fisheries (DoF) field level officers closely monitor field problems that deter the smooth adoption of new technologies and challenges at the farmers' level, but this is not effectively done. However, the staff are busy most of the time with multifarious work and *ad hoc* duties assigned by their senior officers. At times they lack the resources to get to the field. As a result, farmers' problems (technical, financial or administrative) remain unheard and resolved. The extension workers have not been that effective on land (ponds), and it will be more challenging with cage farms in the lake.

Another problem facing the aquaculture/fisheries extension service in many countries is that their workers also have to carry out monitoring and enforcement activities (Brumment et al., 2008; Jamu, et al., 2002)). These duties often have a negative impact on extension activities. For example, in Benin, Gabon and Central African Republic extension workers are game or forest wardens; in Ghana, Kenya, Nigeria and Zambia they enforce fisheries regulations. Through extension work, the researchers engage directly with the producers and get to know firsthand the problems they face in their farms. The researchers then attempt to find solutions to such problems. Continuous feedback between the producers and the researchers is fostered and maintained.

Community outreach

Over the past years, the extension services of public agriculture and fisheries were coordinated centrally. However, after the implementation of the 2010 constitution, the agricultural and fisheries sector was devolved. Various counties usually take the initiative of sending their extension officers for training in aquaculture centres like National Aquaculture Research Development and Training Centre, Sagana. These extension officers thereafter train the farmers in the community on various issues concerning fish. As a consequence, the number of personnel offering extension services became low hence limited facilitation to the community at the grassroots. Therefore, to fill the existing gap of the extension services, community outreach is being carried out by the NGOs and non-profit making organizations to enlighten the community on fish farming and other aquaculture activities *(IGCP, 2018).*

> **"GABON AND CENTRAL AFRICAN REPUBLIC EXTENSION WORKERS ARE GAME OR FOREST WARDENS; IN GHANA, KENYA, NIGERIA AND ZAMBIA THEY ENFORCE FISHERIES REGULATIONS.**

Participating in the community is very crucial in bringing a positive impact in the community(Kinyanjui, J. N. & Onyango, 2018). The aquaculture sector in Kenya works based on "to be heard one must first be seen". In conjunction with this basis, there are several community outreach activities that promote the sector which includes:

Fish eating campaigns

Fish-eating campaigns which have been conducted over several regions in Kenya such as Mombasa, Kirinyaga, and Tharaka Nithi counties promote the aquaculture sector.

Aquaculture Business Development Programme

This is a Programme initiated by Kenyan government through the State Department of Fisheries, Aquaculture, and Blue Economy to sensitize people, especially poor rural households, on aquaculture activities and how they can increase food security, income and nutritional status.

Agricultural shows

Through the agricultural society of Kenya shows, various farmers get to interact with other prospective consumers from the community as well as fellow farmers. Such interactions create awareness of the existing aquaculture technologies and markets.

Local market days

Institutions that deal with aquaculture products such as the fish value-added products sensitize people in the local markets especially on the market days by availing the products in the market at a cheaper price.

Responding to community needs

Most farmers venturing in aquaculture expects immediate outcomes from it. The scientist in research institutes has always devised new ways of meeting the community needs. For instance, KMFRI has been able to provide F7 broodstock generation through selective breeding where it has distributed fingerlings of F7 generation to many farmers. The general characteristics of this generation are better improved than the previous generations thus increased fish yields and lower feed ratio.

Social networking and ICTs

Social media networks such as TV stations, radio stations and magazine have imparted the community with so much information on aquaculture. Some of the programs like smart farm program in Citizen Tv and fish farming in Kenya program in KTN news. Through these programs and many more in Kenya, the farmers interested in fish farming get enlightened.

Farmers field schools

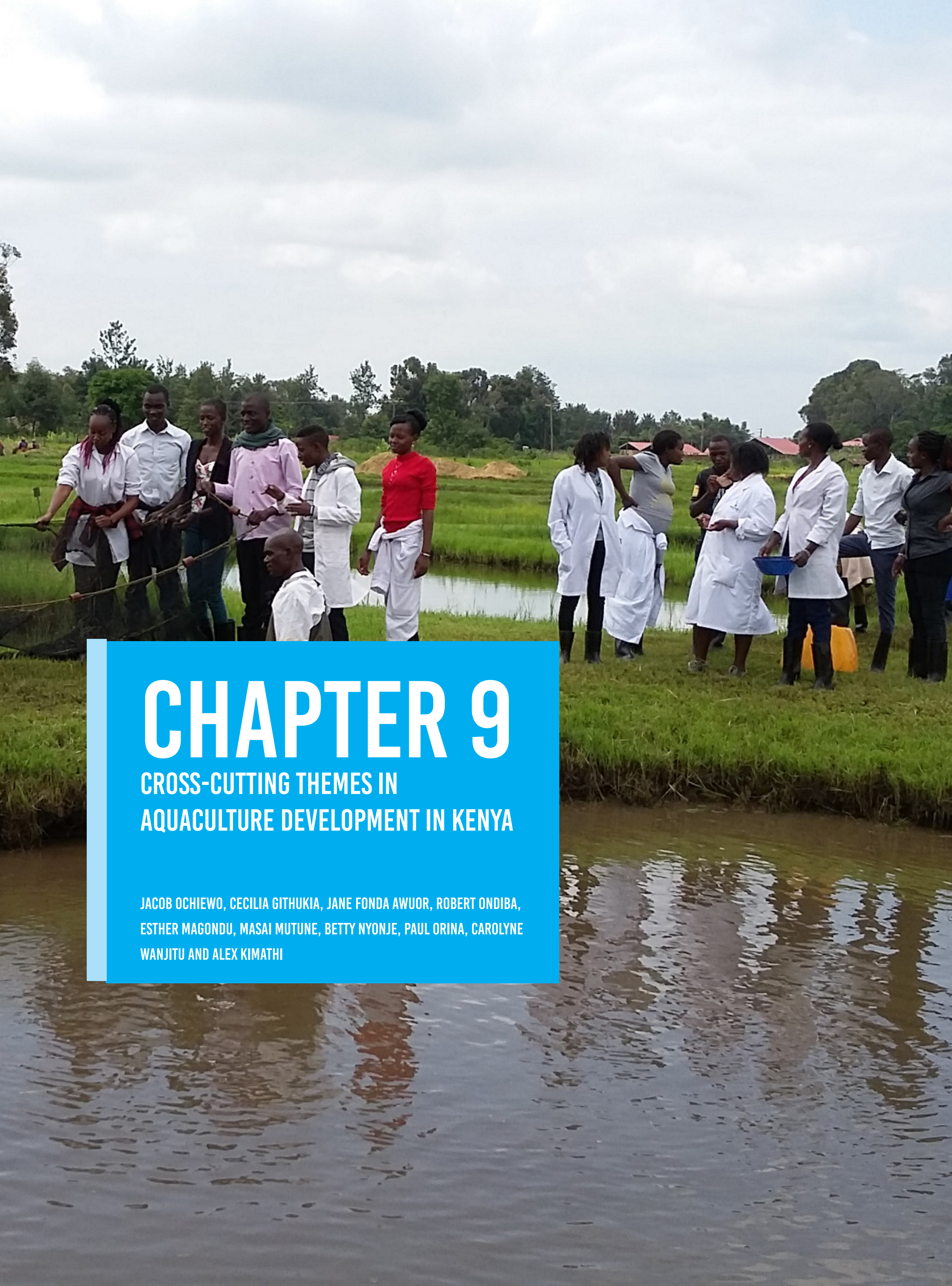
In FFS meetings the farmers are sensitized on various farming activities including aquaculture and how they can do integrated farming.

Mutual partnership

Aquaculture sector goes hand in hand with other agricultural sectors. Therefore, providing a good avenue for reaching the community. For instance, in the advertisement of maize flour, ugali with the accompaniment of Fish is popular in the Kenyan media. Additionally, the waste product of fish is normally utilized as manure in other agricultural products.

Sales of the Aquaculture product to institutions

Through the sales of products like fish value-added products, the institutions get triggered to initiate projects such as fish farming and setting up aquaponics within the institution.



CHAPTER 9

CROSS-CUTTING THEMES IN AQUACULTURE DEVELOPMENT IN KENYA

JACOB OCHIEWO, CECILIA GITHUKIA, JANE FONDA AWUOR, ROBERT ONDIBA, ESTHER MAGONDU, MASAI MUTUNE, BETTY NYONJE, PAUL ORINA, CAROLYNE WANJITU AND ALEX KIMATHI

Key Messages	Policy Recommendations
• Kenya has gained ground and remarkable progress in revamping the aquaculture subsector with overarching institutional and structural reforms. • Despite the speedy growth, climate change is a major challenge as a result of its direct and indirect effects on the sector. Impacts of climate change on aquaculture are much more than those on terrestrial agriculture. • A productive commercial aquaculture industry could also supply high-quality raw material for 'value-added' fish products for local, regional and international markets. • Kenya has diverse coastal and maritime resources that provide huge potential for the development of the Blue Economy. Kenyan waters in the Indian Ocean cover a surface area of approximately 230,000 square kilometres with 142,400 square kilometres of Exclusive Economic Zone (EEZ) and a coastline of about 640 kilometres. • At present, Kenya is food insecure requiring imports of various food commodities and does not export any aquaculture products • Blue Economy covers marine and freshwater spaces comprising the oceans, seas, coasts, lakes, rivers and groundwater. • For effective inclusion, an assessment of roles performed by men and women, youth and the vulnerable and marginalized groups and their relationships is paramount	• The Blue Economy Sector Plan and the MTP III 2018-2022 have also identified Research and Development as the engine of Blue Economy development • Embracing gender equality and social inclusion increases productivity, quality of livelihood and economic benefits for individual participants, the household, society and nation at large. • Addressing inequalities in gender by exposing women and youth to equal access to resources and opportunities just like men increases farm production and raises agricultural output which is beneficial to the entire family. • Since gender equality is enshrined in the Sustainable Development Goal (SDG) of the United Nations as a crucial target to be met by 2030, its achievement in aquaculture is indispensable. • The Kenyan Government has formally enacted legislation that supports aquaculture development anchored on the Constitution promulgated in 2010. The Constitution devolved many functions from the National Government to County Governments. The provisions of the constitution have been operationalized through sector-specific legislation. The legislation that governs aquaculture includes the Fisheries Management and Development Act, 2016, the Lands Act, the EMCA 2016, the Forest Act, 2016.

Ochiewo, J., Githukia, C., Awuor, J. F., Ondiba, R., Magondu, E., Mutune, M., Nyonje, B., Orina, P., Wanjiru, C., & Kimathi A. (2021). Cross-Cutting Themes in Aquaculture Development in Kenya. In: Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition -Sensitive Fish Food Production Systems; Chapter 9: pp 137–152.

9.1 AQUACULTURE AND THE BLUE ECONOMY

Blue Economy covers marine and freshwater spaces comprising the oceans, seas, coasts, lakes, rivers and groundwater. It is defined as the sustainable use of ocean and freshwater resources for economic growth and improved livelihoods while preserving the ecosystem health (United Nations Economic Commission for Africa (UNECA), 2016). It encompasses a range of productive sectors, including fisheries, aquaculture, tourism and recreation, maritime transport, shipbuilding and repairs, renewable energy, marine salt harvesting, bioprospecting and underwater mining and related activities. Kenya has diverse coastal and maritime resources that provide huge potential for the development of the Blue Economy. Kenyan waters in the Indian Ocean cover a surface area of approximately 230,000 square kilometres with 142,400 square kilometres of Exclusive Economic Zone (EEZ) and a coastline of about 640 kilometres. The main inland water bodies cover a surface area of approximately 10,700 square kilometres.

The Blue Economy approach adopted by Kenya is based on a vision of improved wellbeing and social equity while ensuring sustainable development by reducing environmental risks and ecological scarcities. To realize this, Blue Economy initiatives support the creation of a low-carbon, resource-efficient and socially inclusive society. If the ocean and freshwater resources are not sustainably managed, they will not be able to continue providing the ecosystem goods and services that are required to sustain the population that depends on them.

Kenya is endowed with various aquatic resources and enjoys the rains which fall in most of the year thus providing a great opportunity for aquaculture development. These aquatic resources also support a great diversity of life which further can support aquaculture development. Also, the coastal rich brackish waters and estuaries such as Rivers Sabaki form part of the shoreline with suitable aquaculture sites. Inland water systems which consist of lakes and rivers, dams and wetlands as well as springs with year-round waters have been effectively used in the recent past to farm Nile tilapia and catfish. However, despite Kenya's vast marine ecosystems, mariculture is largely underdeveloped. Consequently, will be depleted and, insignificant quantities of marine resources such as Penead shrimp, milkfish, mud crab, and seaweed production have been recorded. The concept of Blue Economy has been successfully implemented in the Asian continent, which is currently the giant in global aquaculture production. Kenya can learn from South East Asia to develop mariculture to provide food and income to the growing population.

Blue Economy approach can be used as a tool to promote sustainable development, poverty alleviation and climate change mitigation. It calls for good governance of the high seas and an integrated ecosystem approach to maintain balanced, healthy, and productive marine ecosystems, as well as highlighting the value of blue carbon. The Blue Economy concept recognizes productivity of healthy freshwater and ocean ecosystems as a pathway for aquatic and maritime-based economies and promotes the conservation, sustainable use, and management of associated marine resources (UNECA, 2016). Good water resources governance and an integrated ecosystem approach which are emphasized in Blue Economy are essential for sustainable development of aquaculture in Kenya.

"KENYAN WATERS IN THE INDIAN OCEAN COVER A SURFACE AREA OF APPROXIMATELY 230,000 SQUARE KILOMETRES WITH 142,400 SQUARE KILOMETRES OF EXCLUSIVE ECONOMIC ZONE (EEZ) AND A COASTLINE OF ABOUT 640 KILOMETRES.

MAINSTREAMING BLUE ECONOMY IN KENYA'S DEVELOPMENT AGENDA

The Government of Kenya has identified Blue Economy as a major growth frontier and has developed the National Blue Economy Sector Plan. The Government went further to mainstream the Blue Economy Sector Plan into Kenya's development planning process by incorporating it in the Third Medium Term Plan (MTP III) 2018-2022 as an economic sector. The Blue Economy Sector Plan and the MTP III 2018-2022 have identified aquaculture as a critical sub-sector. In this regard, Aquaculture Technology Development has been prioritized with the priority interventions being aquaculture technology development and innovations transfers; youth aquaculture programme; national fish breeding programme; development of International Nile Perch Research centre; development of aqua-parks; promotion and development of ornamental fisheries; and development and promotion of recreational fisheries. The Blue Economy Sector Plan and the MTP III 2018-2022 have also identified Research and Development as the engine of Blue Economy development and have detailed the following:

i. Research on the promotion of investments in the Blue Economy

The priorities will include: adoption of applied technology to benefit from the ocean space and resources; undertaking marine aquaculture suitability mapping; developing guidelines for cage culture development; undertaking research on the development of seaweed farming; conducting research on bio-prospecting; identifying bioactive compounds from wild and cultivated aquatic organisms suitable for use in the biomedical and nutritional industry; conducting environmental assessments; up-scaling the network of breeding nuclei and seed multiplication centres; supply of improved seed to fish breeding centres and communities within aquaculture-suitable counties through established networks; and increase community awareness of aquaculture technologies to encourage adoption.

ii. Diversification and commercialization of aquaculture species

This will involve the establishment of a gene bank by genetically and phenotypically characterizing wild strains of fish; conducting culture trials on different species such as prawns, crabs, milkfish, artemia, oysters and mullets; and commercializing seaweeds.

iii. Establishment of a centre for biosecurity and fish disease surveillance in aquaculture

This will involve creating capacity for research and monitoring on fish diseases and parasites; establishing a Fish Diseases and Environmental Monitoring Unit (FDEMU) in Kenya Marine and Fisheries Research Institute (KMFRI), and carrying out diagnostic and molecular genetics assessments of aquatic biosecurity risks.

iv. Fish feed formulation and testing

This will include formulation and testing fish feeds for different culture species and fish stages; development of standards for feed quality control; conducting grow out fish feeds trials for different species in different culture systems, and formulation of fish feeds using locally available ingredients.

9.2 AQUACULTURE ECONOMIC AND

9.2.1 OPPORTUNITIES FOR AQUACULTURE DEVELOPMENT IN KENYA

Kenya has diverse maritime space which provides a significant potential for the development of a commercial aquaculture industry. If this opportunity is tapped, the country will be able to produce huge volumes of fish to bridge the widening gap between fish supply and demand. The country has fast-growing fish species (Nile tilapia, African catfish), extensive freshwater resources that are suitable for the cage, pond and tank-based aquaculture systems. The raw materials that are needed for the production of fish feeds are also being produced locally from the agriculture and fisheries sectors. As a country, Kenya has a huge population that is huge to eating fish thus providing a market for fish locally. Besides, there is huge market potential in the East African Community region while catches from capture fisheries are declining. Kenya also has the advantage of having a highly developed fish processing sector and quality assurance laboratories that until now have been focused on the export of Nile perch products to Europe.

A productive commercial aquaculture industry could also supply high-quality raw material for 'value-added' fish products for local, regional and international markets. At present, Kenya is food insecure requiring imports of various food commodities and does not export any aquaculture products (Nyandat and Owiti, 2013). The per capita annual consumption of fish in Kenya 2009 was 5 Kg/capita/year compared to the world average of 18.6 Kg/capita/ year in 2010. Currently, the per capita annual fish consumption in Kenya is estimated at 4.5 kg/capita /year. The Blue Economy is a global emerging economic frontier. In Kenya, the blue economy represents a huge opportunity and potential to achieve economic growth and generate jobs.

The concept recognizes the productivity of healthy freshwater and ocean ecosystems is a pathway for freshwater aquatic and maritime-based economies and promotes the conservation, sustainable use, and management of associated marine resources (UNECA, 2016). In aquaculture, the approaches for actualizing the aspirations embodied in the Blue economy concept include; Cage culture (Ocean, Lakes, Dams, and Rivers), Integrated Re-circulatory Aquaculture Systems (RAS), Aquaponics/ Greenhouse, Pens, Breeding and restocking of commercially important indigenous species and live fish markets

> "THE PER CAPITA ANNUAL CONSUMPTION OF FISH IN KENYA 2009 WAS 5 KG/CAPITA/YEAR COMPARED TO THE WORLD AVERAGE OF 18.6 KG/CAPITA/ YEAR IN 2010. CURRENTLY, THE PER CAPITA ANNUAL FISH CONSUMPTION IN KENYA IS ESTIMATED AT 4.5 KG/CAPITA /YEAR

9.2.2 MAIN FRESHWATER AQUACULTURE SPECIES.

The main cultured species in Kenya's freshwater systems are Nile tilapia, which accounts for about 80% of production, followed by African catfish, contributing about 14% of aquaculture production. These species are found in virtually all aquatic systems and have high demand in the local and regional markets. Polyculture of Nile tilapia and African catfish is often done to control the prolific breeding of the Nile Tilapia. Other exotic species include common carp (4%), rainbow trout (2%), koi carp, largemouth bass and goldfish. Trout is temperature restricted thus only cultured at temperatures below 19°C mainly in the Mt. Kenya region. Potential indigenous candidates for aquaculture include African Carps, Lungfish and Tilapia jipe. There are great opportunities in ornamental fish culture for they can be marketed within the East African region and in Europe.

9.2.3 MAIN MARICULTURE SPECIES

Mariculture development in Kenya began three and half decades ago (Troell, et al, 2011), having been introduced through developments, research and conservation programs (Mirera, 2011; Mwaluma, 2002) with few success stories (Mirera & Samoilys, 2008). The main culture species include milkfish, mullets, mud crabs, seaweeds and prawns (Mirera, 2011, 2014; Mirera & Ngugi, 2009; Mwaluma, 2002; Wakibia, Ochiewo, & Bolton, 2011). Most mariculture initiatives have been implemented in the coast of Kenya with donor support. The mariculture initiatives involve production systems operated by self-help groups consisting mainly of female farmers (Mirera & Ngugi, 2009). While mariculture development in Kenya is still at its infancy, its introduction in the coast of Kenya has provided economic opportunities that enhance the capacity of coastal communities to access an additional or alternative source of livelihood thus bringing about development *(Mirera & Ngugi, 2009).*

Ngomeni in Kilifi County with funding from FAO (Ronnback et al., 2012; Mirera, 2011; Munguti et al., 2014; UNEP, 1998) to carry out trials for the development of mariculture. The project collapsed due to implementation challenges, but the culture technology has since then been transferred to the local community groups on a small scale basis by KMFRI and development partners. Mud crab farming on the coast of Kenya began in the late 1990s in the form of small-scale community interventions that could act as a source of livelihood and income (Mirera, 2011). Some level of success was achieved by introducing it to local communities. Seaweed farming began on an experimental scale in the late 1990s in the south coast of Kenya. It is mainly carried out by women and employs 100-400 farmers (Wakibia et al., 2011).

9.3 GENDER AND SOCIAL INCLUSION [WOMEN, YOUTHS, VULNERABLE AND MARGINALIZED GROUPS]

Gender refers to the relationships between women and men and their respective status in their society, community, and family. It is not only about women. Gender also refers to the socially constructed norms, roles, and behaviours for men and women in the society which determines their social expectations, access to assets and resources, chain decision making and bargaining power, and control over benefits derived. Gender relations, therefore, affects the social expectations in the society (Agarwal, 1997) which has a great influence on cultural practices, domestic and social interactions and most importantly dictate the performance of the value chain.

Social inclusion, on the other hand, alludes to how individuals or groups of individuals take part in a society and is therefore concerned with giving and or improving opportunities to the disadvantaged in the society such as women, youth, the vulnerable and marginalized *(Barclay et al., 2019).*

RELEVANCE OF GENDER AND SOCIAL INCLUSION (GSI)

Embracing gender equality and social inclusion increases productivity, quality of livelihood and economic benefits for individual participants, the household, society and nation at large. This is based on the fact that individuals in the society have different capacities to respond which is based on their prevailing situations. Social inclusion is therefore vital for the holistic development of the society and nation because exclusion is very costly (Ferrant and Kolev, 2016). Exclusion comes in different ways including bias brought about by people's perceptions resulting in women, youth, the vulnerable and marginalized being excluded from participation and gains from aquaculture.

Prevailing social exclusion should be addressed because at the individual level it leads to loss of earnings, wages and employment while at the national level, it leads to loss of Gross Domestic Product (GDP) and human capital wealth. A gender perspective looks at relationships between women and men to identify where there are differences that generate inequalities, vulnerabilities, fears and exclusion. As such, transforming harmful social ideas and practices requires everyone's collaboration, regardless of their gender.

For successful aquaculture programs, a rigorous GSI is imperative to avoid producing inequalities and negative social impacts and ensure that every section of the community benefits. Worth noting, men, women youth, vulnerable and marginalized groups have different capacities and life situations and therefore the quality of inputs does not necessarily lead to equitable outcomes. Incorporation of a GSI analysis can reveal people's strategic needs, enabling the design of equitable interventions to provide equal outcomes for all *(Barclay et al., 2019).*

To effectively integrate gender and social inclusion, feasible options that encourage participation and productivity of women, youth, vulnerable and marginalized groups should be adopted. To increase productivity and profitability gender-responsive technologies and innovations should be embraced. Besides, it is important to pursue a strategy that is gender-transformative; which is a requisite when initiating social change and transformation of social relations that perpetuate inequality.

CHALLENGES AND WAY FORWARD

Noteworthy, women significantly contribute to many sectors of aquaculture, but their opportunities have not kept pace with their growth (Brugere and Williams, 2017). Women are common in production, post-harvest, value addition, marketing and sales. As a result, they improve the overall well-being of their households and societies. Unfortunately, they get very little in return due to deep-rooted gender disparities in social, cultural and economic spheres (Ndanga et al., 2013). Unlike men who own most of the production facilities, women and youth are challenged by differences in endowments associated with access to factors of production; considering the high levels of investment and the adoption of new farming technology associated with its development (Obiero et al., 2019).

Eliminating hurdles limiting women's and youth access to production facilities will reduce inequality and exclusion. This includes transforming harmful social ideas and practices which requires everyone's collaboration, regardless of their gender. This can be made possible by incorporating a gender perspective in aquaculture value chain analysis which will mitigate the gender differences and increase production and returns (Schumacher, 2014; Kruijssen et al., 2018). For effective inclusion, an assessment of roles performed by men and women, youth and the vulnerable and marginalized groups and their relationships is paramount. Worth noting, addressing inequalities in gender by exposing women and youth to equal access to resources and opportunities just like men increases farm production and raises agricultural output which is beneficial to the entire family (Gallant, 2019). Since gender equality is enshrined in the Sustainable Development Goal (SDG) of the United Nations as a crucial target to be met by 2030 (FAO, 2011), its achievement in aquaculture is indispensable *(Me-Nsope et al., 2015).*

9.4 EMPLOYMENT AND SOCIAL DEVELOPMENT

Kenya has gained ground and remarkable progress has been made in revamping the aquaculture subsector with overarching institutional and structural reforms. Still, the government remains steadfast to its ambitious developmental goals. Kenya Vision 2030, The Poverty Reduction Strategy Paper (PRSP) and the Kenyan Constitution 2010 emphasize on eradicating rural poverty. Kenya enjoys a stable macroeconomic environment that fosters private sector investment. This promising trend offers a unique opportunity for the country to accelerate its priority for inclusive growth and development by putting emphases on aquaculture's transformation and rural development where viable productivity gains are to be seized with such concerted efforts. The country's population is rapidly growing and has doubled over the last 25 years.

This rapid population growth is set to continue and will reach approximately 85 million by 2050 (World Bank, 2010). There is a demographic dividend to be from the large proportion of the youth. The youth make up 35.4% of the total population (18 and 35 years old) and 60% of the total labour force (World Bank 2014). In 2018, the average Gross National Income per capita was USD 1620 (World Bank, 2018); social inequality is significant, with a high poverty level and exclusion despite a decrease in the poverty rate from 46.6% in 2005/2006 to 36.1% in 2015/2016 (KNBS, 2019).

Majority of the unemployed youth (64%) are relocating into cities thereby lowering the labour force required in rural areas. The discerned expeditious and sustained growth of the aquaculture subsector in Kenya offers a major developmental opportunity for eliminating rural poverty, malnutrition and building climate resilience for poor households. Kenya's aquaculture business sector is typified by few large enterprises and several micro-enterprises and/or informal sector, with an overriding 'missing middle'.

The subsector's performance will need to rival the rapid population growth, to feed cities, offer employment and promote overall social development. To do so, increased productive capacities central to transforming the sector, through critical pathways like natural capital that the country is endowed with, innovative capabilities of farmers and rural entrepreneurs and through markets for credit, technology, inputs commodities and value-added products to generates jobs along the private sector-led value chains and in the wider economy.

These will also result in higher incomes and improved livelihood opportunities.

Household incomes will be propelled through increasing the value of production at the farm-level and strengthening aquaculture value chains emanating from off-farm job-creation. Consequently, higher incomes heightened resilience to market and production shocks at the household level, and selected interventions and asset building for vulnerable households will impact on livelihoods. However, such strategies will go beyond economics and ascertain that the environmental well-being synchronizes with human well-being to assure long-term sustainable prosperity a reality for all.

Therefore, championing for responsible and sustainable aquaculture is central. Enhanced Science, Technology and Innovation (STI) and governance will offer a comprehensive strategy to meet the goals of responsible and sustainable utilization of aquacultural resources to secure valuable resources for the benefit of present and future generations.

9.5 CLIMATE CHANGE AND ITS EFFECTS ON AQUACULTURE

Aquaculture sector is one of the fastest growing among the agricultural sectors and is expected to contribute significantly to ensuring food security in the country. The speedy growth has been catalyzed by the entrepreneurial spirit where aquaculture is now viewed as a business and not just for subsistence. Despite the speedy growth, climate change is a major challenge as a result of its direct and indirect effects on the sector. Climate change affects fisheries and aquaculture through acidification of the water bodies, changes in circulation patterns, sea-level rise and associated ecological changes.

Impacts of climate change on aquaculture are much more than those on terrestrial agriculture. In developing economies small-scale fish farmers practice low input and low-output form of aquaculture whereby they depend more on ecosystem services and natural feed materials to raise feed. Many aquaculture enterprises depend on wild stocks for fishmeal and seed (FAO, 2008). With climate change, these stocks are bound to decline because of unprecedented extreme events particularly droughts and floods.

Other changes that are associated with extreme events include reduced water quality, salinization of groundwater, increased run-off etc. The effects come about as a result of run-off washing nutrients from agricultural fields, sewage among others. The saturation of nutrients, in turn, causes algal blooms which lead to reduced dissolved oxygen, increased metabolism and ultimate -fish kills (Diersing, 2009)

9.6 LEGAL, POLICY AND INSTITUTIONAL FRAMEWORK GOVERNING AQUACULTURE IN KENYA

The Government of Kenya has formally enacted legislation that affects aquaculture development in the country based on the National Constitution that was promulgated in 2010. The Constitution devolved many functions from the National Government to County Governments. The provisions of the constitution have been operationalized through sector-specific legislation. The legislation that governs aquaculture includes the Fisheries Management and Development Act, 2016, the Lands Act, the EMCA 2016, the Forest Act, 2016.

9.6.2 LEGISLATIVE FRAMEWORK

THE CONSTITUTION OF KENYA 2010

The Constitution which was promulgated in 2010 has changed governance and operational environment including devolution and bill of rights. It has devolved aquaculture extension and development to the counties with the National Government being left with the responsibility of making policies and undertaking research for the development of the sector. It obliges the state to ensure sustainable exploitation, management and conservation of the environment and its natural resources. It has entrenched the principle of sustainable development (Article 10 2(d)) as one of the national values and principles of governance and provides for sound conservation and protection of ecologically sensitive areas (Article 60 (1) (e)).

THE FISHERIES MANAGEMENT AND DEVELOPMENT ACT, 2016

The Fisheries Management and Development Act, 2016 provides for the preparation of an aquaculture development plan to promote the sustainable development of aquaculture in Kenya (Article 62). It emphasizes the need to ensure that (a) aquaculture development is ecologically sustainable and allows the rational use of the resource shared by aquaculture and other activities; and (b) the livelihood, culture and traditions of local communities and their access to fishing grounds are not affected by aquaculture development (Article 63). It also provides for the protection of local communities by providing measures to ensure that aquaculture activities do not deprive a local community of its traditional access to fishing grounds without good cause and without first consulting the affected community (Article 64 (1)). It defines the role of County Governments in monitoring aquaculture practices and operations (Article 65 (1)).

The new law has established new institutions such as the Kenya Fisheries Service and Kenya Fish Marketing Authority and Fisheries Council and accords roles to communities.

The legislation further provides for the introduction of exotic species of fish or any genetically modified fish in the Kenyan waters; (b) transfer any eggs, fingerlings or seed of exotic or genetically modified species; (c) import or export live fish for aquaculture, or (d) release of any fish into the fishery waters except for indigenous wild fish caught in Kenya and approvals environmental impact assessments (Article 66 (1)). Article 67 provides for inspection of fish before or after they are imported for aquaculture and inspection of fish produced by aquaculture operations that are destined for export, handling of live fish that have been imported or that are destined for import or export for purposes of aquaculture, and shall take such measures where it is determined that the species are diseased or highly invasive.

Article 69 (1) provides for controlling aquaculture fish from escaping into the wild aquaculture in Kenya and (2) provides for damage control. Article 70 (1) provides for how to use pharmaceutical products, antibiotics or other chemicals in a commercial aquaculture establishment any drug, for the treatment of fish diseases or the enhancement of fish growth. Article 71 provides for the collection of information and data on wild and genetically modified species to assess their impact on aquaculture.

ENVIRONMENTAL MANAGEMENT AND CO-ORDINATION ACT (EMCA), NO. 8 OF 1999

The Environmental Management and Co-ordination Act (No. 8 of 1999) has been amended by the Environmental Management and Co-ordination (Amendment) Act, 2015. The amended Act has provided for environmental impact assessment for all development activities including aquaculture.

THE LAND ACT, 2012

The Land Act, 2012 repealed the Land Acquisition Act cap 295. It provides for land tenure systems and zonation which is critical for aquaculture development. It empowers the National Land Commission to make rules and regulations for the sustainable conservation of land-based natural resources including measures to facilitate the access to land, water and other resources by communities who have customary rights to these resources; and measures to ensure benefit-sharing to the affected communities.

FOREST CONSERVATION AND MANAGEMENT ACT NO 34 OF 2016

The Forest Conservation and Management Act, 2016 gives effect to article 69 of the Constitution, to provide for the development and sustainable management, including conservation and rational utilization of all forest resources for the socio-economic development of the country. It categorizes forests between low and high water wherein lies Mangrove forests as public forests. Some aquaculture activities are carried out in the mangrove areas. It has provided for integrated aquaculture in mangrove areas.

LAND CONTROL ACT CAP 302

This Act repealed the Land Control Act Cap 302. The main objective of the Act is to provide for the control of transactions in agricultural land. Therefore, dealings in the land for aquaculture development are controlled with the transacting parties being required to obtain consent from the relevant land control board that has jurisdiction within the area in which the land is located. Controlled dealings include sale, transfer, lease, mortgage, exchange, partition, subdivision or other disposals of land.

THE SCIENCE AND TECHNOLOGY ACT CAP 250

The Science and Technology Act, Cap 250 of the Laws of Kenya, which has since been repealed by the Science, Technology and Innovation Act No. 28 of 2013 established Kenya Marine and Fisheries Research Institute (KMFRI) as a national research institution to research on fisheries and aquaculture.

9.6.3 POLICY FRAMEWORK

1. THE NATIONAL OCEANS AND FISHERIES POLICY, 2008

The National Oceans and Fisheries Policy, 2008 provides a policy framework for the development of aquaculture in Kenya. It mandates the Department of Fisheries to regulate aquaculture while Kenya Marine and Fisheries is obligated to research aquaculture development.

2. VISION 2030

Kenya's Vision 2030, together with other policy frameworks recognizes aquaculture as one of the flagship projects under Fisheries Management and Development that contribute to the economy. The Vision 2030 is being implemented through five-year medium-term plans. Implementation of the second Medium Term Plan (2013-2017) is ending in December 2017 and the preparation of Medium Term III (2018-2022) is on-going. Current policy and legal frameworks address the untapped potential for fish production to supplement diets in a population still suffering from food insecurity and child malnutrition.

Under the midterm period of the "Vision", the government plans to promote fish farming through the construction of fish ponds in every constituency. In particular, the Government supported the inter-sectoral Economic Stimulus Programme (ESP) by investing KShs. 5.7 billion between 2009 and 2012 financial years, to implement the Fish Farming Enterprise Productivity Programme (FFEPP) in 219 constituencies countrywide (SDF, 2013). Within this program, over 48,000 fish ponds were constructed, free fingerlings and feeds supplied to fish farmers, mini-processing plants set up as well as human resource capacity building through training, strengthening of the coordination offices and fish farming institutions.

3. NATIONAL AQUACULTURE STRATEGY AND DEVELOPMENT PLAN

In 2010, Kenya's Ministry of Fisheries Development released the 1st Five-year (2010–2015) National Aquaculture Strategy and Development Plan, 2010. Based on Kenya's natural aquatic endowments, the overwhelming demand for fish rising from rapidly declining fish catches from the wild, the high population growth rate and the high rates of unemployment in the country, the goal of aquaculture development is to increase the quantity, quality and value of aquaculture products and increased earnings to the producers. The strategy defines clearly the roles of different players in the sector to avoid duplication of efforts and wastage of scarce resources, apply best management practices, spur and promote aquaculture business for maximum socio-economic benefits of the people of Kenya.

The following institutions have been established to manage and/or support aquaculture development in Kenya.

1. MINISTRY OF AGRICULTURE, LIVESTOCK AND FISHERIES

MANDATE: To ensure sustainable development of agriculture, livestock and fisheries for food security and economic development.

ROLE IN AQUACULTURE: Responsible for Fisheries Policy which creates an enabling environment for aquaculture.

2. STATE DEPARTMENT OF FISHERIES, AQUACULTURE AND THE BLUE ECONOMY (SDFA-BE)

MANDATE: Fisheries policy; fisheries licensing; development of fisheries; fisheries marketing; fish quality assurance; development of policy framework for Kenya's maritime blue economy; development of Legal, the regulatory and institutional framework for the blue economy; enhancement of technical cooperation; maritime spatial planning and integrated coastal zone management; protection and regulation of marine ecosystems; protection of fisheries in the Exclusive Economic Zone (EEZ); overall policy for exploitation of agro-based marine resources; development of fishing ports and associated infrastructure; capacity building for sustainable exploitation of agro-based marine resources; promotion of sustainable use of food-based aquatic resources; protection of aquatic ecosystem; and promotion of Kenya as a centre for the agro-based blue economy.

ROLE IN AQUACULTURE: Regulating fisheries and aquaculture activities in Kenya

3. KENYA FISHERIES SERVICE (KFS)

MANDATE: Conservation, management and development of Kenya's fisheries resources including aquaculture. Its key functions that are relevant to aquaculture include:

(a) Ensuring the appropriate conservation development of standards on management, sustainable use, development and protection of the fisheries resources;
(b) Formulation and monitoring the implementation of policies regarding the conservation, management and utilization of all fisheries resources within the scope of this Act;
(c) Development of standards for the management of all fisheries and aquaculture activities;
(d) Developing guidelines for the preparation of fisheries specific management plans for the Kenya fishery waters;
(e) Provision of education to create public awareness and support for fisheries conservation, management, development and sustainable use;

(f) Setting and meeting goals for fisheries conservation, management, development and sustainable use;
(g) In consultation with the Kenya Marine and Fisheries Research Institute, approve and coordinate research activities in fisheries and aquaculture;
(h) Subject to the Public Health Act and the Food, Drugs and Substance Act, control and regulate fish Cap 254 safety and quality;
(i) Undertaking the development of appropriate fisheries infrastructure, that relates to its mandate under this Act and the Constitution;
(j) Facilitation of investment in commercial fisheries, in collaboration with relevant agencies, persons or bodies, including Government departments;
(k) Promotion of development and introduction of appropriate technologies in aquaculture production, processing and preservation in collaboration with relevant agencies, county governments and stakeholders; and
(l) Co-ordination of fish quality assurance and operations of the marine and coastal fisheries, aquaculture and inland and riverine fisheries.

ROLE IN AQUACULTURE: Responsible for the development of standards for the management of all aquaculture activities, and approve and coordinate research activities on fisheries and aquaculture in consultation with the Kenya Marine and Fisheries Research Institute, provision of standards and oversight on aquaculture activities

4. KENYA FISH MARKETING AUTHORITY (KFMA)

MANDATE: To market fish and fisheries products from Kenya, develop, implement and co-ordinate a national fish marketing strategy; promote the sustainable use of fish by preventing, deterring and eliminating to the extent possible trade in illegal, unreported and unregulated fishing; enforce national fisheries trade laws and international fisheries-related trade rules; identify fish market needs and trends and advise fisheries stakeholders accordingly, and organize stakeholders to ensure smooth marketing of fish and fishery products.

Role in aquaculture: To market fish and other products from aquaculture.

5. KENYA MARINE AND FISHERIES RESEARCH INSTITUTE (KMFRI)

MANDATE: To research marine and freshwater fisheries, aquaculture, environmental and ecological studies, and marine research including chemical and physical oceanography.

ROLE IN AQUACULTURE: Undertaking research on suitable species for culture including development, adoption and transfer of rearing technology and procedure for aquaculture development.

6. KENYA FISHERIES ADVISORY COUNCIL (KFAC)

MANDATE: To review and advise the National Government on policies in relation to the coordination of fisheries management in relation to the aquatic environment and human dimensions; allocation and access to fisheries resources; intergovernmental agreements and arrangements related to fisheries; research, education, capacity development in fisheries and the management of fisheries resources; management plans and resources for the development of the fisheries sector.

Role in aquaculture:

Review and advise the National Government on aquaculture related policies and allocation of access to aquaculture resources.

7. NATIONAL ENVIRONMENT MANAGEMENT AUTHORITY (NEMA)

MANDATE: Implementation of all policies relating to the environment.

ROLE IN AQUACULTURE: Promote the integration of environmental considerations into aquaculture projects.

9.6.5 REGIONAL FRAMEWORKS

1. Regional Treaties, Protocols and Institutions
2. The regional protocols that are relevant to aquaculture in Kenya are summarized below:
3. **PROTOCOL FOR SUSTAINABLE DEVELOPMENT OF LAKE VICTORIA BASIN:** it established the Lake Victoria Basin Commission to promote fisheries, aquaculture and other economic activities in the Lake Basin and its catchment area;
4. **EAST AFRICA COMMUNITY TREATY:** Adoption of common policies and regulations for the conservation, management and development of fisheries resources;
5. **COMMON MARKET FOR EASTERN AND SOUTHERN AFRICA (COMESA):** Adoption of common policies for conservation, management and development of fisheries resources, the establishment of uniform fisheries investment guidelines for inland and marine waters, enforcement of measures to control transboundary water pollution.

Several regional institutions whose mandates cover aquaculture development in Kenya also exist. These institutions and their respective mandates are listed below.

1. Lake Victoria Fisheries Organization (LVFO)

MANDATE: To promote Sustainable Management and Development of Fisheries & Aquaculture in the East African Community for Food Security and Wealth creation

ROLE IN AQUACULTURE: PROMOTION OF SUSTAINABLE DEVELOPMENT OF AQUACULTURE

2. Lake Victoria Basin Commission (LVBC)

MANDATE: Coordinating the various interventions on the Lake and its Basin and serving as a Centre for promotion of investments and information sharing among the various stakeholders

ROLE IN AQUACULTURE: Promoting aquaculture in the Lake Victoria Basin and its catchment area

3. East African Community (EAC)

MANDATE: Development of policies and programmes aimed at widening strengthening cooperation among partner states in various fields including aquaculture

ROLE IN AQUACULTURE: Adoption of common policies and regulations for the conservation, management and development of fisheries resources, establishment of common fisheries management, and investment guidelines for inland and marine waters

4. Western Indian Ocean Marine Science Association

MANDATE: Promoting the educational, scientific and technological development of all aspects of marine sciences throughout the Western Indian Ocean (WIO) region to sustain the use and conservation of its marine resources. It supports applied research on aquaculture

ROLE IN AQUACULTURE: Promoting sustainable development of aquaculture through the provision of research grants

5. AU-IBAR

MANDATE: Supporting and coordinating the utilization of animals (livestock, fisheries and wildlife) as a resource for human well-being in the Member States of the African Union and to contribute to economic development.

ROLE IN AQUACULTURE: Supporting the utilization of aquaculture as a resource for human well-being.

9.6.6 INTERNATIONAL FRAMEWORKS

The Constitution of Kenya 2010 provides for International Treaties and Conventions to become part of the Kenyan law. Consequently, the following international treaties and protocols form part of the legal framework for aquaculture in Kenya:

1. Convention on Biological Diversity: Provides for sustainable development
2. Sustainable Development Goals 2-14: Goal number 2 addresses the need to end hunger, achieve food security, improve nutrition and promote sustainable aquaculture while goal number 14 addresses life underwater
3. FAO Code of Conduct for Responsible Fisheries: Promotes responsible fisheries including aquaculture
4. FAO Ecosystem Approach to Aquaculture and the Blue Growth Initiative: Promotion of sustainable aquaculture

9.6.7 LEGAL, POLICY AND INSTITUTIONAL REFORMS

The development of Blue Economy needs to be anchored on effective legal, regulatory and institutional frameworks. Development or review of the following instruments will be relevant to aquaculture:

(i) Development of Cage Culture Regulations;
(ii) Review of the Fisheries (Safety of Fish, Fishery Products and Fish Feed) Regulations, 2007;
(iii) Review of Fisheries Beach Management Unit (BMU) Regulations, 2007;
(iv) Review of aquaculture policy, 2011 and National Aquaculture Strategy and Development Plan, 2010;
(v) Development of a strategy to improve governance, the safety of navigation, security, protection of marine environment and shipping operations in the small ports;
(vi) Development of a Fish Marketing Strategy;
(vii) Development of a disaster management framework for the ocean and inland waters; and
(viii) Development of an Integrated National Maritime Policy on maritime affairs;
(ix) Development of a policy on Maritime Spatial Plan;
(x) Development of Integrated Maritime Transport Policy;
(xi) Development of Ornamental and Recreational Fisheries Guidelines;
(xii) Development of a bill to establish admiralty courts and maritime arbitration centre;
(xiii) Harmonisation of legislation and licensing regimes within the sector.

> “KENYA'S VISION 2030, TOGETHER WITH OTHER POLICY FRAMEWORKS RECOGNIZES AQUACULTURE AS ONE OF THE FLAGSHIP PROJECTS UNDER FISHERIES MANAGEMENT AND DEVELOPMENT THAT CONTRIBUTE TO THE ECONOMY. THE VISION 2030 IS BEING IMPLEMENTED THROUGH FIVE-YEAR MEDIUM-TERM PLANS. IMPLEMENTATION OF THE SECOND MEDIUM TERM PLAN (2013-2017) IS ENDING IN DECEMBER 2017 AND THE PREPARATION OF MEDIUM TERM III (2018-2022) IS ON-GOING. CURRENT POLICY AND LEGAL FRAMEWORKS ADDRESS THE UNTAPPED POTENTIAL FOR FISH PRODUCTION TO SUPPLEMENT DIETS IN A POPULATION STILL SUFFERING FROM FOOD INSECURITY AND CHILD MALNUTRITION

REFERENCES

Agarwal B. (1997). Bargaining' and Gender Relations: Within and Beyond the Household, Feminist Economics, 3:1, 1-51, DOI: 10.1080/135457097338799

Balarin, J. D. (1985). Reviews for aquaculture development in Africa: Kenya. FAO Fisheries Circular, (770.7).

Barclay K., Leduc B., Mangubhai S. and Donato-Hunt C. (eds.). (2019) Pacific handbook for gender equity and social inclusion in coastal fisheries and aquaculture. First edition. Noumea, New Caledonia: Pacific Community. 80 p.

BrugereC., WilliamsM.(2017). Profile: Women in Aquaculture. https://genderaquafish.org/portfolio/women-in-aquaculture/

Diersing, N. (2009). Phytoplankton Blooms: The Basics. Florida Keys National Research Centre, Townsville, Australia, pp. 29–40.

Eakin, M.C., Kleypas, J. and Hoegh-Guldberg, O. (2008) Global climate change and coral reefs: rising temperatures, acidification and the need for resilient reefs. In: Status of coral reefs of the World: 2008(C. Wilkinson, ed.). Global Coral Reef Monitoring Network and Reef and Rainforest Marine Sanctuary, Key West, Florida, USA, 2 pp.

FAO (2008) Climate change implications for fisheries and aquaculture. In: The State of Fisheries and Aquaculture 2008. FAO, Rome, Italy, pp. 87–91.

FAO (2011). The state of food and agriculture: Women in agriculture: Closing the gender gap for development, Rome, Italy. 2011.http://www.fao.org/publications/sofa/2010-11/en/

Ferrant G. and Kolev A. 2016. The economic cost of gender-based discrimination in social institutions. OECD Development Centre Issues Paper. Paris: OECD.

Gallant M. (2019). Understanding gendered preferences for Climate-Smart Agriculture adoption in Malawi. Major Research Paper submitted in partial fulfilment of the requirements of the Master of Arts in International Development and Globalization. University of Ottawa, Canada.

Kruijssen F, McDougal CL, van Asseldonk IJM (2018). Gender and Aquaculture value chains: A review of key issues and implications for research. Aquaculture 493:328-337. https://doi.org/10.1016/j.aquaculture.2017.12.038

Me-Nsope N, Larkins M. (2015). Gender Analysis of the Pigeon Pea Value Chain: Case Study of Malawi. Center Report Series, No. 4. Global Center for Food Systems Innovation, Michigan State University, East Lansing, Michigan, USA. ISBN: 978-0-9903005-5-7

Mirera, O. D. (2014). Capture-based mud crab ***(Scylla serrata)*** aquaculture and artisanal fishery in East Africa – Practical and ecological perspective. PhD thesis, Linnaeus University Dissertations No 159/2013, ISBN: 978-91-87427-70-1.

Mirera, D. H. O. (2011). Trends in exploitation, development and management of artisanal mud crab ***(Scylla serrata-Forsskal-1775)*** fishery and small-scale culture in Kenya: An overview. ***Ocean & Coastal Management*, **54, 844-855.

Mirera, O. D., & Ngugi, C. C. (2009). Sustainability and income opportunities of farming milkfish (Chanos Chanos) to local communities in Kenya: Assessment of initial trials of earthen ponds. Ec Fp7 Project SARNISSA.

Mirera, D. H. O., & Samoilys, M. A. (2008). Natural resource dependence, livelihoods and development: Mariculture exchange between Kenya and Tanzania. IUCN ESARO 2008.

Munguti, J. M., Kim, J-D., & Ogelo, E. O. (2014). An overview of Kenyan aquaculture: Current status, challenges, and opportunities for future development. *Fisheries and Aquatic Sciences* 17(1), 1-11.

Mwaluma, J. (2002). Pen culture of the mud crab Scylla serrata in Mtwapa mangrove system, Kenya**.** *Western Indian Ocean Journal of Marine Science,* 1, 127-133.

Ndanga LZB., Quagrainie KK., Dennis JH. (2013). Economically feasible options for increased women participation in Kenyan Aquaculture value chain. Aquaculture 415:183-190. http://dx.doi.org/10.1016/j.aquaculture.2013.08.012

Obiero KO., Waidbacher H., Nyawanda BO., Munguti JM., Manyala JO., Kaunda-Arara B. (2019). Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. Aquaculture International https://doi.org/10.1007/s10499-019-00423-0

Rönnbäck, P., Bryceson, I., & Kautsky, N. (2002). Aquaculture development in eastern Africa and the Western Indian Ocean: Prospects and problems for food security and local economies. *AMBIO* 31(7-8),537–542.

Schumacher KP. (2014). "Gender relations in Global Agri-Food Value Chains – A review.' Erde.https://doi.org/10.12854/erde-145-10.

Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Mmochi A., & Ollevier, F. (eds.) (2011). *Mariculture in the WIO region - challenges and prospects. WIOMSA Book Series No. 11. viii.*

UNEP (1998). *Eastern Africa Atlas of Coastal Resources: Kenya.* Nairobi: United Nations Environment Programme.

United Nations Economic Commission for Africa (2016) Africa's Blue Economy: A policy handbook. Economic Commission for Africa, Addis Ababa, Ethiopia. 92 pp.

Wakibia, J. G., Ochiewo, J., & Bolton J. J. (2011). Economic Analysis of *Eucheumoid* Algae farming in Kenya. *Western Indian Ocean Journal of Marine Sciences,* 10(1),195-212.

Williams, L., & Rota, A. (2011). Impact of climate change on fisheries and aquaculture in the developing world and opportunities for adaptation. *Fisheries Thematic paper*.

CHAPTER 10

DEVELOPMENT STRATEGIES AND PROSPECTS FOR SUSTAINABLE AQUACULTURE DEVELOPMENT IN KENYA

KEVIN OBIERO, ERICK OGELLO, JONATHAN MUNGUTI, DOMITILA KYULE, BETTY NYONJE, JAMES MWALUMA, JAMES NJIRU AND ATSUSHI HAGIWARA

Key Messages	Policy Recommendations
• Kenya has gained ground and remarkable progress in revamping the aquaculture subsector with overarching institutional and structural reforms. At present, Kenya is food insecure requiring imports of various food commodities and does not export any aquaculture products • There is need to realize the strategic goal of 'high-efficiency, high quality, eco-friendly, health and safety', the tasks and relevant measures are identified for sustainable development of Kenyan aquaculture. These will require the following strategies: • Acceleration of establishing the hatchery sector for genetically improved strains/ varieties in aquaculture • A productive commercial aquaculture industry could also supply high-quality raw material for 'value-added' fish products for local, regional and international markets. • For sustainable development of modern Kenyan aquaculture, we need to integrate all the above-mentioned aspects, and scale up production systems in the following ways. First, steady development of production systems for major aquatic products steadily. Second, acceleration of the development of production systems for valuable and rare aquatic products. Third, the expansion of the production systems for export-oriented aquatic products. Fourth, strengthening the development of production systems for aquatic products	• The rapid growth of the aquaculture industry has been enabled through the expansion of aquaculture production areas, intensification of production systems, and adoption of new technologies and systematic improvement of existing technologies that brought control over husbandry and production processes. • Promoting research and extension mechanisms that support the production of nutritious, lower cost farmed fish and shellfish. There is a need for research and extension service providers to improve technical skills and practical knowledge of fish farmers by giving assistance to women and youth to initiate climate-smart culture technologies in small farms. • Use of better-quality feeds and feed ingredients from local suppliers can be supported by improving awareness of the nutritional properties of different feed ingredient options. Insects are rich in crude protein, amino acids, fat content, gross energy and micronutrients. • Supporting land and water tenure arrangements that enable a range of producers to engage in the sector. Successful aquaculture is dependent upon the use of a good site that has controlled access to suitable water resources. • Further research and interventions are recommended to inform sustainable food systems based on the recommended calorific requirement for good health for the major socioeconomic groups, especially pregnant women and children.

Obiero, K., Ogello, E., Munguti, J., Kyule, D., Nyonje, B., Mwaluma, J., Hagiwara, A., & Njiru, J. (2021). Development Strategies and Prospects for Sustainable Aquaculture Development in Kenya. In: Munguti et al., (Eds). State of Aquaculture in Kenya 2021: Towards Nutrition -Sensitive Fish Food Production Systems; Chapter 10: pp 169-175.

10.0. DEVELOPMENT STRATEGIES FOR SUSTAINABLE DEVELOPMENT OF KENYA AQUACULTURE

To realize the strategic goal of 'high-efficiency, high quality, eco-friendly, health and safety', the tasks and relevant measures are identified for sustainable development of Kenyan aquaculture

10.1 ACCELERATE ESTABLISHING THE HATCHERY SECTOR FOR GENETICALLY IMPROVED STRAINS/ VARIETIES IN AQUACULTURE

Research and development of technology systems for culture and breeding of existing and novel aquaculture varieties should be accelerated. Efficient and safe application of breeding technologies should be integrated and innovated, and other genomic technologies for main aquaculture species should be improved. Cell engineering breeding and other new techniques form the frontier of this subject. For the breeding of new varieties, the genes governing high quality, high production, and stress-resistance traits need to be integrated, to produce new breeding materials, with clear target properties and outstanding general properties. In addition, Kenya will have to improve the development of genetically improved varieties/strains and hatchery systems. Based on advanced facilities and technologies, a series of National and County 'Aquaculture Breeding Nucleus and Genetically Improved Species Multiplication Centers' need to be established, to enhance artificial propagation technology, and increase the introduction, testing, demonstration, and geographical spread of genetically improved varieties.

10.2 PLAN FOR THE GROWTH OF MODERN AQUACULTURE PRACTICES

First, aquaculture planning should be established based on environmental carrying capacity. To meet the requirement of environmentally friendly development of aquaculture, baseline surveys of aquaculture areas are needed. Second, assessment systems for carrying capacity of water bodies need to be set up, and assessments of aquaculture carrying capacity, ecological capacity and environmental carrying capacity undertaken. Third, aquaculture development plans should be made according to the result of these assessments, by implementing regional planning or provincial planning, identifying functions and keystones, and applying modern aquaculture practices adapted for various aquaculture areas, production methods, and species. Modern aquaculture production modes should be nested within existing aquaculture planning or be included as major components when a plan is made. One choice is to develop new mariculture modes such as IMTA and RAS. New modes of modern aquaculture are usually constructed in such a way to meet the requirements of high-efficiency, high-quality, to be eco-friendly, and facilitate sustainable development.

- IMTA: Based on carrying capacity assessments, this aquaculture system consists of aquaculture species of different trophic levels, thereby significantly improving the energy efficiency of the aquaculture system. Diversified IMTA modes are currently being trialed in Kenya, including three-dimensional IMTA, and bottom-IMTA farming practices/models (Chapter 3 in this book).
- RAS: Using biological purification techniques, RAS as a new mode of aquaculture stands out in terms of resource conservation, efficiency, and productivity. RAS is slowly expanding in Kenya over the past few years, with diversified system designs, and cultured species.
- Improved ecological engineering has greatly enlarged the geographical and physical area of aquaculture, with varied modes and functions in accordance with different water depths or bottom topography. These new modes include deep-sea cages, multi-functional artificial reefs, and marine ranches. These have won increasing recognition in Kenya because of their semi-natural products, and reduced competition with other aquaculture modes for resources.

10.3 THE ADVANCEMENT OF MODERN AQUACULTURE INSTRUMENTS AND FACILITIES

Aquaculture facilities are important factors influencing aquaculture modes, patterns, species, and production. Kenya will need to extend efforts in improving the standardization and scale of development of traditional aquaculture modes, including inland pond culture and inshore raft culture.

It is expected that aquaculture levels of mechanization and automation will need to be increased significantly, and the application of information technology (web-based and mobile-based applications), and capacity for aquaculture disaster such as major disease outbreaks, degradation of water quality or extreme weather events, or climate change impact mitigation be tangibly improved in the near future.

Special emphasis will need to be given to integrated co-culture and healthy culture modes, land-based industrialized aquaculture and RAS, and deep-sea cages or deep-sea culture platforms, so that the scale of these aquaculture modes will be significantly expanded, and major breakthroughs achieved on key technology research and development. At the same time, unparalleled importance should be attached to the application of energy-saving and ecosystem-conserving technologies in aquaculture. Emphasis should be given to research and development of energy-saving new materials and new instruments, online-monitoring systems, disease diagnosis and control techniques, and aquaculture wastewater reuse techniques.

10.4 STRENGTHENING MODERN AQUACULTURE AND PRODUCT QUALITY MONITORING

Fish disease and pollution control are closely related to product quality in aquaculture. Continued use of banned antibiotics, albeit at much reduced levels, and other bactericides in Kenya has posed new challenges for the aquaculture industry; alternative methods for disease control or prevention must be developed and put into practice as soon as possible. Both basic research and application are urgently needed for establishing disease prevention and control systems, including pathology and epidemiology, evaluation of ecological factors influencing disease outbreaks, and disease prevention technologies such as vaccines, probiotics, and rapid test methods, all have to be developed. In addition, national and local aquaculture disease reference laboratories, aquatic animal disease monitoring and early warning systems, and a series of aquatic medicine and immunotherapy agent manufacturers should also be established.

Besides aquaculture diseases and drug control, control of aquaculture practices is also important to ensure aquatic food safety. Water-quality control is vital for aquaculture development, especially in Kenya where aquaculture facilities are usually located near agricultural and industrial establishments. The development of healthy aquaculture is heavily dependent on clean air, clean water and high-quality feed; thus, enforcement of environmental protection laws and regulations is of the first order of importance.

Aquatic product quality and traceability systems covering the chain of production are currently being established in Kenya. Such traceability systems rely on rapid information release, and the sharing and management of data. They also call for risk assessment and rapid response for aquatic product safety accidents.

10.5 PROMOTION OF AQUACULTURE FEEDS AND FOOD PROCESSING

Digestible feeds with high utilization rates are important for the modern aquaculture industry. Further studies are

> "IN ADDITION, NATIONAL AND LOCAL AQUACULTURE DISEASE REFERENCE LABORATORIES, AQUATIC ANIMAL DISEASE MONITORING AND EARLY WARNING SYSTEMS, AND A SERIES OF AQUATIC MEDICINE AND IMMUNOTHERAPY AGENT MANUFACTURERS SHOULD ALSO BE ESTABLISHED.

recommended on nutritional physiology and metabolism of aquatic animals, to provide the basis for formulating low-cost, low-polluting and high-quality aquatic feeds. Adequate processing and distribution of aquatic products are the basis of a successful and profitable aquaculture industry. Lack of technological sophistication in these sectors has seriously limited the profits of the Kenyan aquaculture industry. Improvements in information dissemination are important for the development of trade of aquatic food, along with the establishment of modern logistics, wholesale markets, and electronic trade networks.

10.6 UPSCALING PRODUCTION SYSTEMS OF MODERN AQUACULTURE

For sustainable development of modern Kenyan aquaculture, we need to integrate all the above-mentioned aspects, and scale up production systems in the following ways. First, steady development of production systems for major aquatic products steadily. Second, acceleration of the development of production systems for valuable and rare aquatic products. Third, the expansion of the production systems for export-oriented aquatic products. Fourth, strengthening the development of production systems for aquatic products.

SYNTHESIS AND WAY FORWARD

The rapid growth of the aquaculture industry has been enabled through the expansion of aquaculture production areas, intensification of production systems, and adoption of new technologies and systematic improvement of existing technologies that brought control over husbandry and production processes. The widening demand and supply gap presents a host of new development opportunities for the small and medium-scale farmers in the region to invest in efficient production systems to significantly contribute to fish consumption, reducing rural poverty and unemployment. In line with a range of research in this book, we make the following recommendations:

(i) DEVELOPING A FISH GENETIC PROGRAM TO PRODUCE IMPROVED FISH BREEDS

The rapid growth of aquaculture in East Africa necessitated a high demand of quality fish seed. However, a lack of coherent Research and Development (R&D) programme for Broodstock improvement at the regional and national level to support selective breeding and genome-based technologies in aquaculture remains a challenge. To enhance aquaculture production, there is need to plan, design and conduct a fish genetic improvement program entail, namely: (1) development of climate-smart culture systems, (2) selection of species, and preservation of germplasm, (3) application of breeding methods and other protocols, (4) on-station and on-farm trials, consolidation of research results, (5) selection of Broodstock and mating system, (6) multiplication and dissemination of improved breeds to hatcheries and fish farmers, and (7) monitoring, impact assessment and comparison of alternative programs.

(ii) FORMULATION AND PRODUCTION OF HIGH-QUALITY AND AFFORDABLE FISH FEED.

Fish feed accounts for over 50-70% of the total variable production costs in aquaculture. For instance, insects are a better option for the expensive fishmeal that accounts for 60 -70% of total production cost in fish production. Use of better-quality feeds and feed ingredients from local suppliers can be supported by improving awareness of the nutritional properties of different feed ingredient options. Insects are rich in crude protein, amino acids, fat content, gross energy and micronutrients. Therefore, rolling-out of insect-based feed protein technologies for improved aquaculture farming would have a huge potential for improving fish production, employment opportunities and livelihoods in the region and beyond.

i. **INCREASING FISH CONSUMPTION FOR FOOD AND NUTRITION SECURITY:** Fish consumption is crucial to women, infants, and children who require high levels of micronutrients and protein for optimal development. With increasing recognition of the benefits of fish as a vital source of essential macro- and micronutrients, nutrition education programmes, such as the *"Eat More Fish Campaigns"* in Kenya, should be devoted to teaching non-fish-eating tribes the benefits of eating fish. The implementation "National Guidelines for Healthy Diets and Physical Activity" should also foster dietary shifts and behavioural changes towards inclusion and consumption of an adequate amount of fish in diets for better nutrition and health outcomes across the population. Fish consumption can further be driven up by addressing barriers to intra-regional trade, cost-effective pricing strategies, post-harvest preservation and value addition technologies, and market information and linkages.

ii. **PROMOTING RESEARCH AND EXTENSION MECHANISMS THAT SUPPORT THE PRODUCTION OF NUTRITIOUS, LOWER-COST FARMED FISH AND SHELLFISH.** There is a need for research and extension service providers to improve technical skills and practical knowledge of fish farmers by giving assistance to women and youth to initiate climate-smart culture technologies in small farms. A range of aquaculture-related extension and communication materials, including posters, hard copy information leaflets and brochures of materials in appropriate languages, short video presentations and radio features, should be initiated to support the smallholder farmers. Public funding for researchers and extensionists is essential for the continued growth of aquaculture production to meet the growing world demand for food. Equally important are the communication pathways by which extension personnel provide input into research programs to direct research efforts to those problems likely to result in the greatest economic and social benefits.

iii. **AVAILABILITY OF ADEQUATE AND AFFORDABLE CREDIT AND FINANCING INSTRUMENTS.** Aquaculture requires an up-front investment in terms of land, infrastructure and inputs (e.g. fingerlings and feed). Insufficient access to capital and cash liquidity is one of the most commonly stated constraints to aquaculture development in Eastern Africa. It is therefore important that financial structures are in place to provide responsible and reasonably priced lending to aquaculture producers as they expand, especially when the investors present a well-considered business case for borrowing and repayment strategies. In most cases, small- scale farmers lack the credibility and collateral for accessing formal credit, sometimes resulting in unfavourable borrowing from informal sources.

iv. Further research and interventions are recommended to inform sustainable food systems based on the recommended calorific requirement for good health for the major socioeconomic groups, especially pregnant women and children. Food security and nutritional programmes should recognize the potential of fish to improve dietary quality, micronutrient intake, nutrient status, and overall health. Although it is generally assumed that fish demand at the global and regional levels are mainly driven by increasing incomes and population growth, at national level, there are other important factors such as increased awareness of the health benefits of fish consumption, changes in consumer taste and preferences, especially in areas where fish was not traditionally consumed. In addition, future studies should also investigate the types of fish consumed, their nutritional status as well as social, cultural, and economic factors influencing fish consumption preferences.

v. **SUPPORTING LAND AND WATER TENURE ARRANGEMENTS THAT ENABLE A RANGE OF PRODUCERS TO ENGAGE IN THE SECTOR.** Successful aquaculture is dependent upon the use of a good site that has controlled access to suitable water resources. In this regard, clear and established rights for access to land tenure and water rights, allied to a transparent, fair and supportive permitting framework is required in Eastern Africa. On land, ensuring land tenure is equally important, and development of pond farming or other forms of extensive or semi-extensive aquaculture are highly dependent upon reliable access to suitable water resources. While cage culture is a promising venture to increase aquaculture productivity, promote employment opportunities and enhance economic wellbeing, recent studies show 45% of cages are located within 200 metres of shoreline which is likely to cause conflict with other lake users. Other concerns related to cage culture include localized eutrophication from excess nutrients, use of poor-quality feeds that may not be fully utilized, high carrying capacity and stocking densities and lack of knowledge and expertise by local cage farmers. This calls for an urgent need to formulate and implement national and regional policies and regulations to reduce the environmental effects and improve the economic performance of cage culture.

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