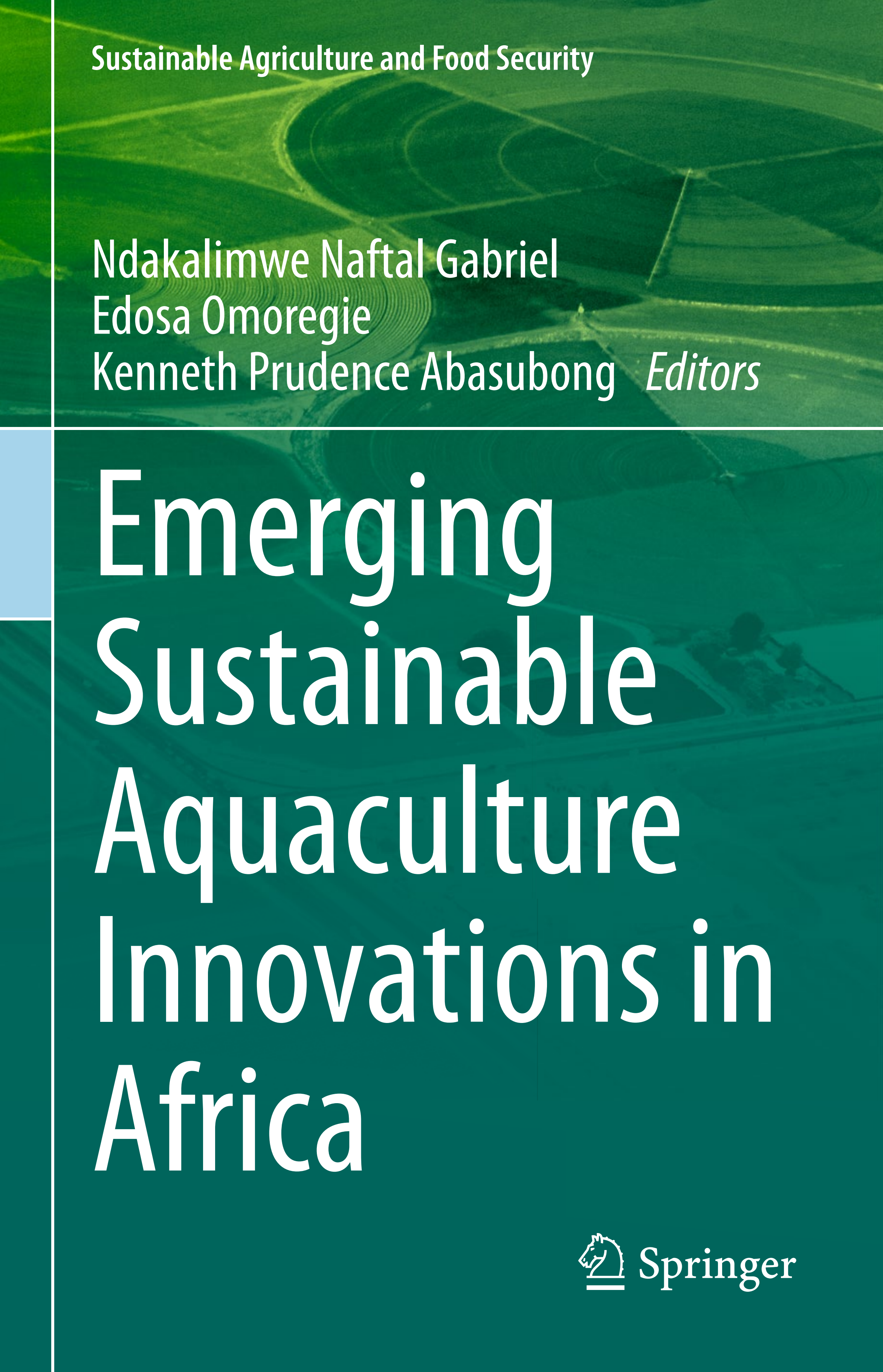

Sustainable Agriculture and Food Security

Ndakalimwe Naftal Gabriel
Edosa Omoregie
Kenneth Prudence Abasubong *Editors*

Emerging Sustainable Aquaculture Innovations in Africa

Springer

Sustainability Sciences in Asia and Africa

Sustainable Agriculture and Food Security

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Ndakalimwe Naftal Gabriel • Edosa Omoregie •
Kenneth Prudence Abasubong
Editors

Emerging Sustainable Aquaculture Innovations in Africa

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Preface

The global food production systems require expanding their capacity to produce almost twice the current levels to safeguard the food security of the burgeoning population worldwide. More than 800 million suffering from undernourishment worldwide pose a great risk to the attainment of sustainable development goal (SDG) 2 of the UN that targets "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" within the next 7 years. The challenge is further exacerbated by the rising weather extremities and unpredictability in rainfall patterns and pest-pathogen dynamics associated with global climate change that has profound negative impact on the agricultural productivity and farm incomes worldwide. Also, the future targets of food production should be secured in a resource-constrained agricultural setting and with least environment footprint, thus calling for sustainable innovations in agri-farming systems and enhanced participation of women in agriculture. The challenge to reduce hunger is alarming in the case of developing nations particularly in Asia and Africa that house the largest proportion of people suffering from malnutrition and other nutrition-related issues. Furthermore, the agri-food systems in Asia and Africa are severely constrained by subsistence nature of farming, declining land and other agricultural resources, increasing environmental pollution, soil and biodiversity degradation, and climate change. Therefore, this book series, "Sustainable Agriculture and Food Security," has been planned to support the global efforts towards sustainability by providing timely coverage of the progress, opportunities, and challenges of sustainable food production and consumption in Asia and Africa. The series narrates the success stories and research endeavours from the regions of Africa and Asia on issues relating to SDG 2: Zero hunger. It fosters research in transdisciplinary academic fields spanning across sustainable agriculture systems and practices, post-harvest and food supply chains. The focus of the series is to provide a comprehensive publication platform and act as a knowledge engine in the growth of sustainability sciences with a special focus on developing nations.

As per the UN's Food and Agriculture Organization (FAO), aquaculture is defined as the '*farming of aquatic organisms including fish, molluscs, crustaceans* *and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated, the planning, development and operation of aquaculture systems, sites, facilities and practices, and the production and transport.*' Although aquaculture has been around for millennia, it started to contribute significantly to the global food supply and rural livelihoods about 30–40 years ago. In the context of target geographic regions of the book series, Asia dominates global aquaculture accounting for 92% of global production, and Africa has <2% share in global production. However, in the last 20 years, aquaculture production in sub-Saharan Africa (SSA) has grown by 11% annually on average, almost twice as fast compared with the rest of the world, and some African countries with a growth of 12–23% per year. However, due to fish disease triggered by poor water and farm management practices in the beginning of 2015, the high cost of local production, competition from cheap fish imports, and then the recent addition of the COVID-19 pandemic, the production level has been stagnated. As per an estimate, the projected increase in demand for aquatic foods in SSA required that aquaculture produces an additional 5 million tonnes by 2030 and 10.6 million tonnes by 2050. However, such growth must not come at the cost of aquatic ecosystem health, increased pollution, animal welfare, biodiversity, or social equality. This requires new, sustainable and equitable aquaculture development strategies.

According to a joint report of Agence Française de Développement (AFD), European Commission, and German International Development Agency (GIZ), '*the aquaculture value chain—whether it be the primary production stage or the subsequent product supply chain—can contribute to achieving SDGs at both national and regional levels.*'

Among different kind of aquaculture types—subsistence aquaculture, small-scale commercial aquaculture, SME aquaculture, and industrial aquaculture—the subsistence aquaculture has the potential to contribute to most of the relevant SDGs. This is due to the family level of operations, where work is well distributed, meaningful, and empowering. Small-scale commercial aquaculture in terms of its contribution to the SDGs also has a greater opportunity to directly contribute to family income, and thus address poverty issues. This will assist to achieve other SDGs at community level, including good health and education opportunities. It can also generate some jobs, and being local, can be undertaken on a part-time basis by women. In the majority of the aquaculture sector in Africa, the above-mentioned two types of aquaculture farming are more common in Africa, and therefore improving aquaculture in Africa will significantly contribute to achieving SDGs.

In view of this, the present book, *Emerging Sustainable Aquaculture Innovations in Africa,* provides a platform to appreciate current efforts and plan future work on this important topic. The book contains 26 chapters written by various experts and practitioners in aquaculture in Africa. The chapters are written under four parts: Aquaculture Nutrition and Feed Management, Water Quality Management, Aquaculture Development and Innovations in Africa, and Aquaculture Animal Welfare. I would like to congratulate the editors, Ndakalimwe Naftal Gabriel, Edosa Omoregie, and Kenneth Prudence Abasubong, and all authors for their valued contributions. I am sure that this book is a great resource for students, researchers, aquaculture farmers, aquaculture educators and extension agents, policy makers, and other stakeholders engaged in transforming aquaculture in Africa and possibly other parts of the world.

I wish to extend my sincere thanks and gratitude to the Springer staff, particularly Aakanksha Tyagi, Senior Editor (Books), Life Sciences, and Naren Aggarwal, Editorial Director, Medicine, Biomedical and Life Sciences Books Asia, for their constant support for the accomplishment of this compendium. The cooperation received from my senior colleagues and research leaders such as David Morrison, Peter Davies, and Daniel Murphy and my laboratory colleagues Anu Chitikineni, Abhishek Bohra, and Vanika Garg from Murdoch University (Australia) is also gratefully acknowledged. I would like to thank my family members Monika Varshney, Prakhar Varshney, and Preksha Varshney for their love and support to discharge my duties as Series Editor.

Perth, WA, Australia Rajeev K. Varshney

Contents

Part I Aquaculture Nutrition and Feed Management

Part II Water Quality Management

Part III Aquaculture Development and Innovations in Africa

Part IV Aquaculture Animal Welfare

Chapter 15
Nutrient Budget of Cage Fish Culture in a Lacustrine Environment: Towards Model Development for the Sustainable Development of Nile Tilapia (*Oreochromis niloticus*) Culture

Safina Musa, Christopher Mulanda Aura, Tumi Tomasson, Ólafur Sigurgeirsson, and Helgi Thorarensen

Abstract Carried out fundamentally in an open system, cage culture-derived nutrients can exacerbate the quality of the lacustrine environment. Information on nutrient loading from African inland waters is scarce, yet sustainable development of fish cage culture depends on it. This chapter reviews siting of fish cages, nutritional content, digestibility of fish feeds, and nutrient load in wastes of Nile tilapia in African inland waters. In addition, this chapter proposes a theoretical model for nutrient (nitrogen N and phosphorus P) budget in a Nile tilapia cage aquaculture farm to calculate the amount (kg) of N and P produced and released to the environment for each ton of fish produced basing on best and worst-case scenarios. The review shows that majority of the cages are sited nearshore and/or in shallow areas that could exacerbate environmental challenges. Poor digestibility of fish feeds, particularly P, raises concern due to the risk of eutrophication. The majority of the feeds used in African inland waters for cage fish culture recorded N deficiency in relation to P that could lead to poor retention, hence high nutrient loading into the

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environment. The theoretical model shows that about 46% of N and 39% of P from feed input are released into the environment for each tonne of tilapia produced. However, when the feed loss is high but at the same time the nutrient retention in fish is inefficient, 91% of N and 89% of P from feed input are discharged into the environment. Sensitivity analysis shows that nutrient loading from cage culture is very sensitive to feed loss, FCR and nutrient retention. The paper concludes with recommendations that need to be considered to minimise nutrient loading and its impact on the environment.

Keywords Nile tilapia · Cage culture · Digestibility, Nitrogen, Phosphorus · Nutrient loads

15.1 Introduction

Globally, wild fish stocks are at their production limit at a time of rapid human population growth, urbanisation and income increase have sent demand for fish protein skyrocketing (Akintola et al. 2013; FAO 2016; Anderson et al. 2017). The dwindling catches have increased the interest in cage culture as an alternative source of fish (Aura et al. 2017; Musinguzi et al. 2019; Hamilton et al. 2020; Musa et al. 2021a), and aquaculture will necessarily play a central role in bridging the widening gap between fish demand and its supply (FAO 2018; Obiero et al. 2019; FAO 2020).

Cage fish culture is an old practice and dates to the late 1800 in Southeast Asia (Bao-Tong 1994) but has recently expanded throughout the world due to its benefits. As compared to pond fish culture, cages can be stocked at higher densities hence high production per unit volume of water; many types of existing water bodies can be used, hence reducing pressure on land, a relatively low initial investment is required in an existing body of water, ease of harvesting of fish, less manpower is required and high return on investment (De Silva and Phillips 2007; EL-Sayed 2006). For a long time in Africa, cage fish culture has been reported to be still in its infancy (Bostock et al. 2010; Asmah et al. 2016; Aura et al. 2018). However, by 2010, the cage fish culture industry in Africa was reported to be emerging at a faster rate than any other region (Bueno et al. 2015). The rapid expansion of cage fish farming on African inland waters has been reported in Lake Victoria in Kenya (Aura et al. 2018), Lake Victoria in Uganda (Blow and Leonard 2007), Lake Volta in Ghana (Asmah et al. 2016), Lake Kariba in Zimbabwe (Berg et al. 1996), Lake Malawi in Malawi (Blow and Leonard 2007), with Lake Victoria recording the highest number of cage aquaculture installations by the year 2019 (Table 15.1). In sub-Saharan Africa, the production of aquaculture fish has increased more than sixteen-fold since 1995 (FAO 2018), driven primarily by the expansion of tilapia cage aquaculture (Satia 2011).

While cage aquaculture is expanding in sub-Saharan Africa, such systems may have negative environmental consequences. Contrary to pond fish farming, which depends on fertilisers with high N and P contents to promote biological productivity, cage systems are seldom fertilised. Yet, N and P are essential elements for

Table 15.1 Estimated number of cages on African inland water bodies by 2019, adopted from Musinguzi et al. (2019)

Country	Water body	Estimated total number of cages
Kenya	Lake Victoria	12,086
Ghana	Lake Volta	3817
Ghana	River Volta	3184
Zambia	Lake Kariba	254
Rwanda	Lake Kivu	208
Rwanda	Lake Muhazi	199
Uganda	River Nile	135
Malawi	Lake Malawi	53
Uganda	Lake Albert	
Uganda	Lake Kyoga	102
Uganda	Kazinga channel	10
Uganda	Lake George	10
Uganda	Lake Kawi	3
Tanzania	Lake Kumba	40
Uganda	Lake Mugogo	
Uganda	Lake Pallisa	4
Tanzania	Lake Tanganyika	
Uganda	Reservoir	10
	Total	20,114

organismal development (Ackefors and Enell 1994; Von Sperling and Chernicharo 2005). Consequently, fish feeds for cages have higher N and P content (Musa et al. 2021b). Cage aquaculture raises concerns about water quality deterioration due to solid wastes (Ngupula et al. 2012; Aura et al. 2018) and soluble wastes, especially nitrogen and phosphorus compounds. Over time, this may cause eutrophication (Aura et al. 2018), algal blooms and changes in zooplankton community structure (Braaten 2007; Ngupula and Kayanda 2010; Villnas et al. 2011; Kashindye et al. 2015; Egessa et al. 2018). Therefore, the rapid expansion of cage fish culture in most African inland lakes, such as Lake Victoria, systems already under severe environmental stress (Hecky et al. 2010), is highly questionable.

With the burgeoning industry coupled with little regulation, the use of more inputs, mainly fish feed, is likely to skyrocket (Henriksson et al. 2018; Musa et al. 2021b), synonymous with increased waste generation. Moreover, the high densities of fish in cages would translate to the high production of wastes from unused feeds and faeces. This could be detrimental to the lake's ecosystem health, threatening the future sustainability of capture fisheries even more and preventing the development of a sustainable blue economy.

Sustainable cage fish culture and the development of a sustainable blue economy will depend on understanding the nutrient loads of cage farms in freshwater aquaculture since every ecosystem has a maximum assimilative capacity, which is determined by the maximum acceptable environmental impacts (Samuel-Fitwia et al. 2012). Furthermore, reducing the environmental footprint of cage culture operations requires estimating the amount of waste associated with such systems and their management. Yet, the fate and quantitative contribution of the new N and P sources emanating from feed wastage in cage fish culture in African inland waters is scarce. Understanding the nutrient budget of cage fish farms is useful in lacustrine development, management, and policy formulation. This chapter reviews factors affecting nutrient loads and their impacts, quantify nutrient loadings from cage fish culture in African inland waters from reported literature and hypothesised nutrient budget and carries out sensitivity analysis on the hypothesised model to explore and better understand the effects of uncertainties on nutrient loadings in the production of Nile tilapia to guide cage culture investments.

15.2 Factors Affecting Nutrient Loads and their Impacts on Inland Waters

15.2.1 Siting of Cages

Cage systems, if not correctly cited, can cause eutrophication, habitat degradation, and cause conflicts with other users (Beveridge 1984). These scenarios are highly likely to occur in African inland waters due to the burgeoning industry and because most cage fish farms in African inland waters use backyard fish feeds with low water stability (Musa et al. 2021b), which can worsen environmental challenges from such systems (Beveridge 1984). The majority of the fish cages (>70%) in African inland waters are sited nearest to the shoreline (Table 15.2), contrary to best practices that require cages to be placed within the 200 m distance from the shoreline of the lakes. Furthermore, almost all cages in African inland lakes are in shallow waters (4–8 m) (Musinguzi et al. 2019) despite recommendations that cages should be placed in deeper waters (>10 m) (Kamadi 2018). Nearshore and shallow areas have low flushing rates, resulting in high nutrient loading and increased phytoplankton

Table 15.2 Estimated distance (range and mean) between the shoreline and cages (Musinguzi et al. 2019)

Water Body	Distance of cages from shoreline (m)	
	Range	Mean
Lake Kariba	220.2–1759.8	894.4
Lake Kivu	5–120.1	41.3
Lake Kumba	N/A	66.7
Lake Malawi	N/A	1100
Lake Muhazi	48.23–150	82.6
Lake Tanganyika	141.99–142.0	141.99
Lake Victoria	21–665	211.6
Lake Volta	0–860	191.7
River Nile	13.4–621	178.5
River Volta	0–321	30.2

biomass from excess feeds. Most inland lakes, such as Lake Victoria, are already choking on excessive nutrients from industrial and agricultural wastes. Therefore, inappropriate siting of cages could exacerbate environmental challenges. Moreover, a regulatory framework for cage aquaculture for most African inland lakes is inadequate. Therefore, the burgeoning industry may pose a threat to ecosystem health.

The majority, if not all, of the African inland lakes, have not been mapped for suitable sites for cage culture, hindering sustainable development of the industry. However, preliminary delineation of suitable sites for cage farms in the Kenyan part of Lake Victoria has been undertaken, with approximately 9% of the total area delineated as most suitable for fish cages (Fig. 15.1) (Aura et al. 2021). The findings could be a model for other African inland lakes where tilapia cage culture already occurs or may occur in the future.

15.2.2 Nutritional Content and Digestibility of the Feeds

Just like other cultured species, nutrition is essential, not only for the growth of tilapia but for the environmental sustainability of cage systems (Musa et al. 2021b). Kong et al. (2020) reaffirm that fish feed quality is a critical factor in determining the environmental impact of aquaculture. Most of the studies carried out on fish feeds in Africa (Table 15.1) have shown that the dietary protein content for feeds follows the recommended levels (25–35%) for Nile tilapia larger than 10 g (Balarin and Haller 1982; Tacon 1987; El-Sayed and Teshima 1991; Khattab et al. 2000). However, backyard feed in Africa seems to record higher fibre content, hence inferior to extruded feed (Table 15.1). Fibre content above 8–12% is undesirable in fish feed because it reduces digestibility (De Silva and Anderson 1995; Leal et al. 2010); hence would translate to high nutrient loading into the environment. A high level of fibre has also been reported to reduce dietary protein utilisation in several species (Leary and Lovell 1975; Fontainhas-Fernandes et al. 1999). The low digestibility of backyard feed could also be attributed to high ash content, which is in line with Kitagima and Fracalossi (2011), who reported low dry matter digestibility for fish and shrimp offal meals with high ash contents. Similar results have also been observed in rainbow trout (*Oncorhynchus mykiss*) (Bureau et al. 1999) and hybrid tilapia (*O. niloticus* × *Oreochromis aureus*) (Zhou and Yue 2012). Overall, the high digestibility of nutrients in extruded feed could have been enhanced by extrusion cooking (Cheng and Hardy 2003; Barrows et al. 2007; Gaylord et al. 2008), thereby making commercial feed superior to backyard feed.

Most of the fish feeds in Africa have higher P content (above 1%) (Table 15.3) despite recommendations that P content for tilapia feeds should be less than 0.7% (KEBS 2015). Hence, apart from losses due to unavailability, the excess P in fish feeds cannot be metabolically utilised by fish and will ultimately be released into the environment (Roy and Lall 2004; Kong et al. 2020). This can increase the pollution potential from fish feeds. Fish feeds are the significant production cost for

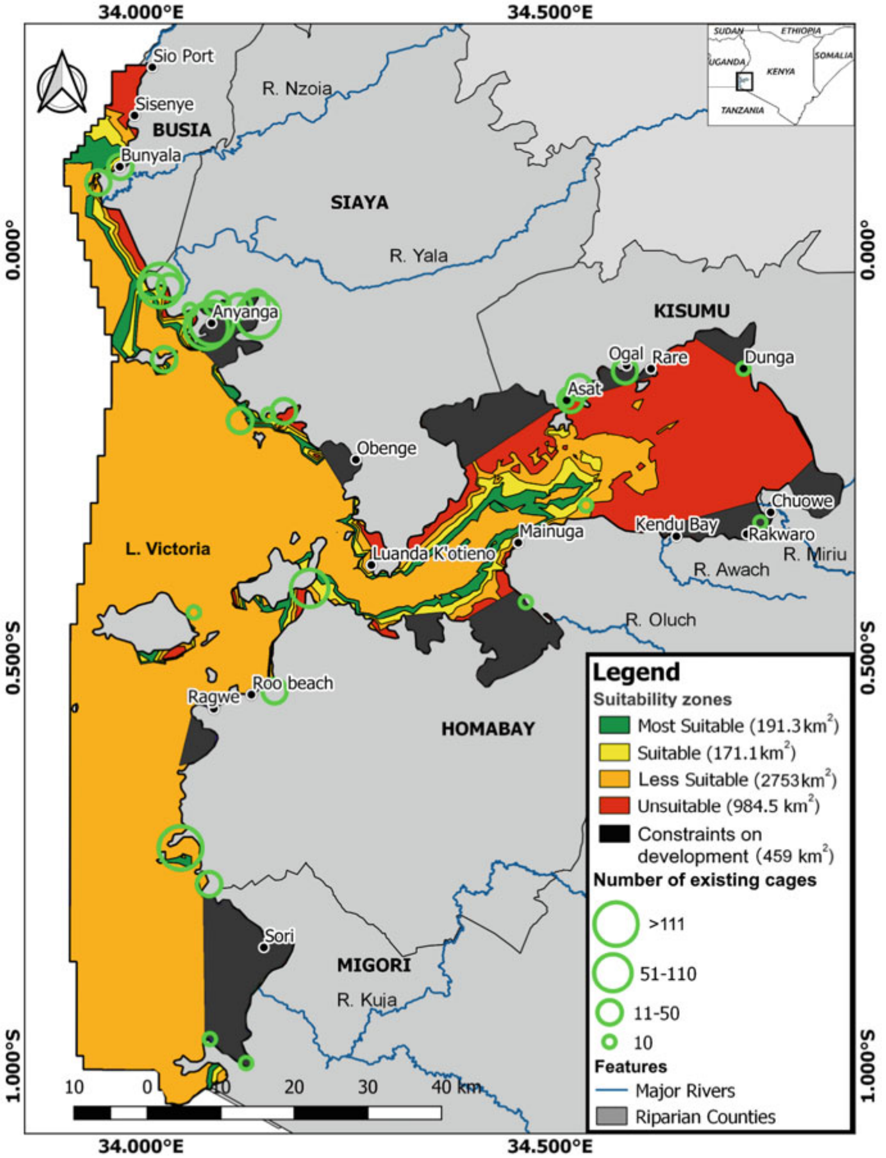

Fig. 15.1 Map of Lake Victoria, Kenya, showing potential suitability for cage fish culture. (Aura et al. 2021)

aquaculture (Naylor et al. 2000; FAO 2020) and commonly account for over 60–70% of the cost of producing tilapia (Bolivar et al. 2006; Elnady et al. 2010; Musa et al. 2021a). Due to the high costs of fish feeds, many efforts are being diverted to replacing the expensive animal protein with plant protein ingredients.

Table 15.3 Nutritional content (g kg^{-1}) for pelleted and extruded feed used for Nile tilapia cage culture in African inland waters

Nutrients (g/kg)	Musa et al. (2021a, b)	Musa et al. (2021a, b)	Neto and Ostrensky (2015)	Gondwe et al. (2011)	Karikari (2016)
Total dry matter	948	947.8	902.3	845	915.5
Digestible dry matter	680.7	560.3	608.5	–	–
Total organic matter	800.2	804.4	806.8	–	–
Digestible organic matter	605.2	577.3	578.9	–	–
Crude protein	301	282	276.7	359.4	350
Digestible protein	277.3	245	236.8	–	–
Crude fibre (g/kg)	42.1	168.2	42.8	–	–
Ash	92.4	130.4		–	77
Total phosphorus	10	11.5 ± 1.0	14.5	8.7	14
Digestible phosphorus	5.87	3.2 ± 0.6	6.5	–	–

Plant ingredients have been reported to increase the digestibility of protein fraction of plant ingredients (Pezzato et al. 2002; Neto and Ostrensky 2015). However, plant ingredients have been associated with higher P loss due to the low digestibility of P. According to Ravindran et al. (1994), Up to 80% of the total P content in plant ingredients is reported to be in phytate. Most monogastric aquatic animals lack endogenous enzymes for phytate hydrolysis (Cao et al. 2007). The low digestible P content in fish feeds in Africa, particularly in backyard feed, could be due to the high inclusion of plant ingredients in the diets (Musa et al. 2021b), raising concern due to the risk of eutrophication, especially in freshwater lakes such as Lake Victoria that has been reported to be highly eutrophic (Ochumba and Kibaara 1989; Lung'ayia 2000; Kling and Mugidde 2001).

15.3 Nutrient Load in Wastes in African Inland Waters

The amount of waste produced in cage fish farming depends on several factors, including feed quality, feed processing method and feed loss. Extrusion processing of fish feeds has been reported to produce quality pellets and improve faecal size and durability in water, hence reducing pollution in effluents (Welker et al. 2018). Notably, extruded feeds have been reported to have high water stability compared to pelleted feeds, hence fewer nutrients leaching from the feeds (Musa et al. 2021b).

Table 15.4 Reported types of fish feed, FCR and nutrient loading in cage fish farming in African inland waters

Reference	Type of feed	FCR	Total amount of nutrient involved (kg)		Nutrient recovered in fish (kg)		Net amount of waste output (kg)	
			N	P	N	P	N	P
Musa et al. (2021a, b)	Commercial feed	1.6	76.8	16	27.2	8.5	49.6	7.5
Musa et al. (2021a, b)	Backyard feed	2.8	126	30.8	21	7.8	105	23
Karikari (2016)	Commercial feed A	2	123.4	26.9	29.9	4.1	93.5	22.8
Karikari (2016)	Commercial feed B	1.7	105.4	22.95	29.83	4.41	75.6	18.6
Gondwe et al. (2011)	Commercial feed	2.7	155.3	23.5	50.6	8.1	104.7	15.4
Neto and Ostrensky (2013)	Commercial feed	1.35	69.23	19.86	24.23	5.56	45	14.3

This reduces the pollution potential from the aquaculture system. Table 15.4 shows the feed types and N and P budgets from available literature on tilapia cage culture in African inland waters. The N and P loading varied considerably with higher FCR (>2), giving the highest N (>100 kg/ton) and P (>23 kg/ton) loadings. Notably, the environmental loading of P and N per kg of tilapia produced seems to be more than twice as high when backyard feed is used compared to extruded feed (Table 15.4).

Mass balance analysis for cage fish culture has been carried out for a long time in temperate environments, and it has shown that about 31% N and 31% of P added through fish feeds were removed as fish biomass, and about 69% of N and 69% of P were discharged into the environment (Gowen and Bradbury 1987; Holby and Hall 1991; Hall et al. 1992). For the few mass balance models for tilapia in Africa, >30% of N added through fish feeds have been reported to be removed by fish at harvest. However, less than 25% of P added through fish feeds were removed by fish at harvest (Table 15.4). The assimilation of N from feed by fish in the tropical region was comparable to the temperate region, while the assimilation of P was much poorer than in temperate studies. The poorer assimilation of P in the tropical region herein could be because the majority of the fish feeds reported N deficiency compared to P, as indicated by lower N:P ratios in feed as compared to fish. The lowest N:P ratio in feeds in the tropical region confirms that P in fish feeds could be more than required for growth. Research in temperate and tropical countries concur that fish feeds are the primary source of added N and P from fish cage culture in a lacustrine environment (Gondwe et al. 2011; Neto & Ostrensky 2013; Karikari 2016; Musa et al. 2021b). Hence, the addition of N deficient fish feeds in African inland waters will not only reduce the growth rate of caged tilapia but will lead to poor retention and high nutrient loading into the environment. In most freshwater lakes such as Lake Victoria, phytoplanktons are limited by N rather than P (Guildford and Hecky 2000; Gikuma-Njuru and Hecky 2005; Mwamburi et al. 2020), favouring heterocystous N-fixing cyanobacteria. Loss of N deficient fish feed from cage farms could exacerbate this effect.

The environmental losses of nitrogen and phosphorus from cages in tropical countries proved to be threefold more significant than those reported in the literature for laboratory experiments and pond culture (Fernandes et al. 2007; Boyd et al. 2008; Azevedo et al. 2011). This could have been associated with culture systems, and it could also be because most of these studies did not estimate feed loss. It could also indicate that fish cage culture may have higher inputs of nutrients to the environment than pond fish farming, which could become a bone of contention for the industry.

15.4 Theoretical Mass Balance Model

In this section, we will use a theoretical mass balance model to estimate the levels of N and P discharged from cage fish farms producing a tonne of tilapia. The hypothetical model uses average values from published literature on the different components to formulate the model using various assumptions on feed loss, FCR, N and P content of feed and fish. The nitrogen content of farmed tilapia is 3% (on a wet weight basis) (Neto and Ostrensky 2013). The phosphorus content of tilapia is 0.85% (Musa et al. 2021a, b). The current cage culture of tilapia utilising commercial feeds limits feeding loss to 5% (Musa et al. 2021b). For juveniles $>$ 10 g, 25–30% crude protein level is recommended (Balarin and Haller 1982; Tacon 1987; El-Sayed and Teshima 1991; Khattab et al. 2000). Phosphorus content in tilapia feeds have been reported to be between 1–1.6 (Neto and Ostrensky 2013, Musa et al. 2021b). Previous studies on Nile tilapia have reported FCR of 1.4–4.4 (El-Sayed 1998; Al-Hafedh 1999; Liti et al. 2005, 2006; Kubiriza et al. 2017; Musa et al. 2021b). In the hypothetical model, a total input of 64 kg and 16 kg for N and P, respectively, is required to produce a tonne of Nile tilapia (Fig. 15.2). With FCR of 1.4, a total of 26 kg (46.42%) N and 5.5 kg (46.88%) P is released into the environment for every tonne of Nile tilapia produced in cages. A total of 30 kg (53.57%) N and 8.5 kg (60.71%) P were retained by harvested fish. According to Boyd and Queiroz (2001), 61.9–77.2% of nitrogen from feed inputs is loaded into the environment, while phosphorus loads account for 43.8–89.4% of feed inputs. The low TN and TP loadings recorded in the hypothetical model (Fig. 15.2) were based on moderate values for FCR and feed loss in tilapia culture. However, higher FCR of $>$3 have been recorded for tilapia (Gondwe et al. 2011; Kubiriza et al. 2017); hence the nutrient loadings, in reality, may be higher than those recorded in the hypothetical model.

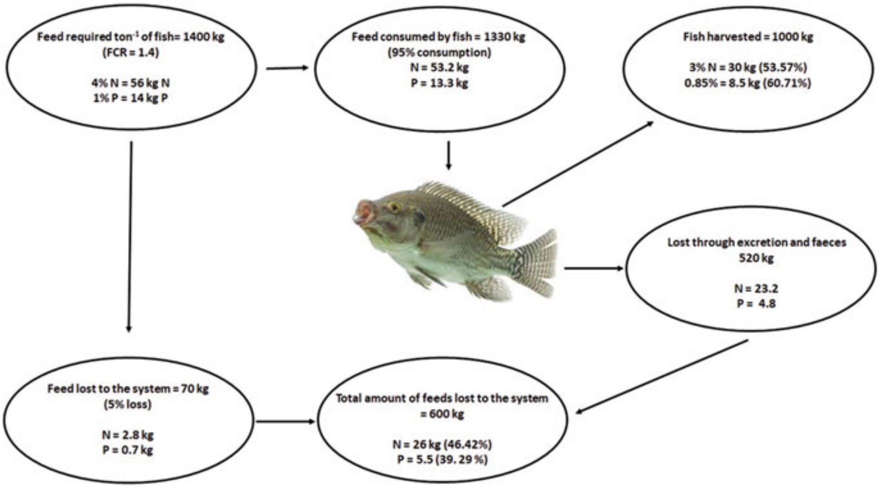

Fig. 15.2 Theoretical model for nutrient mass budget for a conjectured production of one ton of Nile tilapia in cages in a lacustrine environment

15.4.1 Sensitivity Analysis of the Model

Many factors can affect the loading rates of nutrients in a lacustrine environment; hence the nutrient loads reported in African inland waters in Table 15.4 above and in the theoretical model (Fig. 15.2) may vary with different factors. Musa et al. (2021b) reported a feeding loss of up to 25% for cage fish farms in Lake Victoria, Kenya. However, higher feed loss exceeding 30% has been reported under aquaculture elsewhere (Thorpe et al. 1990), with a corresponding increase in FCR values. Wu (1995) recorded a feeding loss of up to 40% when fish were fed on trash fish. Sometimes higher N and P have been reported in fish feeds (8% N reported by Hall et al. 1992 and 2.14% P reported by Foy and Rosell 1991) and lower in fish muscle.

In a scenario where cage farms use fish feeds with higher feed loss (e.g. 20%) and, in essence, higher FCR (e.g. 4), leaving other factors constant, the farm would discharge about 5 times the amount of N and 6 times the amount of P in the environment compared to the theoretical model (Fig. 15.3a). In the second scenario, where the feed loss is high, but at the same time the nutrient retention in fish is inefficient, the cage farms would discharge about 91% of N and 89% of P in the environment (Fig. 15.3b). This is in line with the studies of Handy and Poxton (1993), who showed that when the feed wastage is high and the N retention rate is lower, greater than 90% of the supplied N is lost to the system. The model indicates that nutrient loading from the cage culture of Nile tilapia is very sensitive to feed loss and, in essence, the FCR of the diet. Nutrient retention is the next factor that affects nutrient loading in a lacustrine environment. In aquaculture feed cost accounts to upto 70% of the production costs (Watanabe 2002; El-Sayed 2006; Cheng et al. 2010; Khalil et al. 2019; Allam et al. 2020). The values have been reported to be

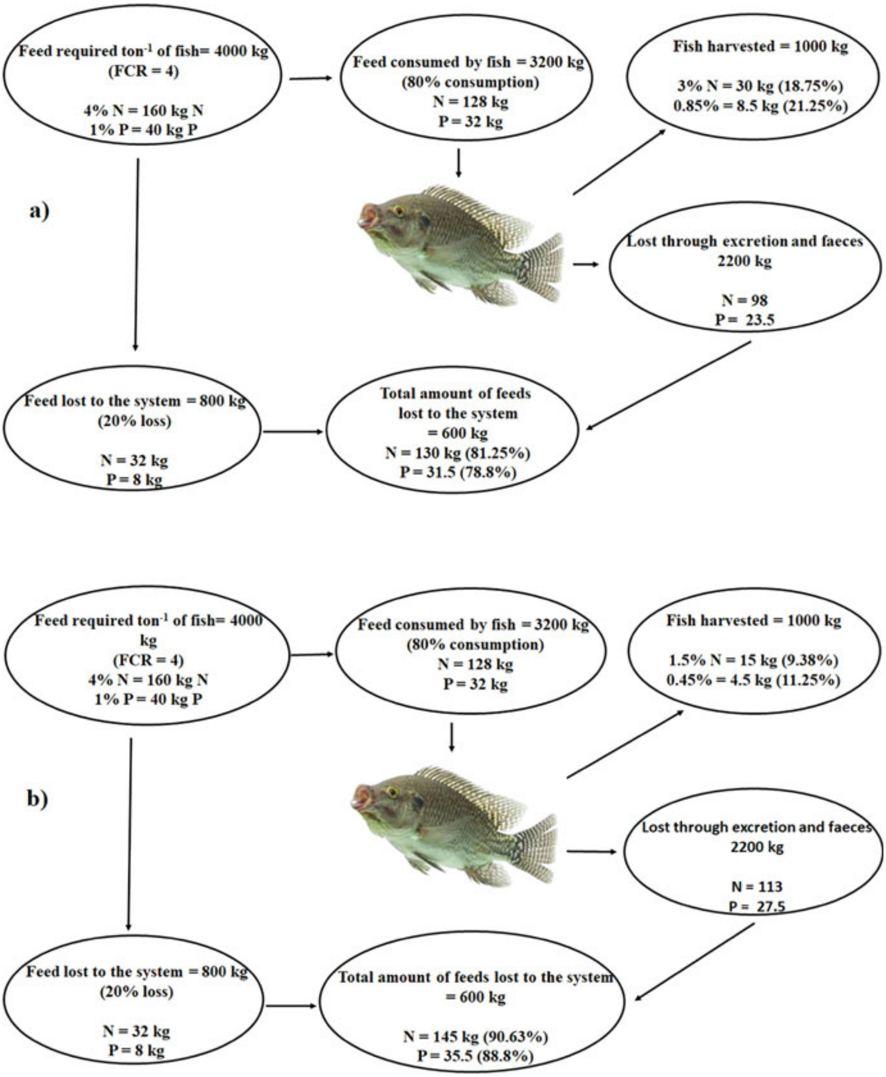

Fig. 15.3 Mass budget for a conjectured production of one ton of Nile tilapia in cages in a lacustrine environment for two different pollution scenarios: (**a**) when the rate of feed loss is high hence higher FCR and (**b**) when the rate of feed loss is high, FCR is high with poor N assimilation and retention

even higher (>70%) in cage culture (Musa et al. 2021b). The need to minimize feed losses cannot be overemphasized, not only for environmental sustainability in fish cage culture but for economic production issues (Talbot and Hole 1994; Musa et al. 2021b).

15.5 Conclusion and Recommendations

Feed quality is a key factor in determining the impact of aquaculture on the environment. The nutrient loads in African inland waters are higher than desirable due to the low digestibility of feeds translating to higher FCRs. The low N content in relation to P and high fibre contents of fish feeds result in a higher nutrient discharge into the environment. In addition, the use of backyard fish feeds for fish cage culture seems inferior to commercial feeds not only due to high fibre content but primarily due to low water stability that could cause a disproportionate increase in total P and N output loading from cage fish farming. The use of commercial fish feed is highly recommended for cage fish culture in African inland waters. We recommend the zonation of suitable sites for cage fish farming in all African inland lakes to ensure proper water circulation and, in essence, good water quality. Good water quality will ensure a high appetite for fish, resulting in the increased digestive function of the intestine and increased digestibility of nutrients in the intestines, translating to low FCRs. In addition, using best practices in feeding regimes will go a long way in reducing FCR and, in essence, the cost of production. There is a need to enhance the N content of fish feeds to reduce P discharge into the environment and limit the proliferation of nitrogen-fixing cyanobacterial species.

Furthermore, there is a need to incorporate phytase in plant-based fish feeds to enhance the bioavailability of P and reduce the nutrient discharge into the environment. The environmental sustainability of the cage culture industry is very sensitive to feed loss. Hence, feeding management practices, particularly those that reduce feed loss, is a crucial point in reducing the input of these nutrients in the aquatic environment. For example, using water-stable pellets through extrusion would be one way of reducing feed loss to the environment. We recommend fast-tracking of regulations for inland waters to control locations of new entrances and relocation of existing cages to appropriate locations. Furthermore, mapping suitable sites for cage fish culture in African inland waters coupled with best management practices is imperative so that aquaculture remains within the carrying capacity of inland water bodies for the environmental sustainability of the industry.

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