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Cover photograph: Dagaa (*Rastrineobola argentea*) is sold at a local market in Tanzania. © Modesta Medard

Preparation of this document

Small pelagic fish species, naturally occurring or introduced to lakes and reservoirs, form some of the most important inland fisheries in Africa and account for the highest volume of inland fishery catches on the continent. The group's contribution to the inland catch is steadily increasing, along with its role in nutrition and trade. This technical paper reviews the status and importance of inland pelagic fish and fisheries, and small fish in general, for sustainable and healthy livelihoods in Africa. It reviews the biology and biological production of the most important pelagic species in lakes and reservoirs, as well as the impacts of environmental and climatic variation on stocks of these species. It examines and discusses the various capture techniques and the potential for improving the fisheries and associated processing and national and regional trade within Africa. The knowledge generated by the technical paper will be useful for policymakers and development practitioners and enable them to design and implement more effective policies, strategies and programmes that will contribute to reducing the food insecurity and conflicts that currently affect the people of sub-Saharan Africa.

Abstract

The recorded catches of most of the larger commercial fish species in Africa, such as large breams (Cichlidae), carps (Cyprinidae) and perches (Perciformes), which have been the focus of fisheries management, have not changed greatly over the past three decades. In contrast, the landings of small species of herring (Clupeidae), carp, bream and characin species – mostly zooplankton feeders, predominantly living in open waters of African lakes and reservoirs – in short, "small pelagic fish"– have steadily increased. These fisheries have developed in addition to the fishing of, and sometimes as a reaction to, decreased catch rates of larger species, introductions and the creation of large water bodies such as reservoirs. They now represent nearly three quarters of the total inland fish catch of the African continent, although there are known difficulties in obtaining accurate inland fishery catch statistics. Despite limited stock assessments, there are no clear examples of a small pelagic fishery being overfished. The expansion, technical development and marketing of these fisheries have nearly all been achieved by a multitude of local stakeholders with very limited scientific monitoring or management.

Even though small pelagic fish species, and small fish in general, have always been part of the catch of subsistence fisheries in the large water bodies of Africa, they have conventionally been regarded by fisheries managers as resources with "low economic value" and consequently have been afforded low priority with respect to research and monitoring. As a result, there are still major gaps in our biological knowledge and understanding of the full potential of many species. Common to all, however, is their small size and corresponding high turnover rate, with most species being able to reproduce their own biomass around five times or more per year, which is at least twice the rate of the larger commercial species. This unparalleled level of production, together with the relatively simple technologies used for their capture, the reduced availability of bigger species because of heavy exploitation and an increased demand for fish, are the main reasons for the considerable increase in fishing effort on smaller species that has been observed in African inland fisheries over the past three decades.

Nevertheless, due to the small size of these species and the corresponding necessity of using fishing gear with small mesh sizes, many of the fisheries are operating within the constraints of the current fisheries legislation, which is largely aimed at protecting juveniles of the larger species. Many of the capture techniques may therefore be illegal and this can cause conflict between fishers and managers. The theoretical foundation for the conventional single species legislation is increasingly challenged and there is an urgent need to examine and evaluate the fishing and management patterns from an ecosystem perspective and revise the legislation where necessary. The fishing pressure on most of the small species is only a fraction of the pressure on large fish species, and therefore there is huge potential for increased production and more balanced exploitation if the overall fishing pressure was directed away from the large fish towards the small. In fact, this is what is already happening in many African fisheries, as evidenced by the huge increase in their catches, but it is taking place without comprehensive scientific evaluation of pressures, ecosystem effects or governance.

Small fish are processed, sold and eaten whole. Most of the catch is simply sun-dried which is the most environmentally friendly and energy-efficient processing technology available, requiring limited investments to obtain potentially high-quality products, although rainy seasons limit year-round preservation, and spoilage through overheating and rainfall remain serious issues. In addition, small whole fish are among the most vital suppliers of micronutrients, such as vitamins, iodine,

iron, zinc and calcium, which all play a critical role in cerebral development, immune system support and general health. Thus, the unique combination of high-quality protein and important micronutrients in small fish plays a significant role in combating the triple burden of hunger, micronutrient deficiency and non-communicable diseases. Malnutrition, or so-called "hidden hunger", is responsible for about a third of premature deaths in sub-Saharan Africa, but national food policies virtually overlook the essential link between the production, distribution and consumption of small sun-dried fish and human health. In fact, the qualities of fish are hardly recognized in the global food security discourse, and fish is strikingly missing from current strategies to combat nutrient deficiency among disadvantaged groups.

The lack of recognition of the importance of small pelagic fish for nutrition, food security, livelihoods and public health has also prevented the necessary investments for improving the quality, shelf life and public awareness of this vitally important resource. Most of the processing and packaging is done under basic, open conditions on the landing beaches, with unhygienic facilities and little protection from contaminants, insect infestations and moisture. Quality control in the whole value chain is virtually absent: there are significant post-harvest losses in the processing and trade of what are essentially low-quality, contaminated products, some of which are even infested with human pathogens. These factors all contribute to a vicious cycle that maintains the image of a "low-value" commodity, prevents the dissemination of knowledge and awareness of the huge potential that small pelagic fish have, and which could be greatly improved with proper policy attention as well as public and private investments.

In summary, catching small pelagic fish, which are simply sun-dried, affordably purchased in local, often remote markets and consumed whole, is the most high-yielding, eco-friendly, low carbon dioxide (CO_2)-emission and nourishing way of utilizing the high productive potential of African inland waters. However, a range of social, technical, economic, legal and policy barriers inhibit the full potential of utilizing small fish to improve nutrition in low-income populations. These include lack of enabling fisheries management legislation and food safety challenges in processing and marketing. In addition, their local use as fishmeal in animal feeds, including for aquaculture, is increasingly competing for these resources.

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Abbreviations and acronyms

BMU	Beach Management Unit
CEDRS	Catch and effort data recording system (of Malawi)
CPUE	Catch per unit effort
E	Exploitation ratio (Y/P or F/Z)
EAF	Ecosystem approach to fisheries
F	Fishing mortality rate
FAO	Food and Agriculture Organization of the United Nations
IOC	Indian Ocean Commission
IPCC	Intergovernmental Panel on Climate Change
K	Brody's growth coefficient (per year)
L_∞	Maximum average length
LED	Light emitting diode (lamps)
LKFRI	Lake Kariba Fisheries Research Institute
LVFO	Lake Victoria Fishery Organization
M	Natural mortality rate (per year)
MSY	Maximum sustainable yield
ODA	Overseas Development Administration
P	Total production (mass per year)
P/B	Production-to-biomass ratio
r	Intrinsic rate of natural increase (per year)
RLLF	Relative lake level fluctuation
RLLF-a	Annual relative lake level fluctuation
RLLF-s	Seasonal relative lake level fluctuation
SADC	Southern African Development Community
SDGs	Sustainable Development Goals
SL	Standard length
TL	Total length
Y	Yield (mass per year)
Z	Total mortality rate (per year)

1. Overview of the role of small pelagic fish in Africa

This report focuses on the potential for the underutilized and often "hidden catch" of small pelagic fish to alleviate the "hidden hunger" – also known as micronutrient deficiency – which afflicts millions of people in Africa. The importance of fish, and in particular small fish, for sustainable and healthy livelihoods in Africa is undervalued and little understood: most small fish species are consumed locally and many go unrecorded in catch statistics and are overlooked by public attention. Even though fish are indispensable providers of animal protein and micronutrients in many African societies, policies around modern food production are almost unilaterally concerned with terrestrial agriculture and livestock production, with very limited attention paid to the role of fish in diets.

In the following chapters we give a brief introduction to the social and economic role of pelagic fisheries and we provide basic information on the biology, production and fisheries of small pelagic fish in relation to environmental and climatic drivers, focusing on selected major African lakes and reservoirs. This is followed by an analysis of marketing and value chains. Lastly, we discuss these results in relation to the governance of the fisheries and natural environment of small pelagic fish.

1.1 BIOLOGY

Small zooplanktivorous pelagic species are generally found in lacustrine environments and Africa is the only continent with large, natural tropical lakes. Outside Africa the lacustrine fish fauna is remarkably poor (Fernando and Holĉík, 1982; Lowe-McConnell, 1999), although small pelagics fisheries are found in the large tropical reservoirs of Asia. Because of flowing water and shifting environmental conditions, the feeding habits of riverine fish species are predominantly based on detrivory, omnivory or piscivory[1], and specialized herbivorous or planktivorous fish species are generally rare. On the other hand, the comparatively more stable environmental conditions of lakes and large reservoirs provide habitats for open water phytoplankton and zooplankton communities, which make room for the establishment of pelagic fish species.

1.2 PRODUCTIVITY OF SMALL PELAGIC FISHERIES

Over the past three decades, fisheries for small pelagic fish species have expanded massively in Africa's great lakes and reservoirs (Table 1). Reviews from the 1980s (Petr and Kaptesky, 1983; Marshall, 1984) noticed their unutilized potential, but questioned their economic profitability, although they also realized that they represented a highly important resource for sustaining the continued growth of Africa's human populations.

Small pelagic lacustrine fish species are abundant and omnipresent in nearly all African natural lakes and have for the most part been targeted over centuries for subsistence purposes by local fishers – men and women using a range of methods such as baskets, scoop nets, cloth (more recently mosquito netting) and other precursors to current methods, including the use of light attraction. Many are endemic to the system

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[1] Detrivory = feeding on dead particulate organic material; omnivory = diet consists of both animal and vegetable tissue; piscivory = eats mainly other fish; herbivore = eating plant material including higher plants; planktivory = feeds on planktonic algae, zooplankton or other planktonic items such as fish eggs and small larvae.

where they are found, and they originate from several different fish families, such as Cyprinidae (carps), Cichlidae (cichlids), Clupeidae (herrings) and Alestidae (characins), but apart from Cichlidae (mainly pelagic haplochromines) small pelagic species of the three other families mostly do not live together naturally.

Despite their biological variety, small pelagic fish are all small bodied, short-lived (1 to 3 years), low down in the trophic food web (being mainly zooplankton feeders at trophic level 3+), and with a high biological turnover rate. This so-called production-to-biomass ratio (P/B) is usually in the order of 3 to 5 per year, but for some of the smallest species it is higher than 5.

This means that most small pelagic fish can sustainably reproduce their own biomass up to five times or more per year (Table 1), which makes them generally much more productive than larger fish species from the same families, even when compared to other low-level trophic species such as tilapia (Cichlidae) that are widespread and fished in practically all African freshwater systems.

The high productivity of most tropical lakes and human-made reservoirs with introduced zooplanktivorous clupeids, can therefore in general be attributed to the short food chains from primary sources (phytoplankton) to harvestable biomass (Marshall, 1984; Lowe-McConnell, 2003; Kolding and van Zwieten, 2006). As a rule of thumb, when using the 10 percent energy transfer rule between trophic levels and knowing that maximum sustainable yield (MSY) ≈ 0.4*production[2] (Patterson, 1992), the potential yield of small pelagic fish (trophic Level ≈ 3) is approximately 0.4 percent of the primary production.

From an ecosystem perspective, the fishing pressure on most of the small pelagic species is only a fraction of the pressure on large fish. There is huge potential for increased production and more balanced exploitation if the overall fishing pressure was directed away from large fish towards small fish. Small, zooplanktivorous fish generally are one to two trophic levels lower in the food web and much more abundant and productive, but their capture is mostly inhibited by selectivity regulations that are focused solely on the targeting of large fish. These regulations have not been comprehensively assessed for their relevance in present day fishery management.

In fact, the shift away from larger, less productive species is already happening in many African fisheries, as evidenced by the huge increase in total catches, but this has taken place without scientific evaluation or governance. Presently, small pelagic species contribute most of the catches in nearly all African lakes, with up to 75 percent of total yields attributed to small fish. Moreover, the current yield for most species has by far exceeded the previous predictions (Table 1), with only Lake Tanganyika as a notable exception[3], although this lake has the longest history of an industrial pelagic fishery which was started in the 1950s by fishers of Greek origin (Magnet, Reynolds and Bru, 2000).

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[2] Pelagic fish biomass and production typically fluctuate interannually, as a result of climatic and hydrological drivers, and therefore MSY also fluctuates. In this report we have adopted a maximum upper level of potential catch to be 40 percent of the current total production (P), thus MSY = 0.4·P ≈ 0.4·B·Z, where B is standing biomass and Z is total mortality (Table 5).

[3] The current total catch of small clupeids from Lake Tanganyika is highly uncertain and may very well be greatly underestimated (see section on Lake Tanganyika). Marshall (1984), based on Coulter (1977, 1981), estimated the potential yield from Lake Tanganyika to be 1.1 million tonnes for the whole lake, which is an order of magnitude bigger than the current estimate of 110 000 tonnes (Table 1; Lowe-McConnell, 2003).

TABLE 1

Production and yield characteristics of the main small pelagic species in a range of major African lakes and reservoirs

Water body L = lake R = reservoir	Surface area (km²)	Main pelagic species	P/B ratio	Pelagic yield (kg/ha) in 1980s (A) predicted (P)	Total yield 1980s (tonnes)	Type of fishery	Present yield (kg/ha)	Present yield (tonnes)	% increase
Victoria (L)	68 800	*Rastrineobola argentea*	3.9	A = 23	158 240	Industrial Artisanal	74	509 120	322
Tanganyika (L)	32 900	*Stolothrissa tanganicae, Limnothrissa miodon*	5	A = 22.5; P = 350	72 380	Industrial Artisanal	34	111 860	151
Malawi (L)	30 800	*Engraulicypris sardella*	3	A = slight; P = 30–40	30.8	Artisanal	37	54 801	1 700
Turkana (L)	≈7 000	*Brycinus minutus, Brycinus ferox*	5.2	A = nil; P = 450	Nil	NA	Nil		
Mweru (L)	5 120	*Microthrissa moeruensis*	5	A = 9; P = 130–185	4 608	Artisanal	98	50 176	1 100
Kivu (Rwanda) (L)	1 055	*Limnothrissa miodon*	6	A = slight; P = 40	1	Industrial Artisanal	150	15 825	≈1 300
Kariba (R)	5 365	*Limnothrissa miodon*	6	A = 22; P = 90	11 803	Industrial	56	30 044	255
Cahora Bassa (R)	2 665	*Limnothrissa miodon*	5	A = nil; P = 30	999	Industrial	60	15 990	6 000
Itezhi-tezhi (R)	370	*Brycinus lateralis, Limnothrissa miodon*	5	A = 27; P = 95	1	Artisanal	74		275
Kainji (R)	1 270	*Pellonula leonensis, Sierrathrissa leonensis*	?	A = small; P = 60-80		Artisanal	109	13 843	≈1 000
Volta (R)	8 482	Same as Kainji plus *Odaxothrissa mento*	?	A = moderate; P = 79		Industrial Artisanal	120	101 784	≈1 000
Average			4.9				81		

Pelagic yield in the 1980s (A) and prediction (P) is based on Petr and Kapetsky (1983) except Turkana, Kariba, Mweru, Itezhi-tezhi and Kainji, which are based on the sources indicated. P/B ratio = production over biomass ratio. Present yield is based on the most recent catch estimate available for a lake or reservoir.

Sources:	Victoria	Natugonza *et al*,. 2016	Kariba	Machena, Kolding and Sanyanga, 1993
	Tanganyika	van der Knaap, Katonda and De Graaf, 2014; this study	Cahora Bassa	Jorge Mafuca (pers. comm.)
	Malawi	Pitcher and Hart, 1995; Allison, 1995; Turner, 1982; this study	Itezhi-tezhi	Mbewe, 2000; Department of Fisheries, 2017
	Turkana	Hopson, 1982; Kolding, 1989, 1993b	Kainji	Marshall, 1984; Pitcher and Hart, 1995; Du Feu, 2003
	Mweru Kivu	van Zwieten *et al*., 1996; Mölsä, 2010; Bos *et al*, 2006 Welcomme 1972; Villanueva *et al*., 2008	Volta	Marshall, 1984; van Zwieten, Banda and Kolding, 2011; Braimah,1995

1.3 CURRENT STATUS OF PRODUCTION

At present, the pelagic fisheries mentioned in Table 1 alone produce close to one million tonnes per year, or 40 percent of the total reported inland catch from Africa of 2.8 million tonnes per year (FAO, 2018). However, this may still be only half of what they could potentially produce assuming an estimated average harvestable production rate of 150 kg/ha/year (Marshall and Maes, 1994; Kolding and van Zwieten, 2006; Kolding *et al*., 2016a) (Table 5). In addition, there is the largely unrecorded contribution from the multitude of smaller lakes and reservoirs all over the continent which are even more productive per unit area than the large water bodies (Kolding *et al*., 2016a) as well as from riverine fisheries.

Numerous studies have been conducted over the past 50 to 100 years in many of the lakes discussed in this document and these form the basis of the analyses of catch patterns and the productivity estimates presented. However, landings and catch and effort monitoring statistics of many lake and reservoir fisheries are not as reliable as could be and in many cases much of the catch of small fish, including small pelagic fish, goes unrecorded and estimates are often based on short-term research rather than formal monitoring programmes. Thus, actual catches and total potential may be significantly higher than suggested by these statistics. For example, noting that the total area of freshwater resources (lakes, rivers, reservoirs, floodplains and swamps) on the African continent is approximately 1.3 million km^2 (Lehner and Döll, 2004; de Graaf *et al*., 2012) and assuming that the natural average annual harvestable production of fish is around 100 kg/ha/year to 150 kg/ha/year (see Section 2.2, Table 5), Africa may have the potential to produce some 15 million to 20 million tonnes of inland fish per year, most of which will be small freshwater pelagic fish or other small species.

PLATE 1
Sun-dried dagaa (Rastrineobola argentea) from Lake Victoria on display at a local market in Tanzania

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1.4 NUTRITIONAL ROLE OF SMALL PELAGIC FISH

As shown by the explosive growth in small pelagic fisheries (Table 1), these fish are very important for the sustenance and livelihoods of many small-scale fishers, seasonal farmer-fishers, and for the increasing development of the semi-industrial, but still relatively small-scale, commercial fisheries. They are also increasingly important as a primary source of protein for a growing population in inland and urban areas, which are far removed from the lakes where they are fished because post-processing, preservation and trade of small fish is very simple. The landed fish are simply sun-dried whole within a few days, in contrast to larger fish which need to be gutted and salted or smoked for non-chilled preservation. The simple preservation technologies and easy transportation mean that small pelagic fish are available at most local markets at low cost. They are sold in small portions by weight, often fetching the same price per volume as large fish (Brummett, 2000; Kolding *et al*., 2017). Heaps of small, dried fish (Plate 1) are ubiquitous on local markets far from the original source (IOC, 2012). For instance, Lake Victoria *dagaa* is found all over the riparian countries (Hoffman, 2010; Medard, 2015); Lake Mweru *chisense* and Lake Kariba *kapenta* is found in all large cities in Zambia and southern Democratic Republic of Congo (Overå, 2003; IOC, 2012); *usipa* from Lake Malawi[4] is traded widely throughout the country and into neighbouring Zambia. Another important characteristic of small pelagic fish is their nutritional value compared to large fish. Since small fish are sun-dried whole, with heads, bones and viscera intact, they represent a concentrated source of multiple essential nutrients, in contrast to large fish which are usually not eaten whole and therefore do not contribute as much to micronutrient intake (Longley *et al*., 2014) (Box 1). Small sun-dried fish are thus affordable for poor consumers, form an important source of animal proteins and micronutrients and improve the diets of vulnerable groups, despite the generally simple methods of preservation and associated loss of quality.

BOX 1

The importance of fish as a source of micronutrients

Micronutrient malnutrition (hidden hunger) is prevalent in many developing countries in which people eat a predominantly cereal (starch) staple food diet (Shetty, 2011). Globally, more than two billion people, especially women and children in sub-Saharan Africa and Asia, suffer from micronutrient deficiency of essential minerals and vitamins like Vitamin A, Iron (Fe) and zinc (Zn) (Sanghvi, Ross and Heymann, 2007; Micronutrient Initiative, 2009; Allison, 2011; FAO, 2014; Kawarazuka and Béné, 2010; Stocker *et al*., 2013; IPCC, 2014). Sub-Saharan Africa has the highest rates of extreme poverty, lowest levels of primary education rates, highest levels of under-five mortality rates and highest levels of maternal mortality rates (World Bank, 2014). Approximately one third of all deaths are attributed to malnutrition (Benson, 2008; ACFP, 2019). Unless progress is made, according to the United Nations Children's Fund (UNICEF) (2016), nine out of ten children living in extreme poverty will be from sub-Saharan Africa and these children will be ten times more likely to die before their fifth birthdays than children in high-income countries.

The unique combination of high-quality protein and important micronutrients in fish plays a significant role in combating the triple burden of hunger, micronutrient deficiencies and non-communicable diseases. Fish is a particularly nutritious food, rich in numerous micronutrients that are often missing in diets, particularly those of the poor. The presence of essential nutrients (such as iodine, vitamin B12 and D), the long-chain fatty acids (LC-PUFA), eicosapentaenoic (EPA) and docosahexaenoic (DHA) omega–3 fatty acids, protein of high quality and fish's very rich content in calcium, iron, zinc and vitamin A, is well documented in the literature. These elements all play a critical role in cerebral development, immune defence systems and general health (Figure 1).

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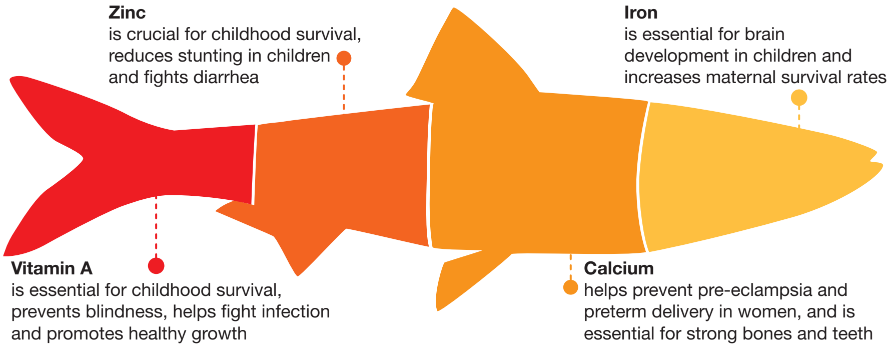
[4] In this document, different names for Lake Malawi, Lake Nyasa, or Lago Niassa are used. These are national names and all refer to the same transboundary waterbody which is bordered by Malawi, Tanzania and Mozambique. This document uses the same name as per the publication, article, or other document from which the original reference was obtained.

FIGURE 1

Fish provides nutrients and micronutrients that are essential for cognitive, immune function and physical development

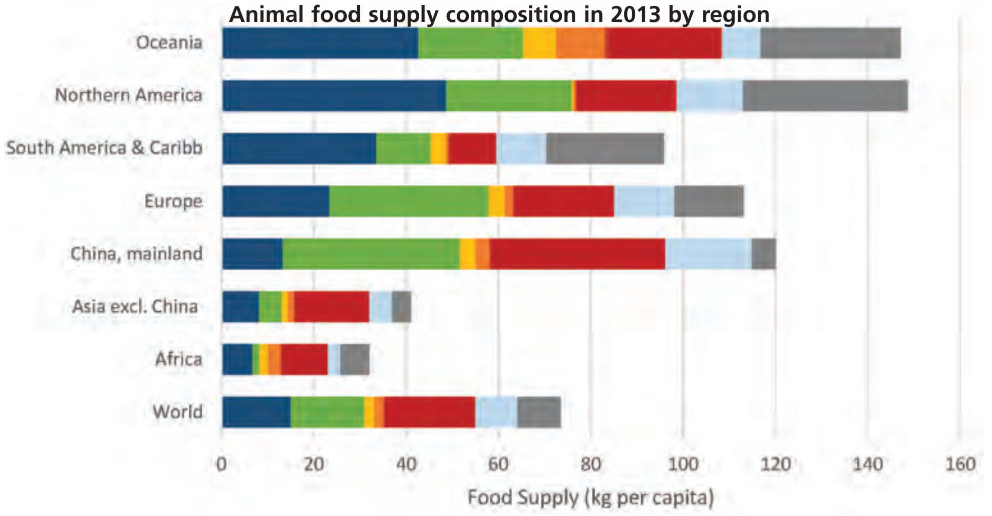


Source: https://www.worldfishcenter.org/content/infographic-fish-nutrition-and-food-security.

In 2013, of all regions Africa had the lowest animal food supply per capita and the lowest fish [5] supply per capita (Figure 2). However, Africa relied quite heavily on fish for its intake of animal protein per capita. Fish contributed over 18 percent of total animal protein intake in overall Africa, and with a share of over 20 percent in 30 African countries, including several landlocked ones.

FIGURE 2

Animal food supply composition in 2013 by region



Source: FAOSTAT

Note: Meat supply is expressed in carcass weight. Fish, seafood is expressed in live weight equivalent and indicates fish, crustaceans, molluscs and other aquatic animals, but excludes aquatic mammals, reptiles, seaweeds and other aquatic plants.

1.5 COMMERCIAL VALUE AND TRADE

The commercial value of these fisheries has also increased with the demand of a growing human population. Because they are cheaply processed and easy to transport and store, being simply sun-dried and shipped in bags, they are now found on nearly every local market in most African countries. Due to the multitude of full-time or part-time fishers, the huge number of landing places, the many informal market outlets and the generally deteriorating state of catch assessment surveys, there is insufficient information on the actual

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[5] The term “fish” indicates fish, crustaceans, molluscs and other aquatic animals, but excludes aquatic mammals, reptiles, seaweeds and other aquatic plants.

landings, which are believed to be seriously under-recorded (Fluet-Chouinard *et al*., 2018). Historically, traditional fisheries for small fish have received less attention than fisheries for larger species which are considered more valuable for commercial development. However, with the recent shift in the human food security debate from quantity to quality, and from a focus on calories and proteins to a recognition of the importance of nutrients, the inclusion of small fish in the diet has gained increased attention.

Catching small pelagic fish, which are sun-dried and consumed whole, is the most high-yielding, eco-friendly and nourishing way of utilizing the natural food that aquatic ecosystems provide. While the marketing of large fish requires processing and cooling facilities or smoke curing with associated negative environmental and health effects, sun-dried small fish usually have a shelf life exceeding six months, can be purchased in small quantities and thus easily stored in low-income homes that lack electricity.

However, there are a series of obstacles to be overcome before small, sun-dried fish may be better utilized. Traditional sun drying methods on beaches, concrete slabs or wire mesh, result in significant post-harvest losses and generate several quality and food safety concerns, particularly during the wet seasons. The nutritional benefits and market value can be greatly improved through better handling and production methods. In addition, the growing aquaculture industry is now competing for small pelagic fish for fish feed used in the culture of high-value aquaculture products that are destined either for domestic middle-class segments of the population, or for export markets (Kaminski *et al*., 2018).

Social, cultural and legal barriers are constraints in many places because fisheries have traditionally focused on large fish only. Small pelagic fish are considered "low value" (Delgado *et al*., 2003; Gordon *et al*., 2013), "poor peoples' food" or even "trashfish" and for this reason many are used in animal feed. Consumer awareness and the promotion and marketing of the nutritional value of small pelagic fish needs to be improved and a refocus by policymakers on the domestic and intra-regional trade that is generated by the activities of millions of people engaged in the production and trade of these "low-value" fish products across the continent is necessary.

The lack of recognition of the importance of small pelagic fish for sustenance, livelihoods and public health has also prevented the investments necessary for improving the quality, shelf life and public awareness of this vitally important resource. Most of the processing and packaging is done under primitive, open conditions on the landing beaches, with poor hygienic facilities and little protection from exposure to contaminants, insect infestations and moisture. Quality control is virtually absent from the entire value chain: there are significant post-harvest losses in processing and trade of what are essentially low-quality contaminated products, and may harbour human parasites and pathogens.

These factors all contribute to a vicious cycle that maintains the image of a low-value commodity and hampers the dissemination of knowledge and awareness of the huge potential that small pelagic fish have, and which could be greatly improved with proper policy attention and public and private investment.

1.6 SMALL PELAGIC FISHERIES HAVE A LOW ENVIRONMENTAL FOOTPRINT

When compared to other food production systems, fisheries in general have the least impacts in terms of contributing to the emission of greenhouse gases and the use of freshwater, fertilizers, insecticides or herbicides (Béné *et al*., 2015; Kearney, 2013; Vries and Boer, 2010) and small pelagic fish are the most energy efficient supply of human food products available (Pelletier *et al*., 2011; Majluf, De la Puente and Christensen, 2017; Hilborn *et al*., 2018). Still, the importance and qualities of fish in general, and small fish in particular, are not fully recognized in the global food security discourse (HLPE, 2014) or in the Sustainable Development Goals (SDGs), such as SDG2 (Zero hunger), which aims to achieve food security and promote sustainable agriculture, and SDG14 (Life below water) which promotes the conservation and sustainable use of aquatic resources. Fisheries are almost invisible in strategies to achieve SDG2, and nutrition and food security are not the primary focus of SDG14. Thus, fish is strikingly missing from strategies for reducing the widespread occurrence of hidden hunger (nutrient deficiency), precisely where it could potentially have the largest impact (Box 1). A transition towards increased consumption of small fish is thus legitimate, from both a health and environmental sustainability perspective. The environmental, economic and nutritional benefits of harvesting, marketing and consuming small fish are in many ways clear, but the obscure nexus of hidden hunger and hidden harvest[6] has to some degree impeded a common understanding and appreciation of the undervalued potential and importance of small fish.

1.7 MANAGEMENT AND GOVERNANCE OF SMALL PELAGIC FISHERIES

While some of these fisheries, like the semi-industrial *kapenta* fishery in Kariba and Cahora Bassa reservoirs, have been commercially exploited from the onset, others have gradually expanded from shore-based household subsistence catches to intensive open water dip net fisheries with light attraction, larger equipment and increasing human effort.

Capture methods for small pelagic fish, such as beach or purse seines, dip nets or other nets with small mesh sizes, often used in combination with light attraction, are prohibited in some countries (although such bans are rarely enforced). Due to the small size of these species and the corresponding necessity of using fishing gear with small mesh sizes, many of the fisheries operate in the shadows of the current fisheries legislation, which has historically been principally aimed at protecting juveniles of the larger species. The continuing use of mesh size regulation as the principal management measure in these fisheries means that many of the capture techniques for small pelagic fish may be illegal and this can cause conflict between fishers and managers.

The narrative of capture fisheries in Africa is dominated by a pessimistic outlook of overfishing and deteriorating resources (Welcomme and Lymer, 2012; Kolding, van Zwieten and Mosepele, 2016). This is unfortunate because the perception is driven by a few examples of decreasing or collapsed catches of some large, predominantly potamodromous (migrating within freshwater bodies) fish species, as well as a general misunderstanding of the inverse relationship between individual catch rates and total catch (Jul-Larsen *et al*., 2003; Kolding, Bene and Bavinck, 2014).

That the recorded inland catches in Africa are, in fact, continuously increasing almost linearly by 3.7 percent per year (Figure 10), and that, based on productivity estimates, many small fish species, including small pelagics, may still not be fully exploited, seems to be overlooked or undercommunicated in the media or in the discourses on fisheries management and food security. The economic consequences of this oversight are significant, both in terms of missed opportunites and investments, and in terms of securing relatively cheap, locally produced and highly nutritious commodities on a continent with the lowest per capita supply of animal-sourced protein, and the second lowest apparent supply of fish per capita (Box 1).

The theoretical basis for conventional single species legislation could be questioned, because there is an urgent need to examine and evaluate the fishing patterns from an ecosystem perspective, and revise policy and legislation where necessary. To understand this better, while setting the stage for further elaboration on the production potential of small fish, a short digression into more fundamental concepts of human aquatic food production in relation to ecosystem functioning is necessary.

1.8 THE TERRESTRIAL AND AQUATIC FOOD CHAIN

Most African rural communities live near water bodies – ponds, rivers, floodplains, lakes – and have been both farmers and fishers for millennia, but modern food production policies are almost unilaterally associated with terrestrial agriculture (HLPE, 2014).

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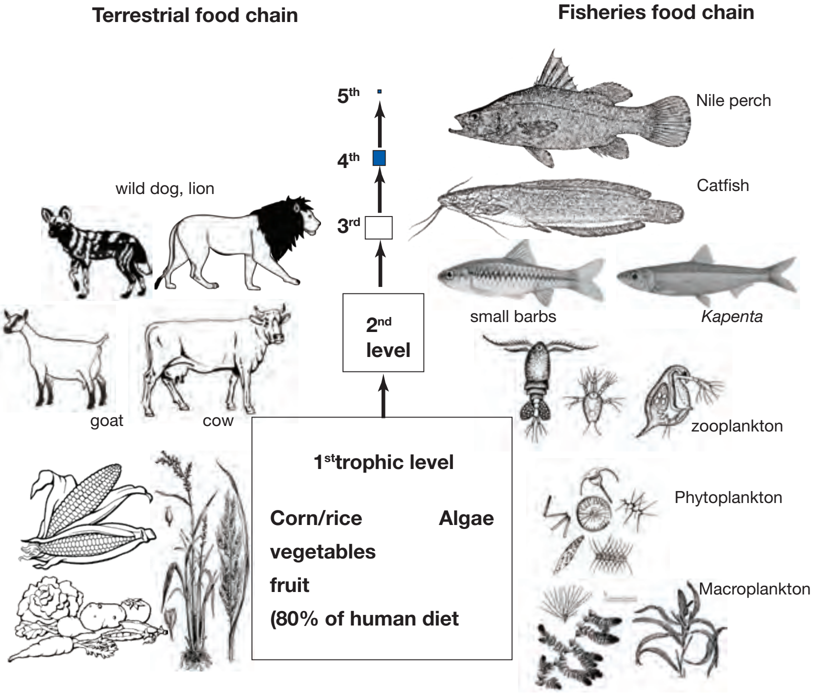
[6] The hidden harvest refers to the fact that small-scale fisheries are often poorly recorded and documented (World Bank, 2012).

Humans are predominantly vegetarians (Bonhommeau *et al*., 2013). Their average trophic level is 2.21, which means that around 80 percent of our food is from trophic level 1 (plants – one step away from the sun) and the rest is mainly meat-based from our domesticated herbivore livestock (trophic level 2 – two steps away from the sun). All the livestock we farm for food are relatively large herbivores that can feed directly on primary vascular vegetation, so-called higher plants, which dominate the terrestrial ecosystem. The agricultural food chain is therefore short, consisting chiefly of two trophic levels. Farming terrestrial carnivores, e.g. lions for human food production makes no sense because about 90 percent of the available energy in metabolism is lost with each trophic level up the chain (Figure 3).

The aquatic food chain, however, is fundamentally different. Most importantly, the majority of primary producers (plants) are microscopic suspended algae, and only small amounts of larger vascular macrophytes inhabit the fringes of the aquatic ecosystems. In general, organisms have to be small to consume minuscule algae, and the major herbivores ("cows" and "goats") of the waters are therefore tiny filter-feeding zooplankton, though there are some important categories of fish that can feed on detritus and algae: for example, tilapia and carp species, important in fisheries and aquaculture systems around the world.

FIGURE 3

A comparison of the modern terrestrial agricultural and the aquatic fisheries food chains along trophic levels



Source: modified from Kolding, van Zwieten and Mosepele, 2016.

The average human trophic level of 2.21 (Bonhommeau *et al*., 2013), is only slightly higher than that of zooplankton! As a consequence, we are feeding about two trophic levels higher than on land in most fisheries targeting large fish, resulting in around 99 percent of the corresponding energy being lost in transfer inefficiency.

The majority of all fish species are primarily carnivorous. But, in contrast to terrestrial predators, they generally have very high fecundities and minuscule progenies that all start their life at the bottom of the food chain, feeding on algae and zooplankton. In short, fish breed like plants with lots of seeds, but feed like lions. Consequently, in aquatic communities nearly all fish, even the largest predators, start their life as small prey for larger fish (Kolding *et al*., 2015c; van Zwieten *et al*., 2016). This means that most fish, during their ontogeny, often traverse several trophic levels before reaching adulthood. Thus, human food production through fisheries that mainly target large adult top predators, such as Nile perch in Lake Victoria, is about two trophic levels higher in water than on land. In terms of energy this is inefficient utilization of primary production and associated aquatic animal production. Focusing on top predators misses the trophic efficiency of harvesting small zooplanktivorous species and small size classes of larger species. Harvesting an aquatic ecosystem matching the productive capacity of all trophic levels in the food chain is called balanced harvesting (Garcia *et al*., 2012; Zhou *et al*., 2019). Balanced harvesting in fact maintains ecosystem structure, an important goal in the ecosystem approach to fisheries (EAF) management, by allowing the greater harvesting of lower trophic level species at the expense of reduced catches of higher trophic level and top end carnivores. The largely unmanaged shift of many African fisheries towards small species may in fact represent a shift to more balanced harvesting (Plank *et al.*, 2017) rather than a sign of overharvesting larger and higher trophic level components of a fish community called “fishing down the food web” (Pauly *et al.* 1998; Welcomme, 1999). In fact, these fisheries may also be described by a process called "fishing through the food web" (Essington *et al*., 2006), where smaller species and sizes lower in the food web are added to the total catch without depleting the higher trophic level components of the fish community that also do not disappear from the total catch of these fisheries. In doing so, the productive capacity of an aquatic ecosystem is used more efficiently by a large group of fishers who gain access to a valuable resource and maximize nutritional benefits from that ecosystem. This is in contrast to optimizing a fishery on income and revenues from a potentially more lucrative, but a much smaller and less productive fishery on adult top predators (like adult Nile perch) that has less nutritional benifits, and that changes ecosystem structure.

1.9 SOME KEY RECOMMENDATIONS FOR ACTION

Based on this review of the pelagic fish and fisheries in African lakes and reservoirs, the following recommendations have emerged, in no specific order of importance:

- Recognize the neglected essential socio-economic and nutritional importance and potential of small pelagic “low-value” fish;
- Compile better catch statistics and implement more regular assessments of exploitation and productivity;
- Improve knowledge of the level of subsistence fishing and informal market channels;
- Acknowledge that environmental and climatic forcing plays a dominant role in stock dynamics;
- Encourage more balanced fishing patterns through a shift towards low trophic level, productive small species and revise the regulatory framework where necessary;
- Invest in improving quality by upgrading post-harvest processing and marketing and reduce spoilage and contamination;
- Create awareness of the trade-off between the use of “low-value” but highly nutritious fish as animal feed or human food and prioritize direct human consumption over animal feed production;
- Devise policies to improve domestic and intra-regional trade regulations around small pelagic fish products;
- Prepare nutrients analyses and label products with detailed content declarations so as to inform consumers;
- Disseminate and highlight knowledge of the beneficial public health effects of consuming small, whole sun-dried fish;
- Integrate fisheries in the policies and strategies that address food security and nutrition.

2. Productivity of the small pelagic fisheries in African lakes and reservoirs

Detailed knowledge from many individual water bodies indicates that African inland fisheries are highly productive compared with other tropical continents (Kolding and van Zwieten, 2006). One reason for the high overall production is the large number of natural water bodies in Africa, including some of largest lakes in the world.

Another reason is the traditional focus on small fish in most African societies. In fact, all of the most productive fisheries target small fish species that weigh only one to a few grams. The *“kapenta”* (*Limnothrissa miodon* and *Stolothrissa tanganicae*) fisheries in lakes Tanganyika, Kariba, Cahora Bassa and Kivu are the most important in all these lakes. Likewise the *“chisense”* (used both for *Microthrissa moeruensis* and *Mesobola moeruensis*) fishery in Lakes Mweru, Bangweulu and Mweru-Wa-Ntipa; the *“usipa”* (*Engraulicypris sardella*) and *“kambuzi”* (many small demersal haplochromine species) or *“utaka”* (many small pelagic haplochromine species) fisheries in lakes Malawi, Chilwa and Malombe; the *“dagaa”*, *“omena”* or *“mukene”* (*Rastrineobola argentea*) fishery in Lake Victoria; *“mazeze”*(mainly small-sized cyprinids and characins) in the Okavango Delta; and *“kapesa”* (small cyprinids and silurids) in the Bangweulu swamps, are all high yielding and extremely important for local consumption.

Many small pelagic species are also exploited in the West African lakes and reservoirs, such as the Kainji and Lake Volta fisheries on *“waranga”*, *“ntita”* or *“isoun”* (respectively the Hausa, Igbo and Itjo names for *Pellonula leonensis*). Hardly anything is known about the riverine and lake fisheries of the Democratic Republic of the Congo, but with 25 000 km^2 of lakes, 34 000 km^2 of river area and 25 000 km^2 to 50 000 km^2 of floodplains, they can be expected to be substantial, with a large proportion of the catch focused on small pelagic species and small fish.

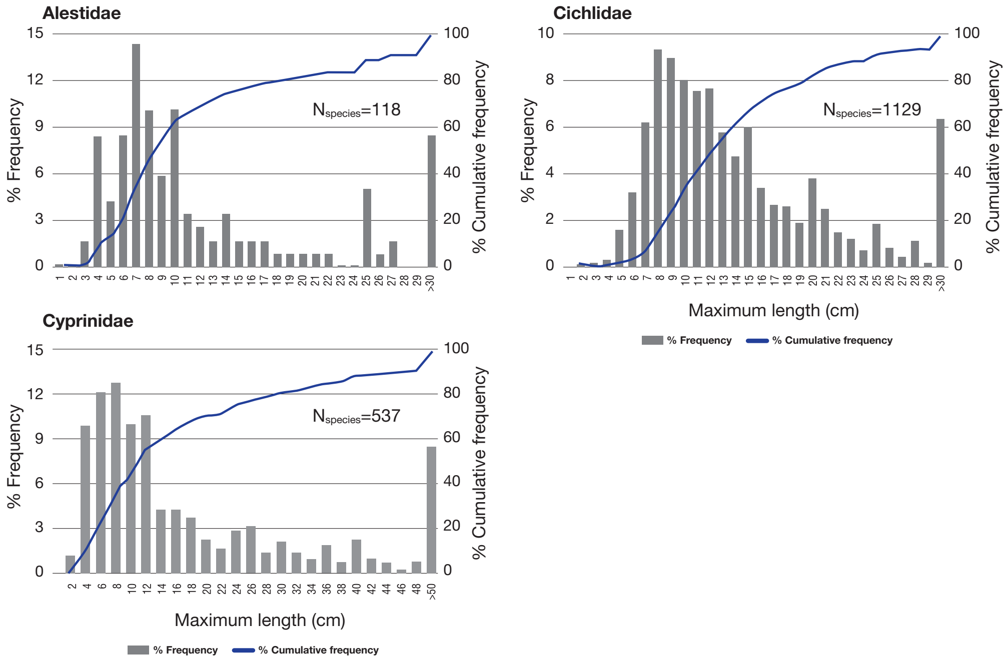
Many of the species referred to above are not accounted for in official catch statistics and go unreported into the local markets. Catch statistics from Africa are notoriously unreliable and under-reported (Welcome and Lymer, 2012).

2.1 BIOLOGICAL CHARACTERISTICS OF SMALL PELAGIC FISH SPECIES IN AFRICA

Most African freshwater fish species are small. For example, within the families Alestidae, Cichlidae and Cyprinidae – which together account for half the number of the 3 500 African freshwater species that are described in Fishbase (Froese and Pauly, 2017) – respectively 76 percent, 63 percent and 70 percent, are less than 15 cm in maximum size (Figure 4).

FIGURE 4

Percentage frequency and percentage cumulative distribution of the maximum sizes reached of the African freshwater fish species within the families Alestidae, Cichlidae and Cyprinidae



$N_{species}$ = the number of species within a family.

Source: Fishbase (Froese and Pauly, 2017).

Only one species of the 25 African freshwater clupeids, the family that harbours most of the zooplanktivorous pelagic species, is larger than 15cm: *Limnothrissa miodon* (*kapenta*) in its Lake Tanganyika habitat form. Most of the small fish species found in shallow riparian or demersal habitats in lakes, floodplains, swamps and rivers do not reach stock sizes that are suitable for commercial exploitation. Nevertheless, these small species are fished and utilized in multispecies subsistence fisheries, often carried out by women and children using baskets, small scoop nets (increasingly made from old mosquito nets), fishing rods and other such simple gears. All clupeid species have pelagic populations in lakes, large rivers and coastal lagoons, predominantly in the Congo River basin and the rivers and lakes of West Africa, to southern African coastal states (Table 2).

TABLE 2
Size, main habitat, distribution and fisheries for pelagic cyprinid and clupeid species

Family	Species	Maximum standard length (mm)	Main habitat	Distribution	Fisheries
Cyprinidae	*Mesobola bredoi*	45	Lake	Endemic to Lake Albert	?
	Mesobola brevianalis	75	River	Cunene, Okavango, upper Zambezi systems and east coastal rivers from the Limpopo to the Umfolozi in northern KwaZulu-Natal; an isolated population is found in the Orange River below the Augrabies Falls. Also known from the middle Luapula (upper Congo River basin) in Zambia.	Subsistence
	Mesobola moeruensis	37	Lake, river	Mweru-Luapula and Bangweulu-Chambeshi areas (upper Congo River basin in Democratic Republic of the Congo and Zambia).	Commercial
	Mesobola spinifer	50	Lake, river	Malagarazi River, Ruaha River and Lake Rukwa.	Subsistence
	Neobola bottegoi	75	Lake, river	Lake Turkana, Omo River, rivers of Somalia.	?
	Neobola fluviatilis	73	River	Athi and Tena Rivers in Kenya.	?
	Chelaethiops congicus	110	River, lake	Widespread in the Congo River basin, from the lower Congo up to the Lufira and Lake Mweru. Also in the Lake Tanganyika basin, including the Malagarazi.	?
	Chelaethiops rukwaensis	100	Lake	Endemic to Lake Rukwa.	Might support a fishery (Eccles, 1992)
	Engraulicypris sardella	130	Lake, river	Lake Malawi and upper Shire River.	Commercial Malawi
	Rastrineobola argentea	90	Lake	Known from Lake Victoria drainage, Lake Kyoga, Lake Nabugabo and the Victoria Nile.	Commercial Victoria, Kyoga

The list of clupeid species is based on Marshall (1984) and Poll (1974) but revised and updated with the aid of Fishbase (Froese and Pauly, 2017).

Family	Species	Maximum standard length (mm)	Main habitat	Distribution	Fisheries
Clupeidae	*Congothrissa gossei*	35	River	Middle Congo River basin, in the area around Kisangani (Democratic Republic of the Congo) and in the Ubangui River at Bangui and upstream (Central African Republic).	Subsistence
	Gilchristella aestuaria	100	Lake, river	Lake Piti, Mozambique along southern African coast to Saldanha Bay, possibly mouth of the Orange River (but perhaps confused by presence of a second undescribed species).	Subsistence
	Laeviscutella dekimpei	46	River	Lower parts of rivers and lagoons in West Africa, from the Casamance River to the Niger Delta, lower Ogowe River in Gabon and Loémé River in the Republic of the Congo. Also reported to occur in the Congo River, but this needs confirmation.	Subsistence
	Limnothrissa miodon	170	Lake	Lake Tanganyika; introduced in Lake Kariba, Lake Cahora Bassa, Lake Ithezi-thezi, Lake Kivu.	Commercial
	Microthrissa congica	60	River, lake	Widely distributed in the Congo River basin, from the Lower Congo River near its estuary up to the Upper Lualaba River, but excluding the Luapula-Mweru. Lake Tumba.	Not important
	Microthrissa minuta	35	River	Upper Uélé (middle Congo River basin) and lower Congo River, in Democratic Republic of the Congo. Reported from the Kisimba-Kilia rapids (Lukuga River) as Microthrissa cf. minuta.	Subsistence
	Microthrissa moeruensis	41	Lake	Endemic to Lake Mweru.	Commercial
	Microthrissa royauxi	99	River	Middle Congo River basin, including the Ubangi system but not the Kasai, in Democratic Republic of the Congo, Central African Republic and Cameroon; report from the Lualaba questionable.	Subsistence
	Microthrissa whiteheadi	57	River	Middle (Ubangi and Uélé) and upper (Lualaba and upper Lualaba) Congo River basin in Democratic Republic of the Congo.	?
	Nannothrissa parva	42	River, lake	Middle Congo River, Lake Tumba area, Ruki River and Ubanghi River in Democratic Republic of the Congo.	Subsistence
	Nannothrissa stewarti	23	Lake	Lake Mai-Ndombe, Democratic Republic of the Congo.	Subsistence
	Odaxothrissa ansorgii	146	River	Lower course of Senegal River, lagoons of Côte d'Ivoire and Niger Delta; also from Ogowe River to Kouilou River and lower Congo River.	Subsistence
	Odaxothrissa losera	130	River	Widely distributed in the lower and middle Congo River basin. Also in upper parts of Congo River and its tributaries, e.g. Ubangi and Lualaba, also Sangha River.	Subsistence
	Odaxothrissa mento	130	River, lake	Found in rivers and streams, including the human-made Lake Volta.	Commercial
	Pellonula leonensis	99	River, lagoon	Lagoons, lakes and lower and upper courses of West African rivers, from Senegal River to Sanaga River. Also in lagoons and lower parts of coastal rivers from Cameroon to Democratic Republic of the Congo, including a record in the Léfini River.	Minor commercial importance; subsistence

Family	Species	Maximum standard length (mm)	Main habitat	Distribution	Fisheries
	Pellonula vorax	120	River, lake	Coastal rivers from Liberia to Angola, but absent in the area between Ghana and Niger River Delta, except for Lake Nokoué. The type locality of the syntypes of *Pellonula stanleyana*, "Stanley Falls" seems to be a locality error and should be "Cette Cama (= Sette Cama)" in Gabon. Except for its occurrence in the Léfini River (middle Congo River basin), this species was not observed far upstream in rivers.	Subsistence
	Potamothrissa acutirostris	70	River, lake	Widespread in the Congo River basin in Central African Republic and Democratic Republic of the Congo. Reports from Lake Mweru and Zambia unconfirmed.	Subsistence
	Potamothrissa obtusirostris	60	River	Middle and upper Congo River system, especially in northern and eastern tributaries, in Central African Republic, Republic of the Congo and Democratic Republic of the Congo. Also reported from the lower Congo.	Subsistence
	Potamothrissa whiteheadi	47	River	Only known from the type locality on the Hombo River (Lualaba drainage, upper Congo River basin) in Democratic Republic of the Congo	No importance
	Sauvagella robusta	47	River	Madagascar, Mangarahara River (Sofia River drainage), the Ambomboa River (= Amboaboa).	No importance
	Sierrathrissa leonensis	30	River, lake	Rivers of West Africa from Senegal to Cameroon, including Senegal, Gambia, Bia, Niger basin and Wouri River; and human-made Lake Kainji and Lake Volta. Also reported from Sanaga River in Cameroon.	Commercial Lake Volta, Lake Kainji
	Stolothrissa tanganicae	100	Lake	Endemic to Lake Tanganyika; in the Lukuga River (connecting the lake with the Lualaba River) known up to Kisimba-Kilia Falls.	Commercial
	Thrattidion noctivagus	21	River	Endemic to the Sanaga River at Edea, Cameroon.	Not important

TABLE 3

The main biological characteristics of selected small pelagic fish species in major African lakes and reservoirs

Water body L = Lake R = reservoir	Main pelagic species	Family	Max length (cm)		Life span (year)	L mat (cm)		Age mat (year)	Trophic level	K (yr^{-1})	L_∞ (TL)	M (yr^{-1})	r (yr^{-1})
Victoria (L)	*Rastrineobola argentea*	Cyprinidae	9	SL	2.8	4.4	SL	0.9	3.4 + 0.49	0.99		2.18	8.46
Tanganyika (L)	*Stolothrissa tanganicae*	Clupeidae	10	SL	1.5	8.2	TL	0.4	2.7 + 0.29	1.87	8.9	3.38	11.5
	Limnothrissa miodon	Clupeidae	17	SL	2.0	6.8	-	-	-	1.40	14.5	-	-
Malawi (L)	*Engraulicypris sardella*	Cyprinidae	13	TL	-	-	-	-	2.9 + 0.22	-	-	-	5.3
Turkana (L)	*Brycinus minutus*	Alestidae	3.3	SL	0.8	2.6	SL	0.3	-	-	-	-	-
	Brycinus ferox	Alestidae	8.1	SL	1.8	5.8	SL	0.6	-	-	-	-	-
Mweru (L)	*Microthrissa moeruensis*	Clupeidae	5.0	SL	0.9	2.8	SL	0.3	-	3.20	4.7	5.9	10.5
Kivu (Rwanda) (L)	*Limnothrissa miodon* (I)	Clupeidae	17.5	SL		6.0	SL	-		1.30	14.5	-	-
Kariba (R)	*Limnothrissa miodon* (I)	Clupeidae	10	SL	-	6.4	SL	-	1.6	3.40	7.5	-	-
Cahora Bassa (R)	*Limnothrissa miodon* (I)	Clupeidae	-	-	-	-	-	-	-	5.40	7.0	-	-
Itezhi-Thezi (R)	*Brycinus lateralis*	Alestidae	14	SL	1.0	10.6	TL	-	3.5 + 0.5	2.81	17.0	4.1	12.3
	Limnothrissa miodon (I)	Clupeidae	15	TL	2.0	-	TL	-	-	1.20	13.5	1.9	-
Kainji (R)	*Pellonula leonensis*	Clupeidae	9.3	TL	1.8	6.5	TL	0.5	3.3 + 0.39	1.56	9.9	3.3	12.9
	Sierrathrissa leonensis	Clupeidae	3	SL	0.7	2.4	SL	0.3	3.1 + 0.3	3.69	3.3	-	-
Volta (R)	*Odaxothrissa mento*	Clupeidae	13	SL	2.9	8.8	SL	0.9	4.3 + 0.75	0.95	13.8	-	-
Edward (L)	*Brycinus nurse*	Alestidae	25	TL	6.9	15.7	TL	1.8	2.5 + 0.2	0.41	26.3		3.9
Average			11.5		2.1	6.7		0.7	3.0	2.2	11.7	3.5	9.3

I=introduced. K=Brody's growth coefficient; L_∞=estimated length at infinity; M=natural mortality; r=intrinsic population growth rate. SL= standard length, TL= total length. Based on Froese and Pauly (2017) and sources indicated.

Sources	Victoria	Eccles, 1992; Graham, 1929; van Oijen, 1995; Greenwood, 1966; Corbet, 1961.	Kariba	Cochrane, 1984
	Tanganyika	Coulter, 1977; Eccles, 1992; Kimura, 1994	Cahora Bassa	Gliwicz, 1984
	Malawi	Whitehead, 1985	Itezhi-tezhi	Skelton, 1993; Mbewe, 2000
	Turkana	Hopson and Hopson, 1982	Kainji	Whitehead, 1985
	Mweru	Whitehead, 1985; van Zwieten *et al*., 1996	Volta	Whitehead, 1985
	Kivu	De Iongh *et al*., 1995	Other	Fishbase accessed 23/24 July 2017

Because of their small size and general biology, pelagic cyprinids and clupeid species are expected to be opportunistic strategists (Winemiller and Rose, 1992) that have high intrinsic rates of population increase (*r*) and P/B ratios (Table 1, Table 3). Opportunistic strategists differ from the classic r-strategists in the *r*-K selection dichotomy in having small instead of large individual clutch sizes of ripe eggs, but multiple or almost continuous spawning bouts per year. Populations of these small fish thus have a high reproductive effort, spread out over the year, and are well equipped to repopulate habitats after disturbances.

For example, the introduced *kapenta* (*Limnothrissa miodon*) in Lake Kariba colonized the whole lake from a few buckets of fry within a few years after introduction (Junor and Begg, 1971). Thus, these species have an early age at maturity, low individual fecundity (clutch size) with relatively small eggs, and low juvenile survivorship. Their reproductive seasons are generally long, based on what is known of some species, year-round.

There may be some annual fluctuation in reproductive effort depending on favourable or unfavourable generally climate-driven, seasonal conditions. For example, *chisense* (*Microthrissa moeruensis*) from the allotrophic[7] riverine Lake Mweru has low breeding activity during the cold/dry season from May to July (van Zwieten *et al*., 1996). Another example is the variable upwelling condition in Lake Tanganyika that is reflected in the highly variable seasonal, interannual and decadal catch rates of the now defunct industrial fleet of Burundi (van Zwieten *et al*., 2002).

2.2 BIOMASS AND ABUNDANCE OF SMALL PELAGIC FISH IN THE AFRICAN LAKES

Regular stock assessments are rare and characterized by insufficient data. Estimates of stock abundance (biomass) are particularly lacking and estimates of fishing pressure and exploitation patterns are therefore scarce and sporadic.

To estimate the fishing pressure and potential production of small pelagic fish, we used a published sample of 18 Ecopath models from 13 African lakes (Figure 5). Twelve of these models, from eight lakes (Victoria, Tanganyika, Malawi, Turkana, Kariba, Kivu, Chad and Tana; Table 4), contain information on biomass abundance, turn-over rates and catches of small pelagic species.

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[7] Allotrophic means that nutrients are mainly brought into the system from outside, mainly from run-off, tributaries and effluent rivers.

FIGURE 5
Map showing the location of the 13 African lakes and reservoirs that have been represented by one or several Ecopath models

TABLE 4
Eight African lakes with "small pelagic species" in the set of Ecopath models available

	Latin name	Local name (s)	Source
Lake Victoria	*Rastrineobola argentea*	*Dagaa,* *mukene,* *Omena*	Moreau, Ligtvoet and Palomares, 1993; Natugonza *et al*., 2016
Lake Tanganyika	*Limnothrissa miodon, Stolothrissa tanganicae*	*Kapenta*	Moreau *et al*., 1993
Lake Malawi	*Engraulicypris argentea*	*Usipa*	Darwall *et al*., 2010
Lake Turkana	*Alestes minutus and Alestes ferox*	*Lokabela*	Kolding, 1993b
Lake Kariba	*Limnothrissa miodon*	*Kapenta*	Machena, Kolding and Sanyanga, 1993
Lake Kivu	*Limnothrissa miodon*	*Kapenta*	Villanueva *et al*., 2008
Lake Chad	*Brycinus macrolepidotus*	*Salanga*	Palomares, Horton and Moreau, 1993
Lake Tana	*Barbus* spp.	Small barbs	Wondie, Mengistouy and Fetahi, 2012

Although the various Ecopath models cover different periods, and while there is a clear correlation between annual productivity and rainfall (Kolding 1989, 1992; Karenge and Kolding, 1995b, Kolding and van Zwieten, 2011; see also the section on environmental drivers below), it can be assumed that most lakes, (except Lake Victoria, see below) have on average reasonably constant productivity features over time. The average potential catch of 150 kg/ha/year (Table 5) must therefore be considered realistic. This estimate corresponds remarkably well with independent yield estimates of 150 kg/ha/yr from other African water bodies (Marshall and Maes, 1994; Kolding and van Zwieten, 2006).

The small pelagic fish in the eight lakes (Table 5) are on average by far the most productive fish components of the ecosystems examined and are also among the least exploited (the ratio of annual yield to annual production E = 16%), with only the small haplochromines (cichlids) having lower exploitation rates (Figure 6). According to these ecosystem models, the total potential unutilized production of small pelagic fish from these lakes alone is estimated to be around 5 million tonnes per year (Table 5).

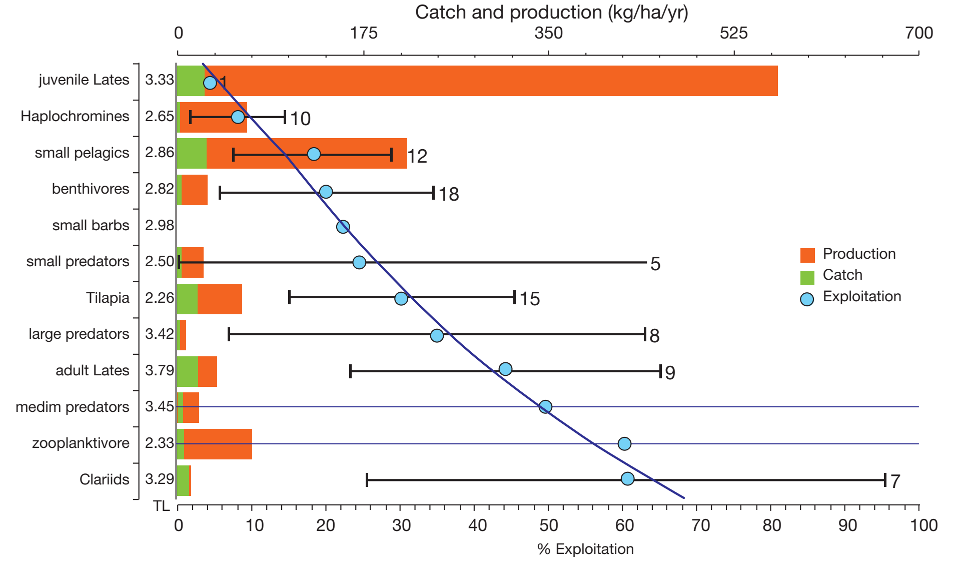
TABLE 5

Biomass, PB ratio, production, catch and potential catch of small pelagic species from eight African lakes with Ecopath models

Model	area (ha)	Biomass (kg/ha)	mean P/B ratio	Production (kg/ha/yr)	Catch (kg/ha/yr)	Exploit-ation ratio	Potential catch (E = 0.4)	Unutilized (kg/ha/yr)	Total potential (tonnes/yr)
Lake Victoria 1971	6 880 000	76	1.8	137	2	0.02	55	52	376 474
Lake Victoria 1985	-	79	2.2	174	42	0.24	70	27	478 298
Lake Victoria 2014	-	191	3.9	751	74	0.10	300	226	2 065 734
Lake Tanganyika 1972	3 290 000	181	4.0	797	40	0.09	319	279	1 048 852
Lake Tanganyika 1982	-	63	4.8	324	20	0.13	130	110	426 384
Lake Malawi 1990s	2 960 000	9	2.8	24	3	0.11	10	7	28 404
Lake Turkana 1973	700 000	299	5.2	1 552			621	621	434 616
Lake Turkana 1987	-	60	5.3	313			125	125	87 760
Lake Kariba 1980s	536 400	37	6.0	222	60	0.27	89	29	47 632
Lake Kivu 2003	270 000	18	4.2	56	14	0.50	23	8	6 086
Lake Tana 1990s	215 600	12	1.6	19			8	8	1 639
Lake Chad 1970s	135 000	36	3.2	116	1	0.01	46	46	6 273
Average		88	3.8	374	28	0.16	150	128	

FIGURE 6

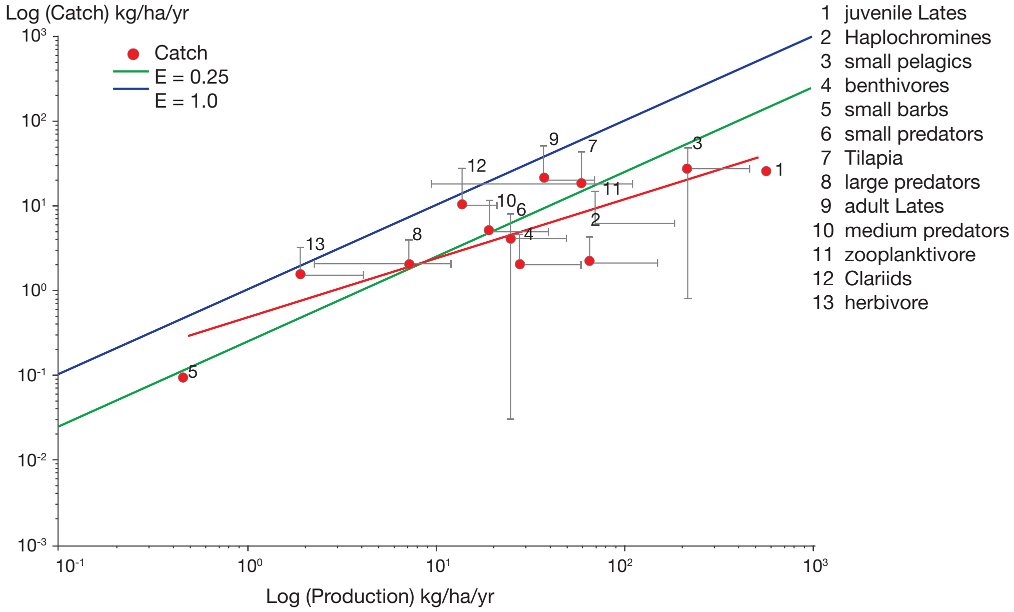
Average annual production in kg/ha/yr (orange bars) and average annual catch (green bars) (kg/ha/yr) in 13 African lakes and reservoirs



Blue circles are the mean exploitation ratios (fraction of annual production caught) with 95 percent confidence limits. The number above the confidence interval bars is the sample size. TL is trophic level. The species are sorted in order of ascending exploitation ratio, with the small pelagics having the lowest ratio and clariids and medium-sized predators, the highest.

FIGURE 7

The average fishing pressure and fishing pattern (± SD) of the main fish groups in 13 African lakes and reservoirs (Figure 5)



Groups above the green line (E = 0.25) have exploitation rates greater than 25 percent to up to 100 percent of production, while groups below the green line have exploitation rates less than 25 percent of production. Small pelagics have the second highest average productivity (375 kg/ha/year) after juvenile Nile perch in Lake Victoria and are only lightly exploited (E = 0.16). To balance the fishery according to production with moderate exploitation rates (Garcia *et al.*, 2012), all stocks should be on a line parallel with and close to the green line (Kolding *et al.*, 2015a). The red line shows the deviation of the stocks from this parallel line and highlights the focus of fisheries on species that have relatively low production capacity. To restore the balance, fishing pressure could be increased on small, highly productive species and decreased on larger species with lower productivity.

The present focus of fisheries exploitation in 13 African lakes and reservoirs on species that are not only large in adult size (Figure 7) but also high in the food chain – much higher than on land (Section 1.8) – can be seen if we compare the average relation between production (kg/ha/yr) and trophic level, which on a logarithmic scale is a downward linear trend, and the corresponding level of exploitation per trophic level (Figure 8). The picture shows the mismatch between productivity and harvest levels, where the low trophic levels (small herbivorous and zooplanktivorous species) are much less exploited, relative to their productivity, than higher trophic levels. Thus, a substantial increase of fish production is only possible if we target lower trophic levels. This, in fact, means "fishing down or through the food web" and increased catches of small-sized fish (Figure 3).

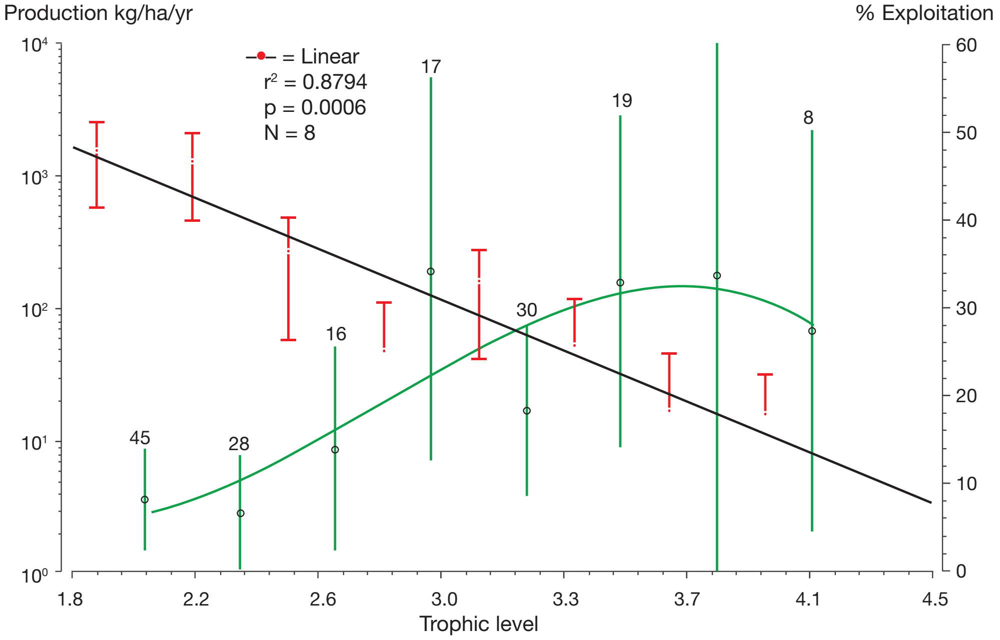
2.3 THE EFFECT OF CLIMATIC DRIVERS ON THE PRODUCTIVITY OF SMALL PELAGIC FISH

There is increasing evidence that fish production in African inland fisheries in general is more dependent on climatic drivers than it is on human exploitation rates and various management interventions (Jul-Larsen *et al.*, 2003; Kolding *et al.*, 2008; Kolding and van Zwieten, 2011, 2012; Gownaris *et al.*, 2018).

Due to the trophic proximity of small pelagic species to the primary base of the food web (Figure 3), they are known to fluctuate strongly in response to changing climate-driven environmental conditions (Marshall, 1982; Karenge and Kolding, 1995a; Jul-Larsen *et al.*, 2003). Lakes and reservoirs do not maintain high fertility unless external loading of nutrients continually takes place (Schindler, 1978) and nutrient availability in lakes and reservoirs is dependent on both exogenous supplies through rain and/or water inflows, and internal wind-driven mixing regimes (Kolding and van Zwieten, 2006).

FIGURE 8

The relation between production (left Y-axis, red) and trophic level (X-axis) in 13 African lakes and reservoirs (Figure 5) and the corresponding level of exploitation (right Y-axis, green) per trophic level



This graphic presents similar information to that in Figure 7 but is now sorted by trophic level. The conclusion is the same, with low trophic level species underexploited and the higher trophic level species fully exploited. The estimates of production (log-scaled) corroborate the general rule of thumb of a 90 percent loss in energy per ascending trophic level. There is a general mismatch between production and fishing pressure in African freshwater systems.

The climatic influence is well known by the local fishers. For them, as with local farmers, the biggest concern is precipitation: “fish come with the rain” is a frequently heard statement when African fishers are asked about the drivers of fish production (Kolding *et al.*, 2016a). Following long-term climatic variations, pelagic fisheries will therefore typically undergo periodic boom and bust oscillations, and in many cases periods of decreasing catches or catch rates are erroneously attributed to overfishing instead of natural fluctuations.

Based on the model projections of the Intergovernmental Panel on Climate Change (IPCC), precipitation in East and Central Africa is expected to increase (Stocker *et al.*, 2013), but observations to date do not seem to support this trend (e.g. Lott, Christidis and Stott, 2013). However, the prediction of increased variability in precipitation across the continent seems to be supported (e.g. Sahel: Dai *et al.*, 2004; southern Africa: Tadross, Jack and Hewitson, 2005). In addition, temperature changes will further influence hydrological regimes by altering the rate of evaporative water loss (e.g. Bootsma and Hecky, 1993) and mixing patterns (Verburg *et al.*, 2003).

Long-term and short-term precipation-driven effects on African lake ecosystems and productivity are reflected in the so-called relative lake level fluctuation (RLLF) index (Kolding and van Zwieten, 2012) which is a combination of the important static parameter of system depth (primary production in water is light limited) and the dynamic parameter of lake level changes (the hydrological configuration):

RLLF = average amplitude/depth*100

Where amplitude represents the difference between the maximum and minimum water level within a given year for intra-annual (seasonal) fluctuations (RLLFs) and the absolute difference between two sequential years for interannual fluctuations

(RLLFa), and where depth represents the mean system depth. This index has proven to encapsulate much of the observed variation in productivity and biological attributes of tropical lakes and reservoirs (Kolding and van Zwieten, 2012; Gownaris *et al.*, 2018).

In a meta-analysis of biological and physical ecosystem attributes, productivity patterns and climatic drivers, using the 13 African lakes and reservoirs in Figure 5, Gownaris *et al.* (2018) showed that significant long-term temporal trends in interannual water level fluctuations existed for seven out of 13 systems, approximately half of which were positive. Furthermore, trends in intra-annual water level fluctuations, using the Theil-Sen estimator, were significant for 10 of the systems and were positive for all but two (Table 6). Thus, the hydrological regimes of many African lakes are already changing consistent with the drier dry seasons and wetter wet seasons expected from climate change (Stocker *et al.*, 2013).

TABLE 6

Average and temporal trends in relative lake level fluctuations at inter- (RLLFa) and intra-annual (RLLFs) scales

System	RLLFa	RLLFs	All water level data (#years annual & seasonal)	1990s–2000s water level data (#years annual & seasonal)	Theil-Sen RLLFa	Theil-Sen RLLFs
Lake Tanganyika	0.04	0.13	1909–1992 (106/106)	1990–2014 (25)	ns	↓**
Lake Kivu	0.13	0.46	1945–1973 (34/34)	1996–2008 (13)	ns	ns
Lake Malawi	0.14	0.59	1900–2014 (93/93)	1990–2014 (25)	↑*	↑***
Lake Victoria	0.64	1.31	1900–1989 (112/112)	1993–2014 (22)	ns	↑***
Lake George	1.18	2.81	1992–2014 (11/11)	2000–2010 (11)	ns	↑**
Lake Turkana	1.59	3.72	1888–1989 (112/22)	1993–2014 (22)	↑*	↑***
Lake Tana	2.15	18.62	1960–1992 (55/55)	1990–2014 (25)	↓**	↑**
Lake Chad	2.59	30.28	1954–1977 (46/46)	1993–2014 (22)	↑*	↑***
Lake Kariba	3.97	15.02	1963–1999 (52/52)	1990–2014 (25)	↓***	↑***
Lake Awassa	4.22	16.04	1970–1999 (30/30)	1990–1999 (10)	↑***	↑***
Lake Hayq	8.85	NA	1975–2012 (29/29)	1990–2012 (16)	↓*	NA
Lake Naivasha	11.32	28.34	1900–1998 (110/110)	1990–2014 (20)	ns	↑***
Lake Nakuru	38.70	40.77	1958–2000 (29/29)	1993–2000 (9)	ns	ns

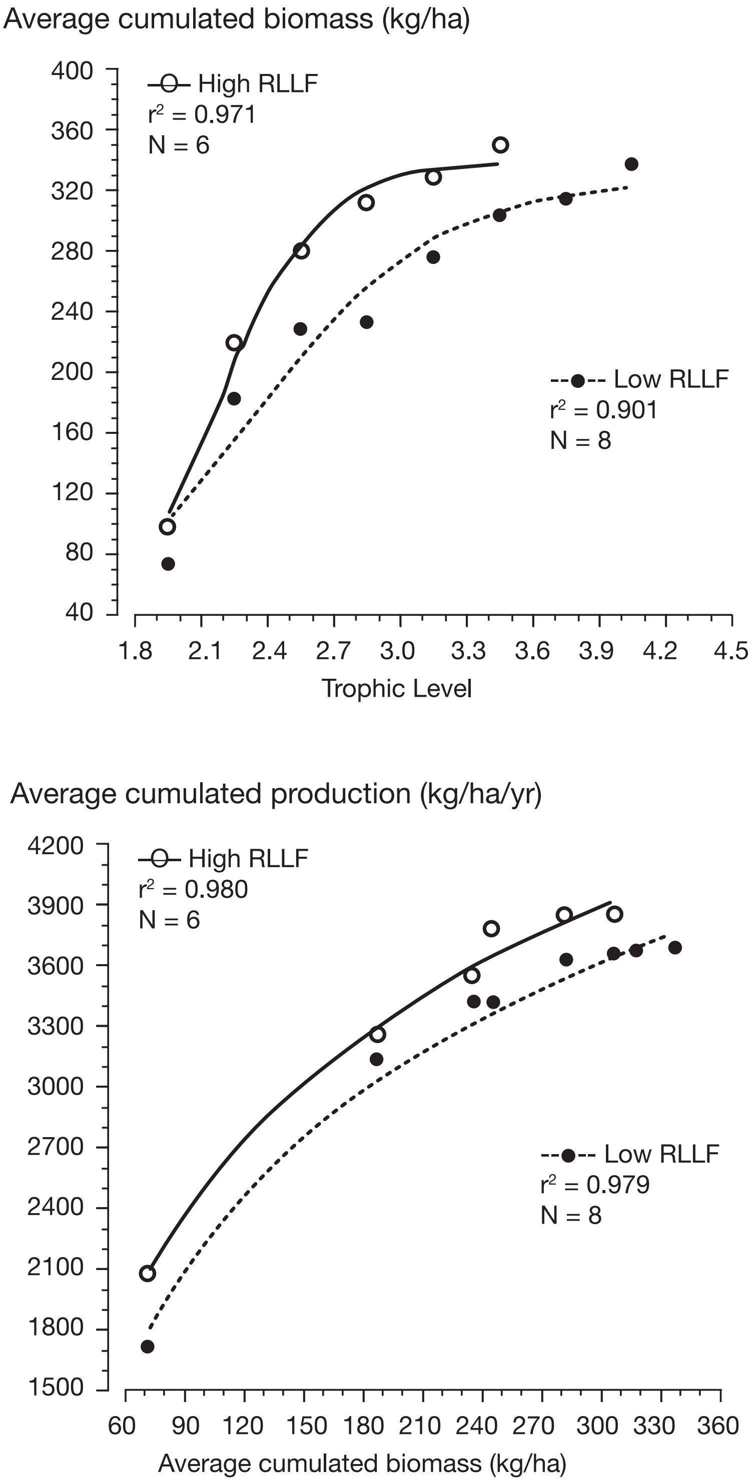
Trends at both scales were calculated using the Theil-Sen estimator and significant levels are as follows: * (p<0.05), ** (p <0.01), *** (p<0.001), ns (not significant), NA (not applicable)

Source: From Gownaris *et al.* (2018).

By splitting the 13 African lakes for which Ecopath models exist into relatively stable versus fluctuating systems, Gownaris *et al.* (2018) found a significantly higher level of standing biomass and cumulative production in the high RLLF systems compared to the low RLLF systems (Figure 9).

FIGURE 9

Logistic (top panel) and logarithmic (bottom panel) regressions (Link *et al.*, 2015) showing the relationship between top: average cumulative biomass and trophic level (in bins of 0.3 trophic levels); and bottom: average cumulative production and average cumulative biomass



The "High RLLF" category represents systems with interannual relative lake level fluctuations of ≥2.15 and intra-annual relative lake level fluctuations of ≥9.4 (Table 6).

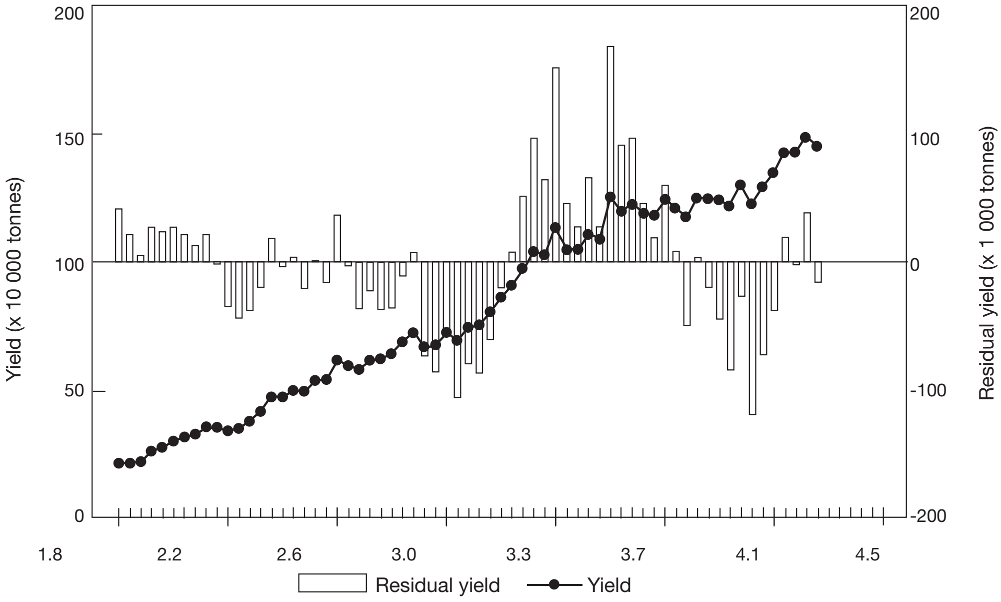
Source: Gownaris *et al*. (2018).

These trends indicate that, in the future, we can expect an increase in the climate-driven lake level fluctuations, accompanied by higher interannual variability in catches, but also higher overall average productivity by low trophic resilent species (Kolding and Zwieten, 2012; Kolding *et al.*, 2016a).

While the recorded yields of African inland fisheries have increased almost linearly by around half a million metric tonnes per decade over the past 60 years, there are clear cyclical variations in the residual yield – calculated as the deviations from a linear trend line regressed over the recorded yields – of about 20 years periodicity above and below the trend line (Figure 10).

FIGURE 10

Total annual recorded yield (black dots) from inland fisheries in 27 African countries and the clustered fluctuating catch anomalies (residual yield, open bars) showing an approximate 20-year periodicity around the trend



Source: FAO FishStat (2016), from Kolding *et al.* (2016).

When comparing this cyclical pattern in the recorded catches (Figure 10) with the most conspicuous observed changes in African lakes and reservoirs – the long-term, interannual and seasonal fluctuations in water level and river inflow – there appears to be a correlation between the de-trended landing statistics (the residuals in Figure 10) and long-term climate-driven oscillations in the water levels (Jul-Larsen *et al.*, 2003; Kolding *et al.*, 2016a, Figure 11), which are remarkably correlated with most of the large lakes over the past 200 years[8].

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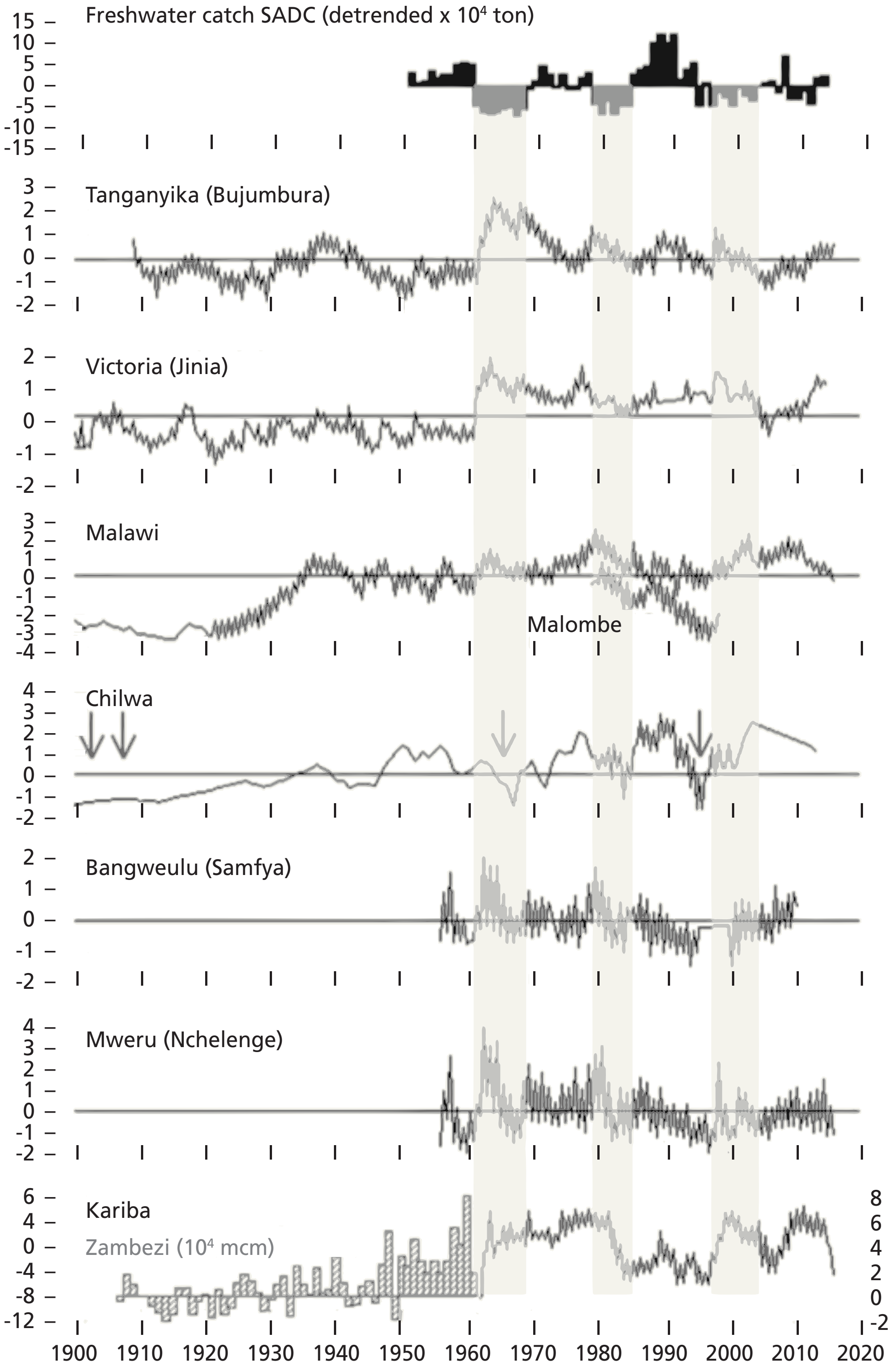
[8] Comparisons between Lake Malawi and Lake Victoria over the past 200 years generally show opposite trends consistent with the most typical patterns of rainfall anomalies that show strong opposition between equatorial and southern Africa in most years (Nicholson, 1998).

FIGURE 11

Relative water levels of lakes Tanganyika, Victoria, Malawi, Malombe, Chilwa, Bangweulu, Mweru and Kariba expressed as deviations from the long-term mean of annual mean levels over the period for which data were available



Light grey bars are the deviations of the 89-year mean annual total inflow of the Zambezi at Victoria falls (mcm = million cubic meters). Arrows indicate the years Lake Chilwa was reported to be dry. Lake Malombe is hydrologically considered a satellite of Lake Malawi: when water levels in Lake Malawi are low, Lake Malombe completely dries up. The top panel shows the variability around the trend of the total fish catches of the SADC region, with grey bars comparing periods of low catches relative to the trend.

Source: Kolding *et al*. (2016).

Jul-Larsen *et al*. (2003) concluded that for most African inland fisheries the environment was a more important driver of fish stocks and production than fishing effort. This was supported by Kolding and van Zwieten (2012) who found that fishing effort across 17 African lakes and reservoirs was strongly correlated with system productivity. The implication is that effort therefore could be a function of catch rather than vice versa as conventional fisheries models assume. This observation can also be illustrated by the fishing development in Lake Victoria (Figure 20), where catches and effort have increased almost linearly over the years, concomitant with the increased eutrophication and productivity of the lake (Kolding *et al*., 2008; van Zwieten *et al*., 2016).

Given the huge annual regenerative capacity of small pelagic species of up to five times their own biomass per year (Table 1), and their general low exploitation rate compared to larger species (Figures 6 and 7), it is unlikely that fishing has a significant adverse effect on their populations, other than the reduction in standing biomass that a removal neccesarily generates. Exploitation rates are generally low on these species (Table 5). However, as the general regulated fishing pattern of African freshwater fisheries is still highly skewed towards high trophic level species (Figure 8), a shift in the overall ecosystemic fishing pattern to increased fishing pressure on small fish species, together with decreased fishing pressure on large fish species, is a prerequisite for restoring and maintaining the natural balance between species and sizes in the ecosystems. Such a shift would also be in line with the EAF and the Convention on Biological Diversity (Kolding and van Zwieten 2014; Kolding *et al*., 2015a, 2015c).

2.4 MANAGEMENT OF LAKE FISHERIES USING A BALANCED HARVEST APPROACH

The general pattern of fishing in African Great Lakes is conventionally directed towards large fish, high in the trophic food web, which are the least productive components of the ecosystem (Figure 3 and Figure 8) and therefore also the most susceptible to potential overfishing. When these segments show signs of depletion, with a corresponding reduction in the individual catch rates of fishers, a natural and logical response of fishers is to target fish species and sizes which are more abundant, but smaller and lower in the food web. This is a general feature of African small-scale fisheries. It has been called the "fishing down" process by Robin Welcomme (1999) and is manifested by a gradual increased exploitation of small fish. This common and widely observed process is based on the successive reduction in the sizes of individual fish and fish species caught. This occurs as fishing pressure (effort) increases, by a corresponding successive reduction in mesh sizes, together with a diversification of fishing gears and fishing methods towards catching previously non-targeted species. The process is induced by the inevitable decline in individual catch rates (also called catch-per-unit-effort, or CPUE) as the number of people and therefore fishers increases (Jul-Larsen *et al*., 2003; Kolding, Béné and Bavinck, 2014). The decline in individual catch rates, however, is generally accompanied by a corresponding rise in the total catch from the combined fishery, as smaller, faster growing, more productive species and sizes replace larger, slower growing, less productive ones. In addition, because many fish-eating predators are among the larger species, the initial reduction of these will boost the abundance of species and sizes lower down in the food chain (Figure 8). There is therefore strong empirical evidence that targeting small fish will give much higher total yields than targeting large fish only (Kolding, Musando and Songore, 2003; Kolding, Ticheler and Chanda., 2003). Unfortunately, the general process of "fishing down", indicated by a decrease in fish size and a decrease in average trophic level, is mistakenly interpreted as a sign of a deteriorating and unsustainable situation (Pauly *et al*., 2008) with the added complication that an increasing number of fishing methods become technically illegal as they target smaller and smaller fish (Irvine, Etiegni and Weyl, 2018). As the regulation of fishing effort (numbers of fishers or fishing units) is difficult to implement in African small-scale fisheries for socio-political reasons (Kolding, van Zwieten and Mosepele, 2016), the fishery regulations in most African fisheries consist of technical measures, such as minimum legal mesh sizes to prevent fishing of small juveniles (Kolding and van Zwieten, 2011). The focus on a single predatory species leads to increasing lack of alignment between fishery regulations and fishery activities, and a snowballing perception that the fisheries are overfished and "doomed" while the fishers themselves are destroying their own resources in line with "the tragedy of the commons" doctrine (Welcomme and Lymer, 2012). Countless enforcement programmes, directives and punitive expeditions are implemented all over Africa in order to prevent fishing methods that violate the conventional mesh size regulations or that target small fish. As shall be elaborated below, however, the fishing down process is not only a rational response of fishers (Plank *et al*., 2017; Peter and van Zwieten, 2018), but also a precondition for maximizing food production while maintaining the health and structure of the fished ecosystem (Kolding and van Zwieten, 2014; Kolding *et al*., 2016a).

Thus, in spite of current rules and regulations and, at times, unsuccessful enforcement efforts, the overall result of the ongoing "fishing down" process is that African inland fisheries are increasingly providing large amounts of small fish (sizes and species), which from a human nutritional point of view is highly beneficial (Kawarazuka and Béné, 2011; Beveridge *et al*., 2013, Longley *et al*., 2014). In spite of widespread concern and misconceptions of how the aquatic ecosystems are functioning, it is also highly advantageous from an ecological point of view because catching more small fish than large fish keeps the aquatic ecosystem structure in balance with its productivity (Law *et al*., 2012, 2014; Kolding and van Zwieten, 2014; Kolding *et al*., 2015c) and maintains the terrestrial ecosystem by reducing the cutting of firewood necessary for smoking and preserving large fish. There are even indications that increased access to affordable fish protein is contributing to the conservation of endangered mammal species hunted for bush meat (Wilkie *et al*., 2005; Junker *et al*., 2015).

Nevertheless, the major governance focus on inland fisheries at present is not on their essential contribution to food security and nutrition (Box 1), but on overfishing and illegal fishing methods of the resources. A major contributing factor to this fear and focus is the ubiquitous misconception that a decrease in individual catch rates and the average sizes of fish landed are signs of overfishing, although in most cases these are simply natural and unavoidable signs of fishing (Kolding, Béné and Bavinck, 2014). Most management effort at present seems oriented towards constraining fishing, particularly on small juvenile fish, instead of studying and understanding the dynamics of local fishing patterns and quantifying their importance for nutrition and impact on the ecosystem. From both an ecosystem point of view and from a human food production and nutrition point of view the fishing down process is a rational way to advance an EAF, and to comply with the international requirements of conserving the structure and functioning of wild harvested ecosystems (Garcia *et al*., 2015, 2016; Zhou *et al*., 2019). This would require moving fishing pattern from conventional selective harvesting of large species into better balance with the current productivity of the various components of a fish community (Garcia *et al*., 2012) which in turn requires a fundamental rethinking of the current objectives of fishery management (Kolding and van Zwieten, 2011, Kolding *et al*., 2016b).

3. Selected small pelagic fish species of commercial importance

3.1 CYPRINIDAE

Only a few cyprinid (carp) species are pelagic, but these form the basis of important fisheries: *Mesobola moeruensis* (*chisense*) in Lake Bangweulu, *Engraulicypris sardella* (*usipa*) in Lake Malawi and *Rastrineobola argentea* (*dagaa, umena* or *mukene*) in Lake Victoria (Table 3). The eight genera of the bariliine lineage of cyprinids comprise genera *Opsaridium* and *Raiamas*, which are predators feeding on crustacea, insects and fish, and the neoboline genera of *Chelaethiops*, *Engraulicypris*, *Leptocypris*, *Mesobola*, *Neobola* and *Rastrineobola*. Neoboline cyprinids are all small (Table 2, 3) and are all open water (zoo)planktivores, although riverine species such as *Mesobola brevianalis* include allochthounous material such as insects and vegetable matter in their diets. Trophic levels thus are expected to be from 3 and up to 4 for most of these species, as they are for *Rastrineobola argentea* and *Engraulicypris sardella* (Table 3). Their breeding biology generally is not very well studied, although some information is available for the species that are of commercial importance, as discussed below. The eggs and larvae of these lacustrine species are all pelagic (references in Skelton, Tweddle and Jackson, 1991).

3.1.1 Rastrineobola argentea

Rastrineobola argentea or *dagaa* (Tanzania), *omena* (Kenya) or *mukene* (Uganda) as this species is known in the three riparian countries of Lake Victoria, is endemic to the lake and its drainage area, including Lake Kyoga, Lake Nabugabo and the Victoria Nile (Greenwood, 1966). In Lake Kyoga it occurs in open water away from waterlily swamps. In Lake Victoria *Rastrineobola argentea* was originally known mainly from the surface of inshore and coastal waters, though the earliest records indicate that it was distributed all over the lake from surface waters to great depths (Graham, 1929). In modern Lake Victoria it is found inshore and offshore across all depths. During the day it lives close to the oxycline or if possible near the bottom. Wanink *et al.* (2001) argue that oxycline-dwelling is not due to predation avoidance, but because *dagaa* are limited by low oxygen levels in reaching their preferred position near the bottom. During the night the species is found near the surface of the lake, feeding on zooplankton and insects. Mature individuals spawn in the lake and seem to produce floating eggs (Corbet, 1961). *Rastrineobola argentea* has a low absolute fecundity of a few thousand eggs, but its relative fecundity (gonad tissue per unit somatic tissue) by weight is enormous: 70 times higher than Nile perch (*Lates niloticus*) and almost 4 000 times that of the tilapia species *Oreochromis niloticus* and *Oreochromis esculentus* (Manyala and Ojouk, 2007). Juvenile fish appear to migrate away from the shore after spending their larval stage in shallow areas.

During the 1980s, after the introduction and subsequent boom in population of the lake by Nile perch and the concomitant reduction/disappearance of the zooplanktivorous haplochromine cichlids from the sublittoral waters (van Zwieten *et al.*, 2016), the zooplanktivorous *dagaa* expanded its habitat and started to explore the deepwater bottom habitats as well. Haplochromines formerly occupied these mainly daytime habitats for zooplankton and macrobenthic invertebrates.

Besides extending its range of vertical distribution, *dagaa* started to include macrobenthic invertebrates in its diet. These environmental changes caused rapid changes in the morphology of the species, which illustrates the ability of many small pelagic species to adapt to changed circumstances. *Dagaa* developed a higher number of gill filaments and a decrease in the number of gillrakers between 1981 – prior to the vast changes in the lake – and 1988, just after the Nile perch boom. Increased gill filaments were thought to be an adaptation to an improved capacity to extract oxygen from the water, crucial for surviving the relatively low oxygen conditions in the new habitat. By decreasing the number of gillrakers, *dagaa* has probably increased its efficiency of feeding on relatively large prey in a benthic habitat (Wanink *et al*., 2001).

PLATE 2

Top: measuring the catch of mukene (Rastrineobola argentea) using a basin; bottom-left: drying mukene directly on the ground, Tanzania; bottom-right: drying racks for mukene at Kikondo landing site, Uganda

TOP AND BOTTOM RIGHT © RESTY NABBANJA; BOTTOM LEFT: © MODESTA MEDARD

Dagaa plays a crucial role in the modified ecosystem of Lake Victoria. It is the main utilizer of zooplankton and it also feeds on surface insects (Witte and Winter, 1995; Wanink, 1999); it is heavily preyed on by birds and fish, such as *siluroids, Schilbe mystus, Clarias gariepinus* and *Bagrus docmak* (Wanink, 1999); and it is a major prey of the introduced Nile perch (Cornelissen *et al*., 2015; 2018). Economically, *dagaa* is the second-most important species in Lake Victoria, after Nile perch (Wanink, 1999). The species currently supports the biggest fishery in the lake by weight, with a catch of almost half a million tonnes per year (Kolding *et al*., 2014) and it may be the most important species of the lake in terms of regional food security (Isaacs, 2016). Most of the biomass of *Rastrineobola argentea* (an average of 68 percent) was distributed in waters of more than 40 m depth (Tumwebaze *et al*., 2007) and its biomass seems to have increased progressively over the decades (Tumwebaze *et al*., 2007; Taabu-Munyaho *et al*., 2014) since the Nile perch boom, in spite of steadily increasing fishing effort.

3.1.2 *Engraulicypris sardella*

Engraulicypris sardella, known locally as *usipa*, is a small pelagic cyprinid that grows to a maximum length of 13 cm and is endemic to Lake Malawi and the Upper Shire River. It is unevenly distributed over the lake: trawl catches during a 1992 to 1994 survey (Menz, 1995) were approximately ten times higher in the shallow southeast arm of the lake compared to the central region, with a slight increase at the northern end of the lake (Thompson, Allison and Ngatunga, 1996). In common with most small pelagic species, considerable fluctuations in biomass and fishery landings occur; these can be up to a tenfold increase or decrease within and between years (Turner, 1982; Tweddle and Lewis, 1990; Lewis and Tweddle, 1990).

PLATE 3

Usipa (Engraulicypris sardella) being sun-dried and packed for sale in Lake Niassa/Malawi, Tanzania

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Engraulicypris sardella is the only fish species in the lake known to have pelagic larvae, but there is no evidence that it is a pelagic spawner. Larvae were found to be most abundant in the upper 50 m of the water column during the day and were virtually absent below 250 m. They moved down by an average of 50 m at night. Thompson, Allison and Ngatunga (1996) suggest the following probable life cycle: adults spawn on the substrate just above the anoxic boundary at about 230 m depth, the level of the permanent barrier to mixing, and the eggs probably remain on the substrate until the embryos hatch. The larvae are then carried offshore by currents. Once the larvae reach about 3 cm in length, they form shoals and migrate inshore and metamorphose into juveniles. At about 6 to 7 cm, the juveniles move to their spawning grounds. This life cycle, which does not involve pelagic eggs, is more typical of a cyprinid (Mills, 1991) than the pelagic-spawning existence proposed by earlier authors (see references in Thompson, Allison and Ngatunga, 1996). *Engraulicypris sardella* may have a different pattern of diurnal vertical movement to the other pelagic fish, with a tendency to move to deeper waters at night. Daytime schools of *Engraulicypris sardella* were observed in the upper 40 m of the water column on acoustic traces. These moved down at dusk and dispersed to form a diffuse layer at 80 to 110 m below the surface, which would then rise at dawn to re-form into near-surface schools.

Engraulicypris sardella has distinct seasonal patterns in total numbers and biomass, production and larval mortality. The species reproduces throughout the year, with a peak in activity around September (Thompson, Allison and Ngatunga, 1996). Larval mortality was lowest from July to December and highest from January to April and was, on average, higher in the south of the lake and lower in the central and northern region. In addition, low mortality of larvae coincided with the windy mixed period when primary and secondary production were at a maximum and correlated with an increased food supply – crustacean zooplankton dominated by *Tropodiaptomus cunningtoni*. Thompson (1996) further argues that a degree of density-dependent mortality for *Engraulicypris sardella* larvae exists, with mortality being higher when the number of larvae hatching was higher. The abundance of *Engraulicypris sardella* is thus principally a function of mortality in the larval phase, and independent of the size of the parent year-class, leading to a probable absence of any stock–recruitment relationship. Some top-down control may also be possible: the main predators of *Engraulicypris sardella* larvae are the pelagic cichlids *Rhamphochromis longiceps* and *Diplotaxodon Limnothrissa*, which both are 2 to 4 times more abundant in the south than the north of the lake which may explain the relatively lower larval mortalities observed in the northern part of the lake.

First feeding larvae of *Engraulicypris sardella* of 2 mm to 3 mm total length is predominantly on *Chlorophyta*, non-colonial green algae. Other types of phytoplankton were rarely seen in the guts of larvae. Larvae > 4 mm feed on *Copepod nauplii*; larvae greater than 5 mm total length feed on copepods and cladoceans (Thompson and Irvine, 1997). Adult *Engraulicypris sardella* feed on the lakefly insect *Chaoboris edulis* and planktonic copepods and cladocerans.

3.1.3 *Mesobola moeruensis*

Mesobola moeruensis, previously known as *Mesobola brevianalis* or *Engraulicypris moeruensis* and locally known as *chisense*, is a small planktivore cyprinid with a maximum size of 37 mm standard length which feeds mainly on algae. It appears in the Mweru-Luapula and Bangweulu-Chambeshi areas of the upper Congo River basin in Democratic Republic of the Congo and Zambia (Howes, 1984; Mubamba, 1993b; van Steenberge, Vreven and Snoeks, 2014). Hardly anything is known about its biology or ecology, and no information is available on its basic population dynamics. The fishery began in the late 1970s, early 1980s (Mudenda, 1989) and around 1995 it employed approximately 500 fishers, fishing with about 150 fishing units and catching an estimated 400 tonnes using dip nets and beach seines from the shore or from canoes, with or without light attraction. As with other small pelagic fisheries in the region (e.g. Lake Mweru, Lake Mweru Wa Ntipa) the fishery goes largely unrecorded. In 1995 the estimated catch accounted for around 10 to 15 percent of the recorded total catch (Benneker, 1996) and no further data are available.

3.2 CLUPEIDAE

Most of the clupeids (herring-like) species from African freshwater lakes and reservoirs are found in West Africa, the Congo River Basin and the coastal areas up to southern Africa, in addition to a few Malagasy species (Table 2). Both *Limnothrissa miodon* and *Stolothrissa tanganicae*, the endemic freshwater herrings of Lake Tanganyika, are members of a subfamily called pellonuline species, all of which are of marine origin. Molecular phylogenetic reconstructions indicate that herrings colonized West Africa 25 million to 50 million years ago, at the end of a major marine incursion in the region. Pellonuline herrings subsequently experienced an evolutionary radiation in West Africa, spreading across the continent and reaching East Africa's Lake Tanganyika during its early formation. While Lake Tanganyika has never been directly connected with the sea, the endemic freshwater herrings of the lake are the descendants of an ancient marine incursion (Wilson, Teugels and Meyer, 2008). All clupeid species are small; *Limnothrissa miodon* with 17 cm total length is the largest, but smaller morphs live in some of the introduced reservoirs (see below) and are found in pelagic riverine and lacustrine habitats.

3.2.1 *Limnothrissa miodon*

The *kapenta* or Tanganyika sardine (*Limnothrissa miodon*) is a small planktivorous pelagic freshwater clupeid originating from Lake Tanganyika in East Africa, where it is endemic. This fish has proved to be among the most successfully introduced species into new locations in Africa. There are no adverse effects reported on the resident community, besides demographic changes in the zooplankton composition. It was introduced into the natural Lake Kivu in 1958 to 1960 (Spliethoff *et al*., 1983; de Iongh, Spliethoff and Roest, 1995), and into the human-made lake Kariba (1960 to 1962), from where it spread downstream into lake Cahora Bassa on the Zambezi River (Bell-Cross and Bell-Cross, 1971; Whitehead, 1989). Later, the species was introduced into the Itezhi-tezhi reservoir in Zambia in 1992 (Mubamba, 1993a; Mbewe, 2000). It is a lacustrine species, preferring open waters nearshore and in bays in Lake Tanganyika, but when introduced it readily occupies open pelagic niches where it soon establishes itself. *Kapenta* is considered one of the prime candidates for introduction into other or future human-made lakes (Marshall, 1995). It forms large schools and shows diel migration over the water column, feeding close to the surface during the night. It feeds on plankton, especially atyid shrimp, but also on copepods and prawns (Paulsen, 1993; Mandima, 1999). In Lake Tanganyika larger individuals also take larval *Stolothrissa tanganicae*. Cannibalism does occur (Eccles, 1992; Paulsen 1993). In Lake Tanganyika, it breeds close to shore throughout the rainy seasons, but with peaks in May to June and December to January.

PLATE 4
Freshly caught kapenta (Limnothrissa miodon) in Lake Kariba

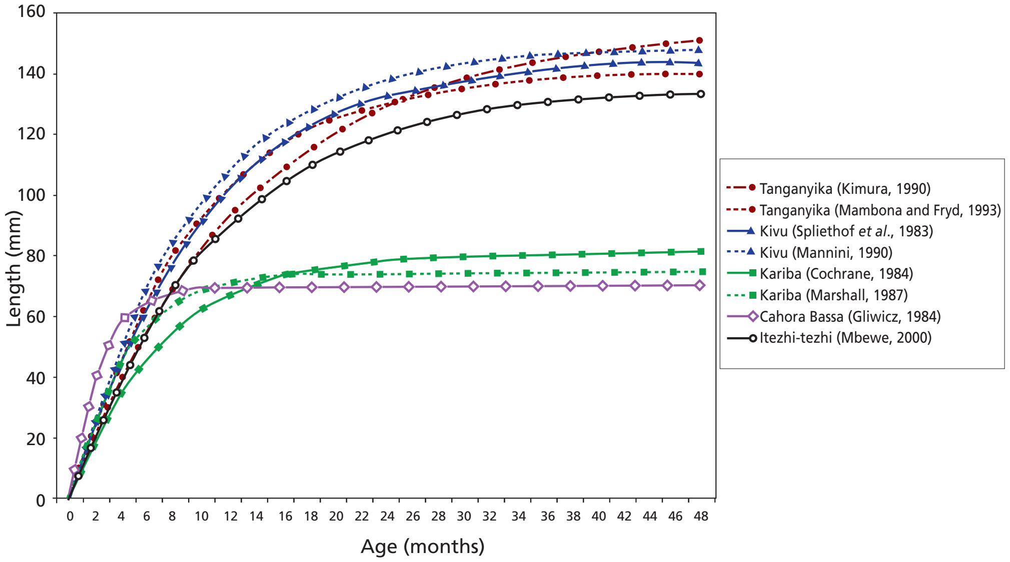
© JEPPE KOLDING

It is a very fast-growing species with a flexible life history resulting in estimated biomass regeneration rates (production to biomass ratio) of between 3 to 6 per year and with a lifespan between one and two years depending on the habitat (Anon., 1992; Marshall, 1995). The commercial importance of *kapenta* is reflected in the considerable research that has been conducted on this species, particularly in Lake Tanganyika and Lake Kariba. However, despite this effort, many of the basic dynamics of the various stocks have never been satisfactorily resolved. Growth, recruitment, and - especially - natural mortalities and the impact of fishing, have only been rudimentarily studied. As a result, there are still significant uncertainties about the biological potential and limits for production. Added to these uncertainties are the apparent marked phenotypic plasticity that the species exhibits in different habitats, resulting in distinctly different life history traits that also affect productivity. In Lake Kariba, for example, the various estimates of maximum sustainable yields differ considerably, there is no clear relationship between biomass indices (expressed as CPUE) and fishing effort, despite the fact that effort has been steadily growing over the years, and there is no clear understanding of whether the observed "stunting" (i.e. reduced size and early maturity of the fish) is due to food limitation, size-selective mortality, or physical parameters of the environment (Marshall, 1993; Paulsen, 1993; Mandima, 2017).

One of the most striking phenomena of the introduction of *kapenta* to Lake Kariba and Cahora-Bassa is the reduction of the maximum individual fish size to about half that of the native population and conspecifics in Lake Kivu and Itezhi-tezhi reservoir (Figure 12).

FIGURE 12

Growth curves of *kapenta* (*Limnothrissa miodon*) from Lake Tanganyika and the four lakes (Kivu, Kariba, Cahora Bassa and Itezhi-tezhi) where it has been introduced

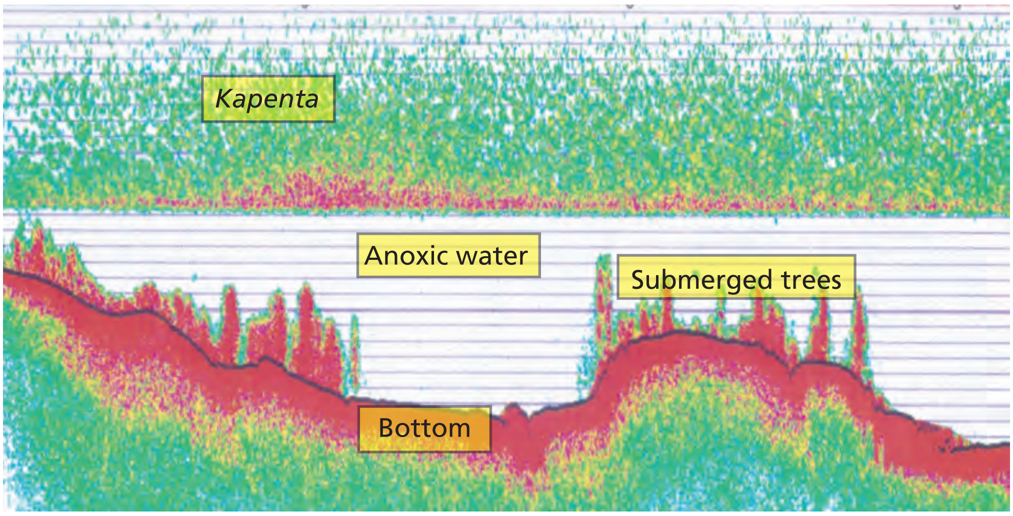


Source: modified from Mbewe (2000).

Such change may reflect either large phenotypic flexibility that allows fast and in principle reversible adaptation to new environments, or directional genetic changes because of selective forces. However, Hauser, Carvalho and Pitcher (1995) and Hauser (1997) compared samples of *Limnothrissa miodon* from Lake Tanganyika, Kariba and Kivu using allozyme and mitochondrial DNA analysis. They found no significant genetic differentiation and therefore the changes in growth and life history of *kapenta* in Lake Kariba were regarded as mainly phenotypical. The reason for this phenomenon is still disputed and food limitation has been suggested (Paulsen, 1993). However, a more likely explanation is the seasonal hypoxic conditions that the stocks of the two lakes are subject to, where thermal stratification renders the bottom layers hypoxic with the result that the population concentrates on the oxycline during the diurnal vertical migrations (Begg; 1976; Figure 13). The same phenomenon has been observed for *dagaa* in Lake Victoria (Wanink *et al*., 2001). Dwelling at the oxycline entails recurrent suboptimal oxygen conditions for extended periods of the year and controlled laboratory experiments on Nile tilapia and guppies have shown strong similar phenotypic effects on growth and maturation from hypoxia (Kolding, Haug and Stefansson, 2008; Diaz-Pauli *et al*., 2017). It is reasonable to infer that periodic hypoxia has the same effect on *kapenta* in Kariba and Cahora Bassa, and that this explains the observed dwarfing.

FIGURE 13

Acoustic echogram of *kapenta* in Lake Kariba during the day, and thermal stratification (11 January 1994, austral summer)



The fish are observed concentrated in a dense layer on the oxycline, unable to penetrate deeper. This seasonal exposure to suboptimal oxygen conditions is a possible reason for the observed stunting or dwarfing of the *kapenta* stock in the lake compared to elsewhere (see Plate 4)

Source: Ngalande (1996).

3.2.2 *Stolothrissa tanganicae*

The Lake Tanganyika sprat, *Stolothrissa tanganicae* (Plate 5), is the dominant clupeid species in Lake Tanganyika where it is endemic (Gourène and Teugels, 1994) appearing up to Kisimba-Kilia Falls in the Lukuga River in the Democratic Republic of the Congo that connects the lake with the Lualaba River (Kullander and Roberts, 2012). It is a lacustrine species that forms very large schools. Few studies have been conducted on basic population parameters such as growth, recruitment, natural mortality and the impact of fishing. The intrinsic population growth rate is estimated at r=11.5 yr^{-1} (Table 3), which is very high, indicating a high population turnover rate (P/B ratio) and a large fishery potential. Nevertheless, there are still significant uncertainties about the biological potential and limits for production.

Stolothrissa tanganicae is mainly a zooplankton feeder (Coulter, *et al*., 1991); with a trophic level of 2.7 it feeds relatively low down in the food chain. Larval and juvenile clupeids in Lake Tanganyika feed essentially on copepod zooplankton with marked preference for larger organisms when available (Mannini *et al*., 1999; Sarvala *et al*., 2002; Isumbisho *et al*., 2004; 2006). A major prey of clupeids is the calanoid copepod *Tropodiaptomus simplex*. Local and lake-wide average phytoplankton and zooplankton abundances have been shown to be well correlated at Lake Tanganyika (cf. Coulter *et al*., 1991), and increases in *Stolothrissa tanganicae* abundance is related to local increases in zooplankton abundance. Nevertheless, strong cohorts sometimes appear to occur in the absence of high zooplankton abundance (Mulimbwa, Raeymaekers and Sarvala, 2014), indicating that there may be other pathways of production.

PLATE 5
The Tanganyika sprat, Stolothrissa tanganicae

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The species is an important component of the pelagic food web of Lake Tanganyika where it is thought to be a major prey item for the pelagic predator *Lates stappersi* (Coulter *et al*., 1991; O'Reilly *et al*., 2002). Earlier literature attributed a negative correlation between local abundance of *Stolothrissa tanganicae* and *Lates stappersii* to predator–prey dynamics, particularly due to predator avoidance behaviour of the prey. However, *Lates stappersii* is dominant in the south of the lake where it predates mainly on pelagic shrimp, while *Stolothrissa tanganicae* dominates the pelagic zone in the north. The inverse correlation probably mainly reflects the underlying fluctuating limnological environment and patchiness in fish distribution, which result from patchiness in the lake environment. The abundance of *Stolothrissa tanganicae* is positively correlated to plankton biomass, while water transparency, depth of the mixed layer and oxygenated water appear to be important drivers for the abundance of *Lates stappersii*. Alternating "mixing" and "stable" states of the epilimnion[9] related to seasonal and internal waves variability probably determine the short-term variability in abundance of *Stolothrissa tanganicae* and *Lates stappersii* (Plisnier *et al*., 2009; Kimirei and Mgaya, 2002). *Stolothrissa tanganicae* movements of 20 km per day have been reported (Coulter *et al*., 1991) and the species can be expected to appear quickly in a favourable feeding area with local phytoplankton blooms and associated zooplankton abundances. These occur regularly around April to May each year, connected to changes in trade winds. During these months, the main wind direction changes from northeast to southeast, resulting in thermocline tilting and release when wind-stress decreases, generating strong internal waves called "*Yala*" by fishers in the south. This, in turn, causes upwelling of deepwater nutrients to the surface (Mulimbwa, Sarvala and Raeymaekers, 2014).

Small juveniles of *Stolothrissa tanganicae* (less than 50 mm standard length) tend to stay closer to shore. The species shows a diel migration, appearing to stay below about 60 m depth by day, rising up to 8 to 15 m depth at night, particularly on dark, moonless nights. Adults move inshore to breed from about 60 mm standard length upwards, with ripe individuals present almost throughout the year, indicating that reproduction continues throughout the year. However, major spawning activities are during the rainy seasons in May and June and again in December and January, causing large seasonal fluctuations in stocks and fishery production.

3.2.3 *Microthrissa moeruensis*

Microthrissa moeruensis is endemic to Lake Mweru, a relatively shallow lake that is mostly between 3 and 10 m depth but has a maximum depth of 27 m in the part of the lake located near the border between Zambia and the Democratic Republic of the Congo (Gourène and Teugels, 1989; Bos, 1995; Bos *et al*., 2006). It is a lacustrine species

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[9] Top-most layer in a thermally stratified lake.

but it also appears close to shore near sandy beaches and in floodplain areas, as well as in small streams and rivers feeding onto Lake Mweru. The species has a maximum length of 50 mm (standard length). Few studies have been conducted on basic population parameters such as growth, recruitment, natural mortality or on the impact of fishing (van Zwieten *et al.*, 1996; Kapasa and van Zwieten, 1993; Mölsä, 2010). The turnover rate Z=P/B, estimated at 10.5 yr^1 is high, indicating a ten-fold renewal of the biomass per year and a large fishery potential. The species appears to have two morphotypes: type I is opaque white in colour, with a clear silvery line slightly dorsal over the length of the body, with a deeper body depth and blunt snout compared to type II, that is more slender, clear in colour, with a less distinct silvery line and a pointed, yellow-tipped snout. While these visual distinctions have been confirmed, the morphometric distinction between the two types is not strong enough to justify a separation of species (Guy Teugels, pers. comm.). An analysis based on allozymes indicated that the two types had a separate gene pool, but mixed geographical occurrence and a rather weak indication of any population structure within the morphological types. This presents no definite proof of separate species, although it is still a possibility (Strømme, 1999).

Microthrissa moeruensis breed throughout the year but with a distinct drop in breeding activity between May and August and the lowest activity observed in June to July during the cold, dry season. A distinct breeding peak appears from January to March after the rainy season, compared to overall constant breeding activity between August and December. These seasonal patterns are broadly shared by all species from Lake Mweru for which breeding activities are known.

Small *Microthrissa moeruensis* (<30 mm standard length) feed predominantly on copepods, diatoms/algae. Specimens of >30 mm standard length feed less on diatoms and algae and shift towards diptera larvae, predominantly chaoborids and some chrironomids, and terrestrial insects, while copepods are still the main food item. The two morphotypes differ in feeding: type I specimens were predominantly zooplanktivorous while type II specimens were mixed zooplanktivorous and insectivorous.

The species shows diurnal movements over the water column: during the day it stays near the bottom and during the night it moves to the lake surface. A single acoustic survey was carried out in October 1995, following which a standing biomass of 6 300 tonnes was calculated. With the various estimates of P/B ratio available, a total production of 67 000 tonnes/year to 95 000 tonnes/year (equivalent to 130 kg/ha/year and 175 kg/ha/year) was deemed possible (van Zwieten *et al.*, 1996).

3.2.4 *Pellonula leonensis*

Pellonula leonensis is found chiefly in rivers and streams, but also in lakes, reservoirs and lagoons of West African rivers (Whitehead, 1985; Gourène and Teugels, 1990; Ikusemiju, Oki and Graham-Douglas, 1983) from the Senegal River to Sanaga River (Gourène and Teugels, 1991) and in coastal rivers and lagoons from Cameroon to Democratic Republic of the Congo (Gourène and Teugels, 1991; Teugels, 2007). It is apparently able to enter brackish water and bodies of seawater.

The size of *Pellonula leonensis* in Lake Kainji is smaller than that recorded from other West African freshwater locations. In the Volta Lake, Reynolds (1970) described a maximum length of 99 mm and weight of 13.5 g. The largest *Pellonula leonensis* captured in Kainji Lake was 75 mm, with a weight of 6.5 g. This difference in size is thought to be due to the comparatively more oligotrophic conditions in Kainji Lake (Otobo, 1976). In Kainji Lake, the smallest mature individuals were 27 to 28 mm standard length for both males and females (Otobo, 1978).

The adults form schools and are nocturnal feeders, feeding on terrestrial and aquatic insects but also on ostracods (“seed shrimp”), entomostracans and fish larvae, leading to an adult trophic level of 3.3. In Lake Volta their main breeding period is from September to July (Ikusemiju, Oki and Graham-Douglas, 1983). In Lake Kainji mature individuals were found year-round but with a prolonged peak of activity from December to May.

Limited data are available on basic population dynamic parameters. The population of the Anambra River, a tributary of the Niger river in Nigeria, had an average maximum length of 9.8 cm with Brody's growth parameter K=1.3 year^{-1}, an estimated total annual mortality rate (Z or P/B) of 4.0 year^{-1} (Uneke *et al.*, 2010). This is considerably lower than the estimate presented in Fishbase (Froese and Pauly, 2017) where the intrinsic rate of increase is estimated as r=12.9 (=Z=P/B). Based on its maximum size of 93 mm standard length, Fishbase records an estimated lifespan of 1.8 years and a size at maturity of 65 mm or 0.5 years of age.

3.2.5 *Sierrathrissa leonensis*

Sierrathrissa leonensis, also known as the pygmy herring, is the smallest of African clupeid species for which a commercial fishery exists: it reaches a maximum size of 30 mm and the common name in Ghana is "one-man-thousand" illustrating its very small size (Plate 6). It is distributed in the rivers of West Africa from Senegal to Cameroon, including the Senegal, Gambia and Bia rivers, the Niger River basin and the Wouri and Sanag rivers. It also appears in Lake Kainji, where it is found at shallower depths than the larger species *Pellonula leonensis*, and in Lake Volta together with *Pellonula leonensis* and *Odaxothrissa mento* (Whitehead, 1985; Gourène and Teugels, 2003; Teugels, 2007; Vivien, 1991).

In Lake Kainji and Lake Volta, *Sierrathrissa leonensis* forms schools in open waters at about 2 m to 8 m depth; rising to about 30 cm from the surface at night. In Lake Kainji, mature individuals were found year-round but with a prolonged spawning peak from December to May. Based on its maximum size of 30 mm standard length, Fishbase records an estimated lifespan of 0.7 years and a size at maturity of 24 mm or 0.3 years, but the smallest mature male and female individuals observed were between 18 mm to 19 mm standard length (Otobo, 1978). *Sierrathrissa leonensis* mainly feeds on zooplankton, especially cladocerans, and insects (van Zwieten *et al.*, 2011) and has a trophic level of 3.1.

The species dominates the clupeid biomass in Lake Kainji: during a trawl survey in May 1997 it formed 97 percent of the clupeid biomass. At that time, fishing was mainly with beach seines, but these were later banned (Omorinkoba *et al.*, 1997). Presently an open water paddle-driven seine/trawl fishery has developed (Plate 9).

3.2.6 *Odaxothrissa mento*

This is a third important clupeid species found in rivers and streams of the lower parts of the Volta River and Niger River basins, including Benue River; it is also known from the Cross River to Wouri River in Cameroon, but apparently not in the Congo river system (Whitehead, 1985; Gourène and Teugels, 2003; Teugels, 2007; Vivien, 1991). It is also found in the reservoir Lake Volta. Based on its maximum size of 13 cm standard length, Fishbase (Froese and Pauly, 2017) records an estimated lifespan of just short of three years and a size at maturity of 88 mm or 0.9 years. It feeds on small fishes, including its own juveniles, and on aquatic insects and has a trophic level of 4.3.

PLATE 6
Ghanaian food hawker carrying pygmy herring, locally called "one-man-thousand", for sale

© HTTPS://COMMONS.WIKIMEDIA.ORG/WIKI/FILE:ONE_MOUTH_THOUSAND.JPG

3.3 ALESTIDAE

The family Alestidae (Characiformes) contain more than 100 species known as the "African characins" or "African tetras" because they are found exclusively on the African continent. However, the fishes are widely distributed in nearly every country and freshwater habitat across Africa. They are typically small (Figure 4), often shoaling species that occur inshore. Some are pelagic or open water semi-pelagic. They are easily distinguished from the similar shaped cyprinids by sharp teeth on the jaws and a small adipose fin. Few are of commercial interest, but many are important components of subsistence fisheries all over Africa. Large tigerfish (*Hydrocynus vittatus* and *Hydrocynus forskahlli*) are also valued as an angling species by recreational fishers.

The most important genera are the two closely related silversides or robbers (*Alestes* and *Brycinus*), consisting of small- to medium-sized omnivorous species, and the larger piscivorous tigerfish (*Hydrocynus*). Many Alestidae, for example the tiger fish *Hydrocynus vittatus* or silversides/robbers (*Alestes* spp.), form pelagic populations, but small African characins are predominantly found in rivers and riparian habitats of lakes. Only a few of these small fish are truly pelagic, such as, for example, the *Brycinus* species found in Lake Itezhi-thezi and in Lake Turkana (Table 3). However, juveniles of the larger pelagic species are often exploited. An example is the torpedo robber, *Alestes macrophthlamus*, a piscivorous species that reaches a maximum size of up to 60 cm. In Lake Mweru, it forms the dominant species in the catch of a gill net fishery that utilizes mesh sizes of 6.35 cm, when it has a size of around 15 to 20 cm standard length. Juveniles of *A. macrophthalmus* of less than 15 cm standard length, together with small mormyrids, cyprinids, clupeids and other small species, are also caught in a specialized fishery that utilizes small floating reeds anchored to the bottom as attracting devices (FADs) to which a net with a mesh size of 2.5 cm to 6.5 cm is attached (van Zwieten *et al*., 1996; Kapasa, 1998).

Due to the generally small size of most species and because they are mainly consumed locally, they are largely unrecorded in catch statistics. Important species are *Alestes dentex* and *Alestes baremoze* (Chad, Niger, Volta, Nile and Turkana basins); *Alestes macrophthalmus* (Congo basin, Tanganyika and upper Luapula); *Brycinus lateralis* and

Brycinus imberi (Congo, Zambezi and Okavango basins); *Brycinus nurse* (West Africa, Chad and Nile basins); and *B. macrolepidotus* (Senegal, Niger, Chad and Volta basins).

In Lake Turkana two small endemic species *Brycinus ferox* (6 cm fork length) and *Brycinus minutus* (3.7 cm fork length) are truly pelagic, together with *Alestes baremoze* (Hopson and Hopson, 1982). The *Brycinus* species of Lake Turkana form a dense midwater scattering layer of several meters in vertical extent and comprise the main biomass of fish in the lake, with densities up to 300 kg/ha, although the standing biomass fluctuates in synchrony with water flowing into the lake (Kolding, 1989, 1993b; Muška *et al.*, 2012, Gownaris *et al.*, 2017). These stocks, with a potential yield of up to 300 000 tonnes per year (Table 1) are still not exploited, mainly due to the inaccessibility of the lake, lack of infrastructure and the technological level of the fishery.

3.3.1 *Brycinus nurse*

Brycinus nurse, known as *ragoogi* around Lake Albert where an important fishery exists, is considered a delicacy in much of West Africa where it has a wide distributution (Paugy, 1990). In the Lower Guinea it is present in the Cross and Mémé rivers (Paugy and Schaefer, 2007); and it appears in the Chad basin and the Nile River up to Lake Albert (Greenwood, 1996; Paugy, 1986). It has a maximum size of 25 cm standard length and a life span of seven years and matures after 1.8 years at a size of 15.7 cm. The species has an intrinsic growth rate of $r = 6.9$ year^{-1}. *Brycinus nurse* is found in rivers, lakes, irrigation canals and fringing vegetation. Dwarf populations are described in the lake basins of Lake Turkana: *Brycinus nurse nana* (Pellegrin, 1935) and Lake Chad: *Brycinus nurse dageti* (Blache and Miton, 1960) (Paugy, 1990; Paugy, 1986). It feeds on zooplankton, *Caridina* spp., insects, snails and vegetation leading to an adult trophic level of 2.5. The small pelagic light fishery on Lake Albert – targeted at *Brycinus nurse* as well as the cyprinid *Neobola bredoi* (*muzizi*) in approximately the same proportion – contributes over 80 percent to the total catch of around 160 000 tonnes (Mbabazi *et al.*, 2012; Taabu-Munyaho *et al.*, 2012) which is around 30 percent of the total recorded fish production of Uganda (Wandera and Balirwa, 2010). *B. nurse* is caught at night and during the day. Night fishing uses seines with 5 mm mesh sizes operated from canoes and with light attraction. During the day, *ragoogi* is harvested with the same seines and a bait consisting of cassava "*Ugali*" mixed with fish offal and sometimes cow dung and humus soil. Other fishers, mostly women, use perforated basins to harvest the species.

3.4 CICHLIDAE

The cichlids are widespread and very successful in African freshwater lakes and reservoirs and many of the medium-sized tilapia species form the mainstay of several fisheries. A distinctive feature of the African Great Lakes is the copious adaptive radiation of the mouthbrooding genera *Haplochromis* into a multitude of endemic species. They have been able to exploit almost every available food source, including zooplankton (Fryer and Iles, 1972; Marshall, 1984).

Pelagic forms (consisting of many similar but different species) occur in several lakes and the best known are the assemblages called "*utaka*" of lakes Malawi and Malombe, and the group of haplochromines called "*fulu*" (Kenya), "*furu*" (Tanzania) or "*nkeje*" (Uganda) of Lake Victoria. Utaka are abundant in inshore areas but decline rapidly with distance from shore and these fish do not fully occupy pelagic waters (Marshall, 1984).

The pelagic zone of Lake Malawi furthermore contains numerous species of the larger deepwater zooplanktivorous cichlids of the genus *Diplotaxon* ("*ndudum*a") that are hardly exploited and the larger piscivores *Rhamphochromis* ("*mcheni*") (van Zwieten *et al.*, 2011; Konings, 1990). Lake Malawi's offshore stock was estimated at 170 000 tonnes, of which around 88 percent is cichlids (Menz, 1995).

Many of the endemic Lake Victoria haplochromines are truly pelagic and after a collapse in the 1980s (van Zwieten *et al.*, 2016), they now constitute the third largest stock in the lake with a production rate of 320 kg/ha/year (Natugonza *et al.*, 2016).

4. Fishing methods for small pelagic fish in the African lakes: small-scale to large-scale

4.1 INTRODUCTION

A wide range of fishing methods have developed to catch small pelagic fish. It is only relatively recently, since the 1960s and 1970s, that small pelagic fisheries were transformed into commercial, market-oriented operations. Many commercial fishing methods are modifications of traditional methods – such as beach seines and dip nets – although some specialized methods such as mechanized lift nets have developed as well. Many small-scale pelagic fisheries started as nearshore fishing activities, predominantly by women using baskets or traps and gleaning activities. Early light attraction methods included the use of torches to attract fish along the shores of Lake Victoria (Witte and van Densen, 1995). Currently, the kerosene pressure lamp (Tilley lamp) mounted on floaters (Plate 7) or on specialized light boats as an attraction device is almost universally used in shore-based or offshore freshwater fisheries for small pelagics in Africa, although in some places the Tilley lamp is now being rapidly replaced with battery operated light and light emitting diode (LED) lamps (Mills *et al*., 2014). Because of their reliance on light attraction, virtually all the small pelagic fisheries are dependent on the moon cycle and generally no fishing and preservation activities take place around full moon. Many fisheries therefore only operate for a maximum of approximately 20 nights per month. All fisheries also make short (less than 24-hour) trips where the catch is brought ashore for drying immediately after a night or day of fishing.

PLATE 7

Kerosene pressure lamps (Tilley lamps) mounted on reed rafts and ready to be deployed for the coming nights catching Mukene (Rastrineobola argentea) in Lake Victoria, Uganda

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Despite their commercial and nutritional importance, most fisheries remain small-scale, low investment operations. Even the largest freshwater fisheries, both in terms of tonnage and numbers of fishers employed – the *dagaa/mukene/omena* fishery on Lake Victoria – uses relatively simple, manually operated, labour-intensive purse-seine methods, often from non-motorized, paddle-driven, vessels deployed a few kilometres from the shore (Nabbanja, 2016). Very few larger-scale methods involving hydraulic winches, power blocks, power lamps, generators and inboard engines have developed such as, for example, the Lake Kariba and Cahora-Bassa lift net fisheries (Plate 14). The pelagic industrial purse seine fisheries in Lake Tanganyika which target *Lates stappersii*, *Stolothrissa tanganicae* and *Limnothrissa miodon* collapsed economically by the end of the previous century and the fishery was taken over by an expansive small-scale fishery that employs a range of methods. All are commercial fisheries – including the smallest, the Lake Bangweulu *Mesobola moeruensis* fishery – in the sense that the bulk of the catch is sun-dried, sold and traded to more distant markets. In the following sections we will describe fishing methods used in African lakes and rivers, ranging from small-scale, low investment fisheries as employed in Lake Bangweulu, Zambia, to the relatively larger scale, high investment fisheries of Lake Kariba.

4.2 LAKE BANGWEULU

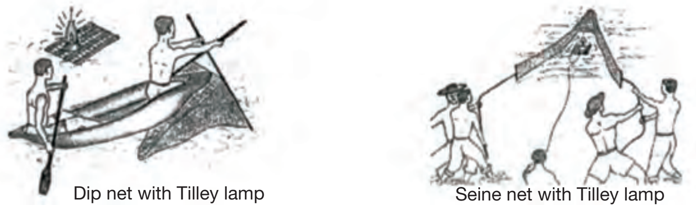
In the shallow Zambian Lake Bangweulu, with an average depth of <4 m and a maximum depth of 10 m, the fishery began to develop in areas where women who had used baskets for fishing discovered that they could be more efficient using “Chitenge” cloth[10] and mosquito nets to catch these fish. The first record of a directed fishery for *chisense*, the cyprinid *Mesobola moerensis*, using a dip net employed from a canoe, was in Lake Kompolombo, a small lake in the south of the Bangweulu complex, in the late 1960s. The methods that are still in use today are simple and do not require much investment, while fish catches are dried, sold and traded to markets in the Copperbelt and Lusaka.

FIGURE 14
***Chisense (Mesobola moeruensis)* fishing methods employed in the Lake Bangweulu complex. Tilley lamps are kerosene pressure lamps**

Dip net, walking

Dip net, canoe

Beach seine



Dip net with Tilley lamp

Seine net with Tilley lamp

Source: Drawings by Mabo Sammuel Kapai (from Benneker, 1996).

By 1995, walking through the water with a dip net was the most common method used (Figure 14). Two fishers walk in the water close to the shore to breast height and draw the net some 20 m to 50 m through the water before the fish are removed. Fishing operations last 3 to 4 hours. Most dip nets are made from mosquito-nets (Figure 14) but

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[10] A Chitenge is a piece of cloth, two or more meters in length, that women wrap around their bodies.

are repaired with all kinds of materials, including curtains, t-shirts, potato bags, maize-meal bags, etc. Most fishers using this method are women. The dip net deployed from a canoe developed in Lake Kampolombo (Figure 14) requires four people using two canoes to operate the net and boat: two persons hold the net between the canoes while two others paddle as fast as they can against the current (see also Plate 9). The nets are the same mesh size and made from the same materials as the dip nets.

PLATE 8

A dip or scoop net made of mosquito net used to catch small fish in the Kilombero River, Tanzania. Source: from Kolding et al., 2017

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PLATE 9

"Pair trawling" for small pelagic clupeids on Lake Kainji, Nigeria. Two fishers paddle as hard as they can while dragging the dip net between the two canoes

© DAVID MILLS

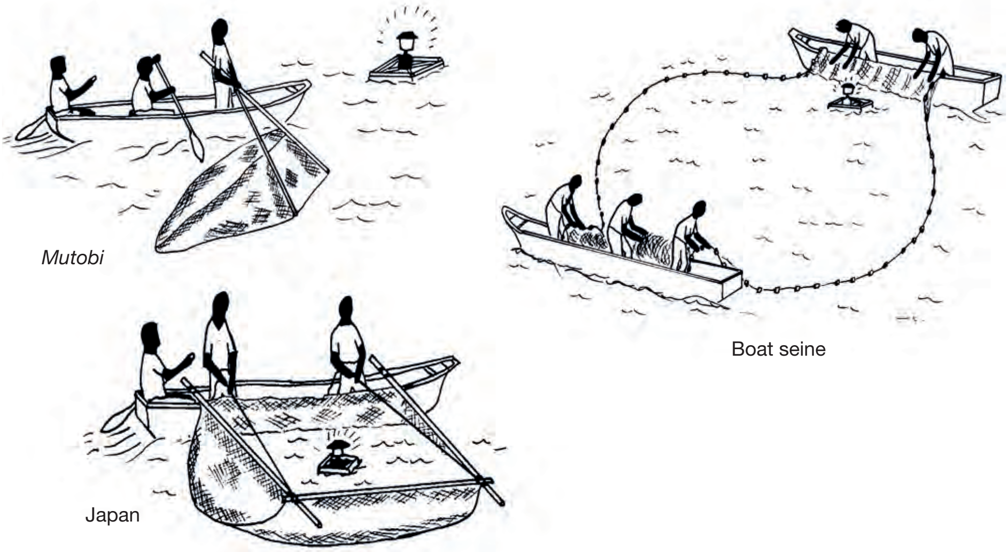
Beach seining is a method commonly practiced all over Africa. In Bangweulu, most gillnets have mesh sizes between 3.8 cm and 5.0 cm from which *chisense* escapes. *Chisense* fishers employ "meshless" seines, often made of mosquito nets. Beach seining for *chisense* is mainly, but not only, carried out at night, when light attraction with the aid of kerosene pressure lamps is used. Two to three lamps mounted on bamboo floaters are anchored between 15 m to 200 m from the shore. Fishers wait for two hours to allow for the attraction of schools of *chisense*. Sometimes the light is pulled slowly to the shore until the net can be set around it. Two to four people operate the net by setting it with the aid of a canoe approximately 25 m to 50 m from the shore. The net is then hauled to shore in five to ten minutes. Operations often last up to six to seven hours a day or during the night. No night fishing takes place during the period of the full moon. These methods are used by both men and women.

All methods described so far are used close to the shore, but a more recent development is the use of dip nets in combination with kerosene pressure lamps employed further offshore in the open waters of the lake (Figure 14). An average of four lamps on floaters are anchored. After 30 minutes to two hours fishers first observe the swimming direction of the school of *chisense* before they scoop it out around the lamp in the opposite direction. An operation lasts close to two hours, and fishers spend between ten hours fishing per night. Vessels are rarely motorized and are propelled by muscle power and paddles (all descriptions taken from Benneker, 1996).

4.3 LAKE MWERU

The *chisense* (*Microthrissa moeruensis*) fisheries on Lake Mweru require more capital investment than those of the Bangweulu fishery, but are still simple (Figure 15). The fishery started developing during the late 1960s and early 1970s in deeper water along the northeastern shore of the lake and was fully developed around 1985, with operations all along the Zambian shores of the lake and the Luapula River, wherever there are beaches or flat areas to allow for the drying of fish.

FIGURE 15
Chisense (Microthrissa moeruensis) **fishing methods used in Lake Mweru**



Source: Based on Scullion, 1985; van Zwieten, Aarnink and Kapasa, 1995.

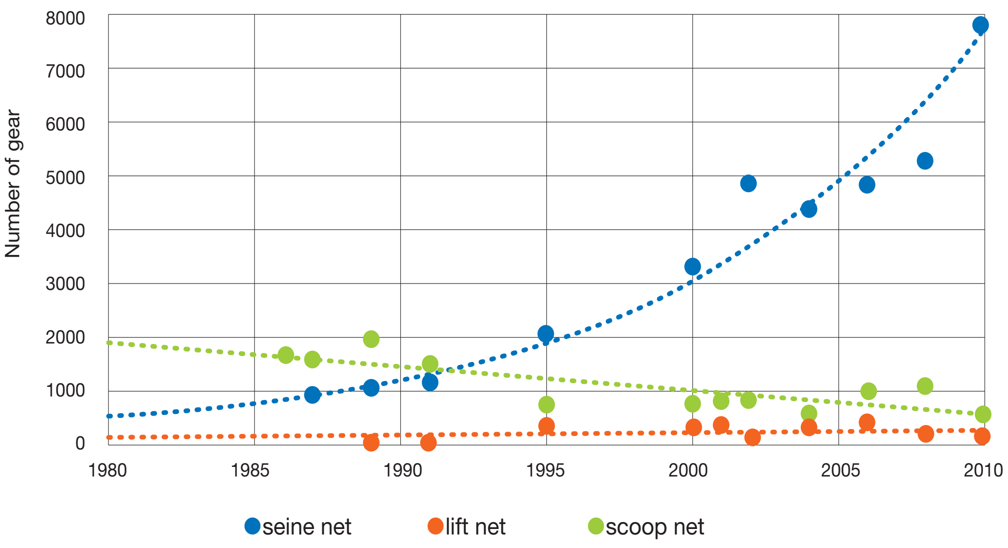
All methods rely on light attraction and small meshed nets constructed from mosquito nets, any suitable clothing material or 6 mm knotless mesh. Often a small patch of 6 mm or 10 mm stretched mesh netting material is sown into the middle of nets made from mosquito nets or clothing material to ease hauling. Each fisher uses four to seven kerosene lamps mounted on small floaters that are anchored at some distance from each other to attract fish. The net is cast and hauled at each lamp separately. Fishers make “rounds” and count the number of times all lamps have been fished successively during a night to assess their catch.

Beach seines are also deployed in the river: lights are set along the banks of the Luapula River and surrounded one by one by a seine operated from the land. On the lake, the most common method employed is an outrigger lift net, called “Japan”. The net is mounted on a moveable outrigger consisting of three bamboo sticks connected to form a square with the boat. The net is set upwind from a light, and the boat drifts toward the light until it is above the net. The light is taken on board and the net is hauled. Fishing is done with a crew of three persons. Boat seines, or surround nets comparable to a purse seine, are utilized mostly in the shallower southern parts of the lake. The operation consists of two boats each with a crew of three to four persons who surround a kerosene pressure lamp with the net as in purse seine fishing. The net is hauled onto both vessels, one of them taking the catch. Less common methods are "Mutobi", a scoop net or dip net used with light, and a lift net set between the two vessels of a catamaran. The latter method was introduced by a British development aid program during the 1980s, which also introduced the 6 mm to 10 mm knotless mesh nets (Scullion, 1985). Most vessels are non-motorized and use paddles for propulsion. Sometimes groups of five to ten boats are towed by one vessel with an outboard engine to the fishing grounds. All fisheries have a bycatch of the main predators of *chisense*, *Serranochromis macrocephalus* and *Schilbe mystus* (all descriptions taken from van van Zwieten, Aarnink and Kapasa, 1995).

4.4 LAKE VICTORIA

FIGURE 16

Development in the number of *dagaa* fishing gear types in Tanzania between 1986 and 2010



Source: Data from Medard (2015).

The Lake Victoria *dagaa* fishery (*Rastrinobola argentea*), one of the largest single species small-scale fisheries in the world, uses simple, low investment light fisheries. Historically, *dagaa* was fished for subsistence by Luo women, using plunge baskets (Graham, 1929). A group of women would wade into the water carrying large, open conical baskets and form a circle. They would then proceed towards the center of the circle, splashing the water and scooping out fish using the conical baskets, transferring the fish to baskets carried on their heads. Reports from the 1960s describe manually operated nearshore dip net and scooping methods like those used in Lake Bangweulu. *Dagaa* was used mainly to feed chickens and ducks and was at that time not for human consumption. In the 1960s, a fishery using pressure lamps and employing seine nets known as *mkokoteni* ("hurry up") in shallow waters started developing. During the dry season *dagaa* started to be prepared in dried form for human consumption as well as being used as animal fodder. The fishery began to gain commercial significance towards the end of the 1960s and in the early 1970s, first in Kenya by Luo fishers, later copied by Kerewe fishers in Tanzania, when new technologies developed involving dugout canoes, pressure lamps and purse seine, encircling types of nets. The method was derived from the "hurry up" fishery and is known as "*kokolo la dagaa*" and employed in nearshore waters up to 500 m from the shore. In the 1980s the fishery moved further offshore using a scoop net – *mgono/kijiko* – that involved three pressure lamps, an 8 m long canoe and two fishers. After 1974, coinciding with a decade of shocks and crises that plagued the Tanzanian economy as well as the collapse of the haplochromine and other fisheries during the Nile perch boom, the *dagaa* fishery started to become popular as a coping strategy.

Between 1980 and 1990 the fishery rapidly developed with the *dagaa* seine nets (*kokolo la dagaa*) as the main fishing method, while the scoop net fishery started to decline (Plate 8). Today, *dagaa* seine nets are made of 2.5 mm to 10 mm netting material and are operated 3 km to 4 km from the coast from a canoe with three to four crewmembers utilizing three to four kerosene pressure lamps (Plate 10) or more recently, battery-driven LED lights (Mills, Gengnagel and Wollburg, 2014).

PLATE 10
Dagaa purse seining method of Lake Victoria

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A third method, based on the catamaran ("*kipe*") fishery of Lake Tanganyika was introduced in Lake Victoria in the 1980s. A catamaran consists of two vessels placed 3 m to 4 m apart, held together with poles. The method called "*kokolo la kipe*" involves a lift net with 8 mm to 10 mm mesh size with an average circumference of 40 m to 50 m and operated by four to six fishers who utilize three to six kerosene pressure lamps. Haplochromines, tilapia and Nile perch are bycatch species associated with *dagaa* fishing (Taabu-Munyaho, 2004). The haplochromine bycatch can be substantial; on landing the catch is dried and *dagaa* and haplochromines are manually separated and traded separately (descriptions based on Medard, 2015).

Medard (2015) calls the period from 1991 to 2011 the *dagaa* commercialization era. During these years the fishery transformed because of significant changes in investment and organization. Specialized *dagaa* fishing camps now operate on many islands around the lake. Camps are usually formed around an owner who has invested in between five and 25 vessels, with associated outboard engines, nets, pressure lamps and utensils such as life jackets, and who employs 60 to 180 labourers – *dagaa* crew (*Wajeshi*), processors, cooks, net repairers and one or two supervisors (*Matajiri*) – who form the camp. Security guards armed with guns are employed to protect the fishing fleets and camp equipment. Investment in a commercial *dagaa* fishing unit, using six pressure lamps, an outboard engine, a net (9 to 11 panel small meshed net) and a hardwood fishing vessel amounts to USD 5 500. Boats are 8.5 m to 11 m long, 1.5 m to 1.8 m wide and can carry up to 0.5 tonnes to 0.8 tonnes of fresh *dagaa*. A fishing operation uses up to 40 liters of fuel per day. A single vessel has four crew and one or two associated female processors. Competition between camps for skilled personnel is intense and incentives from USD 32 up to USD 190, as well as goods such as bicycles, mobile phones, watches, mattresses or crates of beer, etc., are offered to highly skilled fishers at the beginning or end of each dark phase of the moon (Medard, 2015).

4.5 LAKE MALAWI

In Lake Malawi, the *chilimira* net is the dominant gear used for pelagic fisheries (Plate 11). It is the only lake where this specific fishing method is employed, although it resembles purse seining. The gear, used at night in a light fishery to catch the cyprinid *Engraulicypris sardella* or *usipa*, is an open water seine net with a conical appearance. The mesh size of the bunt ranges from mosquito netting to 25 mm. The net has a headline length from 20 m to 90 m, and a depth ranging from 5 m to 50 m. The headrope is almost always twice as long as the footrope. The net is operated from two dugout canoes and one planked boat with a total crew of nine persons. The planked boat and the larger dugout canoe are involved in the casting and hauling operations.

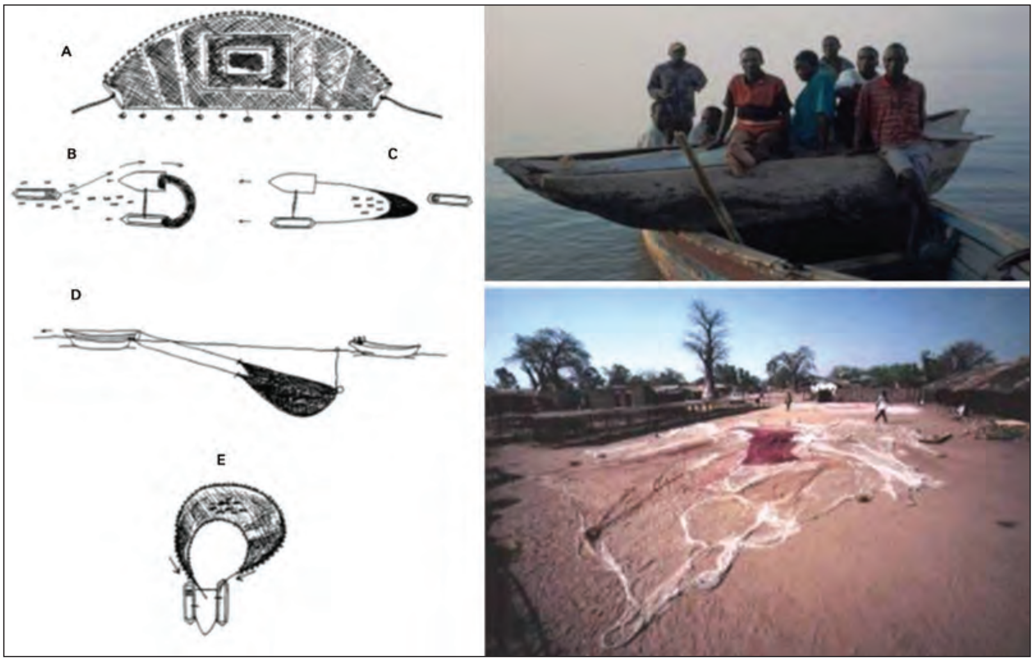
At night the headman, located in the smaller dugout canoe equipped with a lit kerosene pressure lamp, directs the actions of the crew in the other craft. When he locates a fish school, usually *usipa*, he tells the other fishers when to shoot the net. The net is towed in the opposite direction to the movement of the fish. When the fish are caught, the headman joins in hauling the net into the boat and the larger dugout.

During the day, the net is used for fishing pelagic haplochromines, "*utaka*", as it can quickly be prepared for this by removing the mosquito-net lining that is needed for catching *usipa* (FAO, 1993). The *utaka* fishery is mainly found in the shallower southeast and southwest arms of Lake Malawi. By by 2004, the annual catch of this fishery ranged between 19 tonnes and 24 tonnes per net, per year (Weyl *et al*., 2004) with a total of 62 species from 28 cichlid genera, and 13 species from nine non-cichlid genera landed.

Of the 37 genera identified, only five; *Copadichromis*, *Dimidiochromis*, *Oreochromis*, the pelagic predatory *Rhamphochromis* and *Engraulicypris sardella*, contributed more than 5 percent to the total annual catch in either area, while the combined contribution of these species to the annual catch was over 85 percent in both strata. Manase *et al*. (2002) estimated that the species composition of the *chilimira* fishery showed that *utaka* contributed 50 percent and *usipa* around 30 percent to the total catch. Other small haplochromine cichlids form the remainder of the catch.

PLATE 11

Chilimira seine operated on Lake Malawi to catch small pelagics. Left: net and operation of the net (adapted from FAO, 1993); top right: crew, light boat and secondary boat on the main vessel; bottom right: a chilimira net drying on a beach. Note the large size of the net!



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4.6 LAKE TANGANYIKA

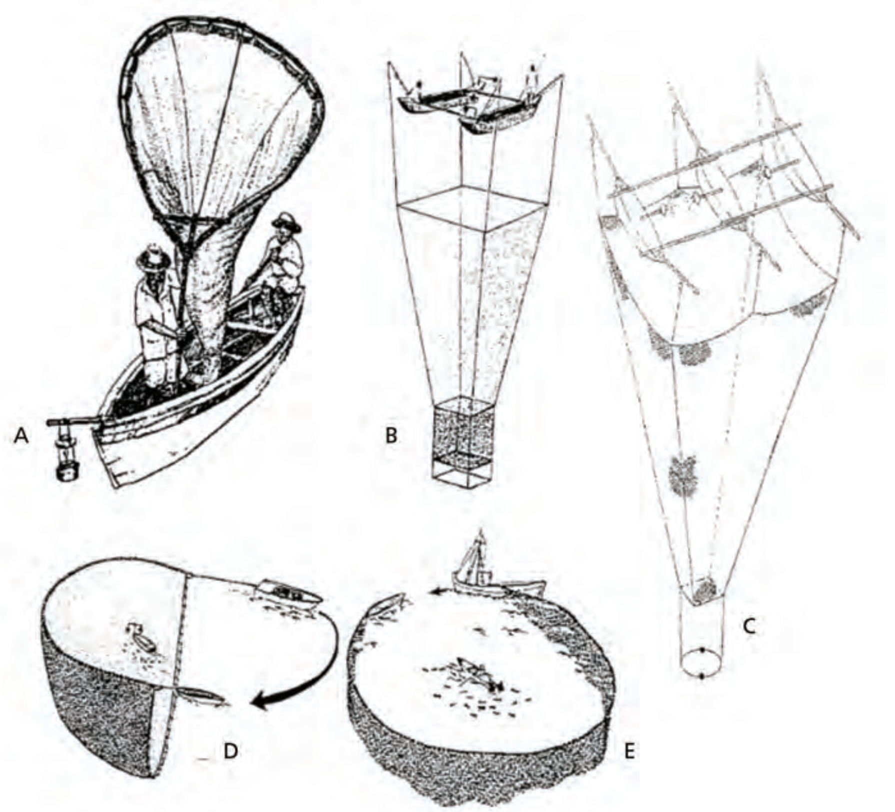
In Lake Tanganyika most fishing of pelagic species (the two clupeids and the larger *Lates stappersi*) is conducted at night. Most fishing methods – purse seines, lift nets, beach seines and scoop nets – rely on light attraction. As early as 1860, the explorer Richard Burton described the use of circular nets lowered from a canoe to catch fish attracted by the light of an "*mbaula*" (wood-fired brazier). As is common to all light fisheries, fishing activities practically cease every month in the period around full moon. There are three recognizable types of fisheries on Lake Tanganyika, each with a different specialized activity (Munyandorero, 2002). A semi-industrial fishery started in 1954, when Greek fishers introduced the purse seine. A typical industrial fishing unit consisted of a 16 m to 20 m long steel vessel, a purse seine and auxiliary steel boat, five lamp boats and a total crew of 30 to 40 (Plate 13). The fishery ceased to exist in Burundi during the 1990s. Some purse seiners fishing on *Lates stappersii* remained in the fishery in Zambia but have now also stopped. The artisanal fishery, now dominant in the northern part of the lake, mainly uses catamarans. A typical catamaran fishing unit consists of two 6 m to 7 m long mainly planked wooden hulls, a lift net of 55 m to 65 m circumference, six to seven kerosene pressure lamps and an average of four to five crew members. The "Apollo" unit (Figure 17) is a large catamaran with a 7 m to 9 m long canoe, a lift net with an opening circumference of up to 100 m, 14 to 19 pressure lamps and eight to 11 crew. Trimaran lift net fisheries were also used but have now disappeared from Burundi. They are still operational in Lake Kivu, however (Plate 12).

There are very few catamarans in the Zambian part of the lake. Most artisanal fishing nets in the south of the lake are beach seines that are operated at night, with lights, mainly to catch clupeids. A few ring nets or *chiromila* units are also active in these waters (Plate 13).

These consist of four lamp boats operated by one person, that are transported on a mother boat carrying a ringnet. At night, the lamp boats are deployed about 50 m from the mother boat, where they float kerosene pressure lights mounted on floaters on the lake's surface. The lights attract zooplankton that in turn attracts *buka buka* (*Lates stappersi*) or *kapenta* (*Limnothrissa miodon*) into the ring nets. The catch is hauled onto the mother boat.

FIGURE 17

Important fishing gears used in the clupeid and latidae fisheries of Lake Tanganyika: a – scoop net (*Lusenga*); b – traditional catamaran lift netting (“Apollo” net); c – trimaran lift net; d – ring net (*chiromila*); e – purse seining



Source: Coulter *et al*. (1991); Challe and Kihakwi (1994); Munyandorero, 2002.

PLATE 12

Liftnet fishery (catamaran) fishing for kapenta (Limnothrissa miodon) on Lake Kivu (FAO, 1979). Left: operation of the net; right: a trimaran lift net fishing unit on lake Kivu

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PLATE 13

A "chiromila" or ring net fishing group from Mpulungu, Zambia

PHOTO GUY OLIVER/IRIN, FROM HTTP://WWW.IRINNEWS.ORG/REPORT/92318/ZAMBIA-LAKE-TANGANYIKA-FISHING-INDUSTRY-ADRIFT

The smallest-scale fisheries in Lake Tanganyika employ scoop nets and beach seines. The scoop net fishery, or *Lusenga*, is operated from a dugout or planked canoe, usually with one or two crew members using a scoop net and a kerosene pressure lamp. Nets are made from mosquito nets or fine-meshed netting material. When the scoop netting method was described in the 1960s, light came from wood fires or was produced by burning bundles of cane. Later, in the northern part of the lake – in Burundi and Uvira (Democratic Republic of the Congo) by 1953, in Tanzania in 1952, and in Zambia in 1957 – kerosene pressure lamps were introduced. The *Lusenga* fishery has disappeared from the Zambian fleet but still predominates in the northern half of the Tanzanian and Burundian part of the lake.

4.7 LAKE KARIBA AND CAHORA BASSA

At present, the most capital-intensive pelagic fisheries in inland Africa are the catamaran-based mechanized lift net fisheries for *kapenta* (*Limnothrissa miodon*) in Lake Kariba and Lake Cahora Bassa reservoirs on the Zambezi River (Plate 14), and now also appearing on Lake Victoria. They consist of double-hulled steel pontoon rigs with a winched crossbeam for lowering and lifting a circular, fine-meshed dip net with a diameter of around 6 m to 8 m and 10 m deep. Electric lights, powered from an onboard generator, are mounted on the beam or are lowered into the water above the submerged net. After 1 to 2 hours of light attraction, the lights are turned off and the net is hoisted. Most of the rigs are non-motorized but are towed by a "mother rig" onto the fishing grounds every evening before sunset. This method was developed on the Zimbabwean side of Lake Kariba in 1976, after a short period of using purse seines, but soon proved to be economically more efficient. The technology has remained more or less constant ever since then and was introduced to Cahora Bassa in 1993 by immigrating *kapenta* fishers from Zimbabwe.

PLATE 14

Top: a couple of kapenta pontoon catamarans from Lake Kariba. Left: a kapenta pontoon rig with dip net in Cahora Bassa (from Pegado and Bettencourt, 2016). Right: light fishing for kapenta from a dip net rig in Lake Kariba

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5. Small pelagic fisheries of individual African lakes

5.1 LAKE VICTORIA

FIGURE 18

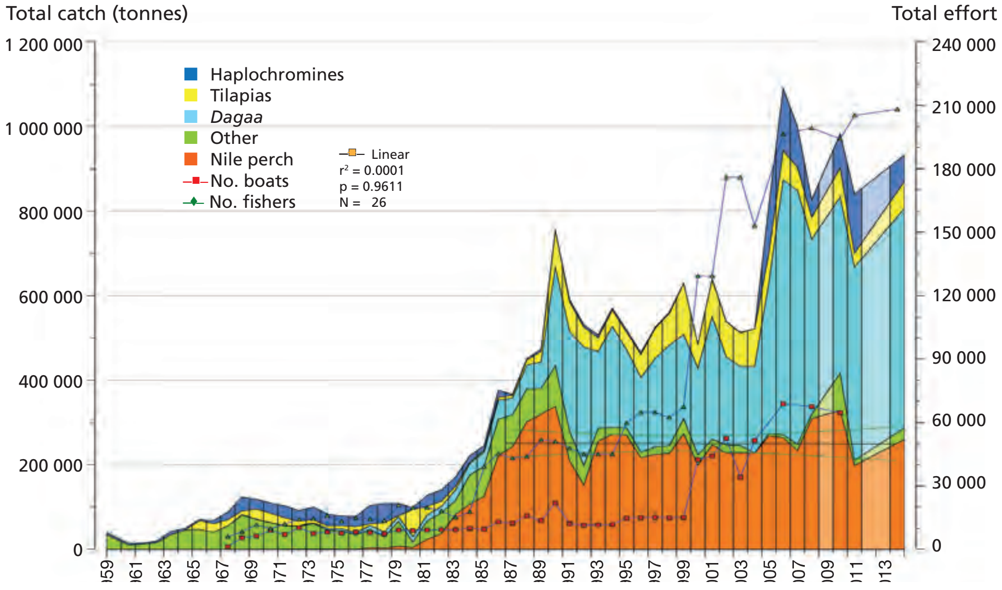
Lake Victoria and its catchment area. It is the world's largest tropical lake, with a surface area of 68 800 km² and a shoreline of 3 440 km

With an annual catch of around one million tonnes per year over the past decade (Figure 19), Lake Victoria is the largest and most productive fishery system in Africa. It is also one of the most studied tropical lakes, owing to the major changes its ecosystem has undergone over the past three decades, specifically with regard to persistent eutrophication, fish communities and fisheries (Kolding *et al*., 2008; van Zwieten *et al*., 2016). Lake Victoria is also one of the most heavily contested and debated lakes, in terms of the utilization of fish stocks and the management of fisheries. After the switch to a Nile perch-dominated lake in the late 1980s, the total catch in the lake increased five times, and almost doubled again after 2003. While most attention has been given to the Nile perch fishery, the fishery for a small pelagic cyprinid species *Rastrineobola argentea* (*dagaa*, *mukene* and *omena* in the local languages of Tanzania, Uganda and Kenya, respectively) that developed around the same time as the Nile perch fishery (Okedi, 1981), contributed as much to the initial increase as Nile perch did. The increase after 2003 is wholly attributable to the light fishery for *dagaa*, that also has a large bycatch of small haplochromine species. Catches of small pelagic fish increased by an average of around 16 000 tonnes per year from 1985 to 2014. Data suggest that this current catch may be as little as ten percent of total annual production (Table 7).

The increase in productivity attracted many new entrants to the fishery: prior to the Nile perch boom, effort hovered around 15 000 fishers, but increased four times to around 60 000 fishers because of the development of the Nile perch industry after 1984. While total official landings remained the same – at around 500 000 tonnes in the first years of the new millennium – fishing effort grew quickly to around 150 000 fishers and later to 200 000 fishers, with the development of the *dagaa* fishery. The rapid and considerable transformation of the *dagaa* fishery was the result of a range of factors that shifted the focus of trade in *dagaa* from local markets to regional and export markets. For example, in Tanzania, the EU ban on Nile perch exports from 1997 to 2000 because of concerns around hygiene, drove many investors in Nile perch into the *dagaa* trade; large trading facilities, such as the Kirumba market in Mwanza, Tanzania – which is now the center of the *dagaa* trade – were established; and hygiene standards in processing were improved (Medard, 2015). Only 30 percent of the *dagaa* production is used for human consumption, with much of the remaining production going into industrial feed mills for the production of feeds for livestock (LVFO, 2016).

FIGURE 19

Total catch (tonnes) split into five major groups (Nile perch, haplochromines, tilapias, *dagaa* and "others") and total effort (number of fishers and number of boats) in Lake Victoria 1959 to 2014



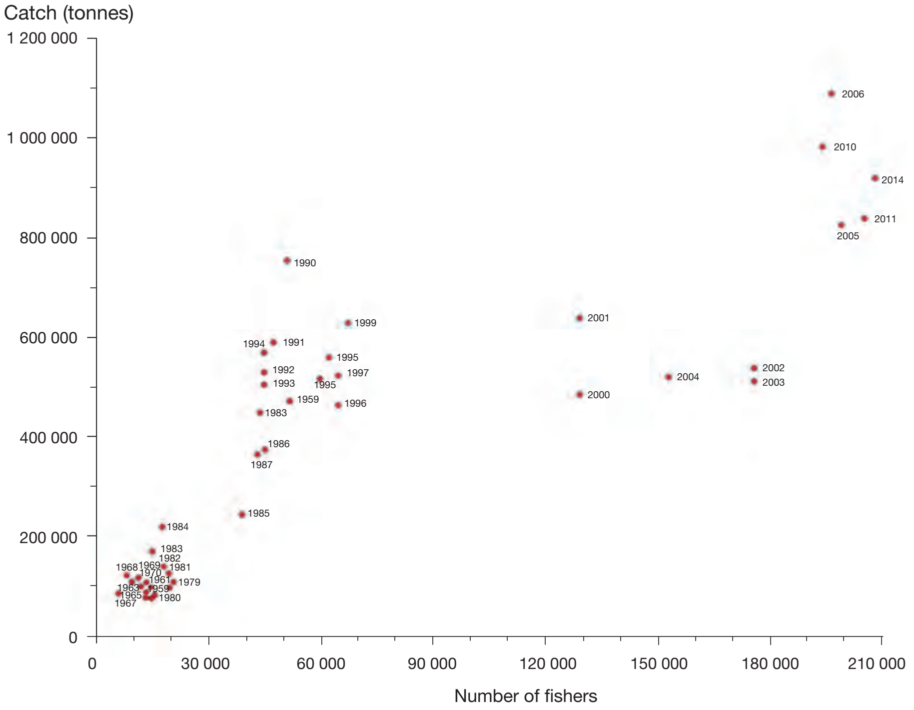
There has been no significant long-term change in the total Nile perch catch (mean ± SD = 247 000 ± 50 000 tonnes) since 1986 (r^2 0.001, p = 0.96). There has been a significant linear increase in *dagaa* catches of about 16 000 tonnes per year since 1985 ($r^2 = 0.69$, $p < 0.001$).

Source: Data from Kolding *et al*. (2014), supplemented by Lake Victoria Fisheries Organisation (LVFO) from 2011 to 2014. Data is missing for 2009 and 2012 to 2013.

Despite the massive increase in the extent of the fisheries around Lake Victoria, with over a ten fold increase in numbers of fishers in the 20 years since 1984 (Figure 20), the overall average catch rate per fisher, when taken as total catch over the total number of fishers, decreased from 10 tonnes per fisher around 1968, to 5 tonnes per fisher by 2014, a decrease of 100 kg per year over almost half a century (Figure 21).

FIGURE 20

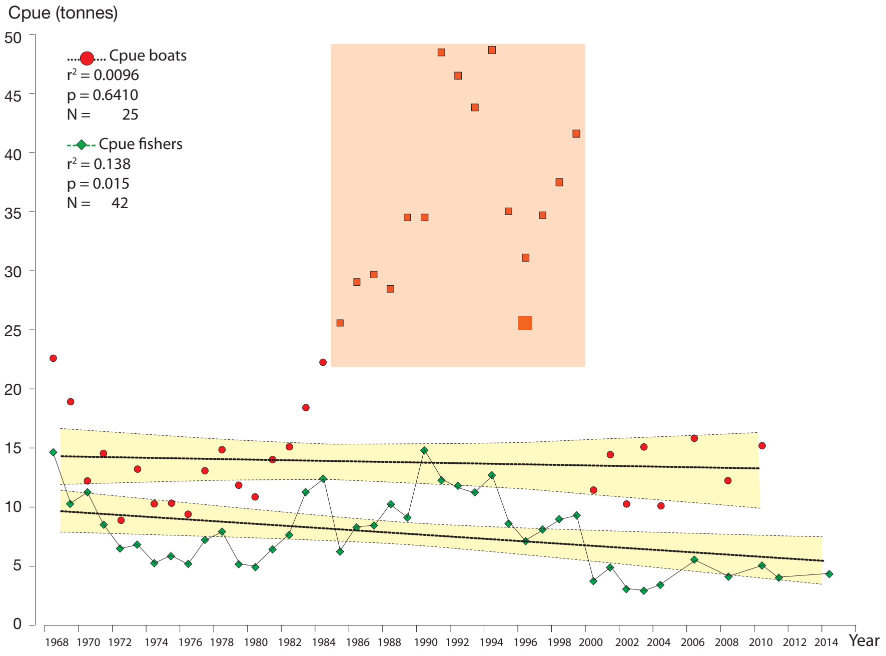
Total catch (tonnes) plotted versus total number of fishers in Lake Victoria (each point is a year of observation moving along the X-axis as effort has increased)



Source: Data from Kolding *et al*. (2014) updated for 2010 to 2014 from data supplied by LVFO.

FIGURE 21

Total catch (tonnes) per unit effort (fishers represented by green diamonds and boats by red circles) in Lake Victoria, 1968 to 2014



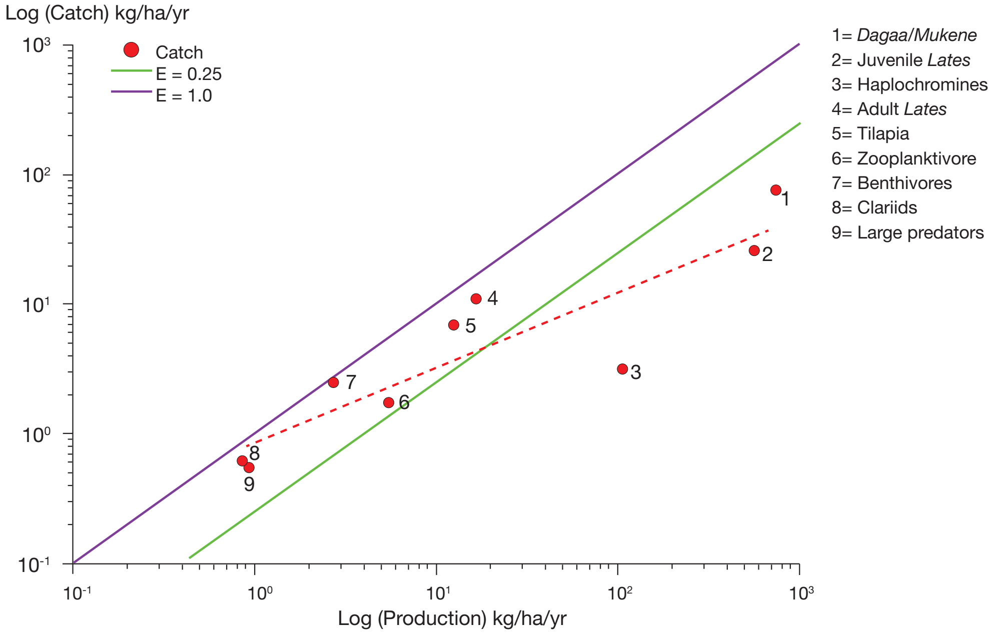
Total catch per fisher, per year has slightly decreased by about 100 kg per year, from around 10 tonnes in 1968 to 5 tonnes in 2014. When excluding the "boom" years between 1985 and 1999, represented by orange squares) there has been no significant change in catch per boat of around 15 tonnes per year.

This is contrary to what is to be expected from steady-state reasoning on the impacts of increased effort on stocks: in fact, it corroborates the vast increase in the productivity of the lake through eutrophication that not only was instrumental in offsetting the Nile perch takeover of the lake (van Zwieten *et al.*, 2016), but also caused vast changes in the biomass available to the various fisheries of the lake. Several Ecopath models have summarized the available data and information on different components of the Lake Victoria ecosystem (Moreau, Ligtvoet and Palomares, 1993; Villanueva and Moreau, 2002; Natugonza *et al.*, 2016), that show these changes. Total estimated fish biomass decreased from 373 kg/ha (of which 70 percent were haplochromines) in 1971 to 1972, to 228 kg/ha (of which 80 percent were the introduced Nile perch and Nile tilapia) in 1985 to 1986. However, the latest 2014 estimate (which includes more accurate pelagic biomasses estimated by acoustic surveys) showed a doubling of total standing fish biomass at 508 kg/ha, with the species targeted by the main fisheries on the lake being Nile perch, *dagaa*, and haplochromines, making 97 percent of the total (Table 7). The current lake-wide catch of all species taken together amounts to 132 kg/ha/year, which constitutes only about 8 percent of the annual production of 1 679 kg/ha/year.

Dagaa, juvenile Nile perch and haplochromines are the most productive components of the lake's fish community but are only lightly exploited, with exploitation rates of between 4 and 10 percent (Figure 22). If the fishery was balanced with a constant exploitation ratio of 0.4, the total yield could be increased by a factor of nearly 4 to 4.5 million tonnes per year (Table 7).

FIGURE 22

Log yield versus log production plot of Lake Victoria 2014. The most productive small fish (*dagaa*, juvenile Nile perch and haplochromines) are only lightly exploited



Source: Data from Natugonza *et al.*, 2016.

TABLE 7

Biomass, production and catch in Lake Victoria according to the 2014 Ecopath model (Natugonza *et al*., 2016) and potential catches and differences if the fishery was balanced with an overall exploitation rate of 0.4. If the model assumptions are correct, the fishery could significantly grow from the present annual take of 1 million tonnes

Groups	Biomass (kg/ha)	% Biomass	P/B	Production (kg/ha/yr)	Catch (kg/ ha/yr)	E = Y/P	Total production (t/yr)	Potential catch (t/yr)	Difference if balanced
Small pelagic	191	37.6	3.93	750.6	74.0	0.10	5 164 128	2 065 651	1 556 875
Juvenile *Lates*	162	31.9	3.50	567.0	25.5	0.05	3 900 960	1 560 384	1 384 669
Haplochromines	124	24.4	2.35	321.7	9.6	0.04	2 213 296	885 318	819 546
Lates	18	3.6	0.92	19.8	11.0	0.65	115 584	46 234	-29 102
Tilapia	6	1.2	2.02	12.6	7.0	0.55	86 688	34 675	-13 141
Benthivores	3	0.5	1.00	2.8	2.5	0.89	19 264	7 706	-9 219
Zooplanktivore	2	0.5	2.37	5.5	1.7	0.32	37 840	15 136	3 165
Clariids	1	0.2	0.99	0.9	0.6	0.61	6 192	2 477	-1 376
Large predators	1	0.2	1.12	0.9	0.6	0.74	6 192	2 477	-1 858
Total	508	100.0		1 678.7	132.0	0.36	11 550 144	4 620 058	3 709 627

5.2 LAKE MALAWI

FIGURE 23

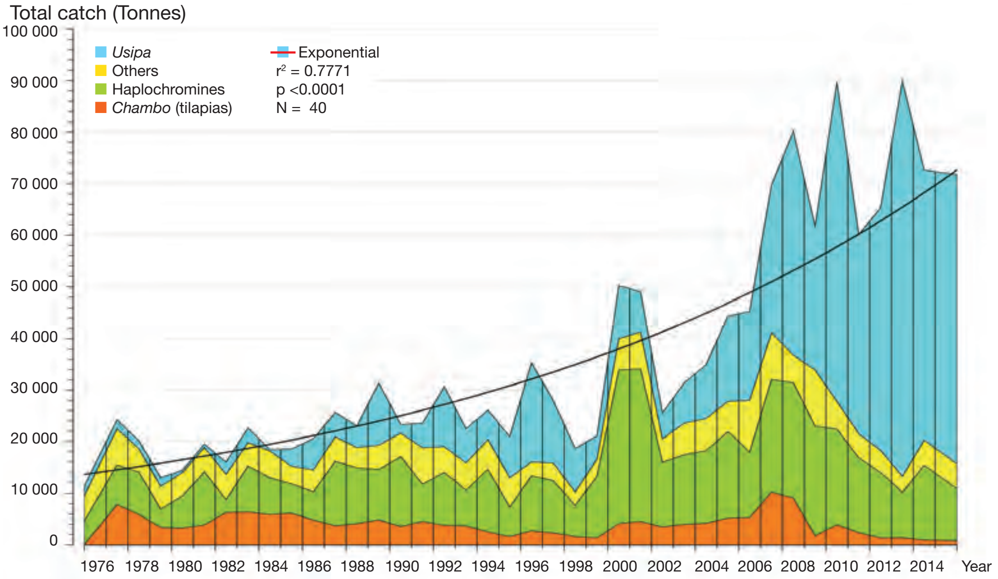
Lake Malawi/Lake Nyasa and its catchment area

Lake Malawi is a large (30 800 km^2), deep (756 m) Rift Valley lake shared by Malawi, Tanzania and Mozambique (Figure 23). The pelagic ecosystem, productivity and fishery were described by Turner (1982) and the comprehensive Overseas Development Administration (ODA)/Southern African Development Community (SADC) report of Menz (1995), based on a 1990 to 1995 lake-wide project. Primary production in Lake Malawi's pelagic zone is primarily driven by the southeast tradewinds that normally blow from May to September, causing mixing of nutrient-rich hypolimnion[11] water into the photic zone (Patterson, Hecky and Fee, 2000). Values for primary production appear to be strongly correlated with periods when this mixing was assumed to be highest. Primary production in Lake Malawi thus seems driven by physical, climatic factors, notably ambient temperature and wind regimes. This conclusion is supported by the large differences between estimated production values in successive years that is attributed to a lesser or greater degree of internal seiching[12] activity. Increased seiching activity, caused by increased wind activity across the lake, increases the extent of nutrient loading in the upper water layers (Patterson, Hecky and Fee, 2000).

The biomass of the offshore pelagic fish of Lake Malawi was estimated to be 168 400 tonnes and is currently unexploited by a fishery. This biomass comprises, by weight, 81 percent cichlidae, 15 percent catfish and 4 percent cyprinidae. The total sustainable yield from the offshore fish population was estimated to be 34 000 tonnes yr^{-1} and, if harvested, would almost double the yield of fish from the lake. Potential yields of 14.2 kg ha^{-1} yr^{-1} are low but are consistent with expectations from studies of pelagic ecosystem productivity (Thompson and Allison, 1997). The relatively low fish productivity in Lake Malawi, compared to Lake Tanganyika, has been attributed to the abundant presence of lake fly, *Chaoborus edulis* (Degnbol, 1993). The ODA/SADC survey (Menz, 1995) found that more than half the adult fish production in the pelagic ecosystem is sustained by consuming *C. edulis* and *Engraulicypris sardella* larvae, rather than by feeding directly on herbivorous zooplankton (Allison, 1995). This extra step in the food chain means that the conversion of primary production to fish production is less efficient than in a system with a shorter food chain: an estimated 0.3 percent of primary production goes into fish production in Lake Malawi, compared with 3.3 percent in Lake Tanganyika (Allison, 1995).

FIGURE 24

Total catch (tonnes) split into four major groups (*usipa*, haplochromines, *chambo* [tilapias], and "others") in the Malawian part of Lake Malawi, 1976 to 2015. There has been a significant exponential increase in the catches of *usipa*



Source: Department of Fisheries, Malawi.

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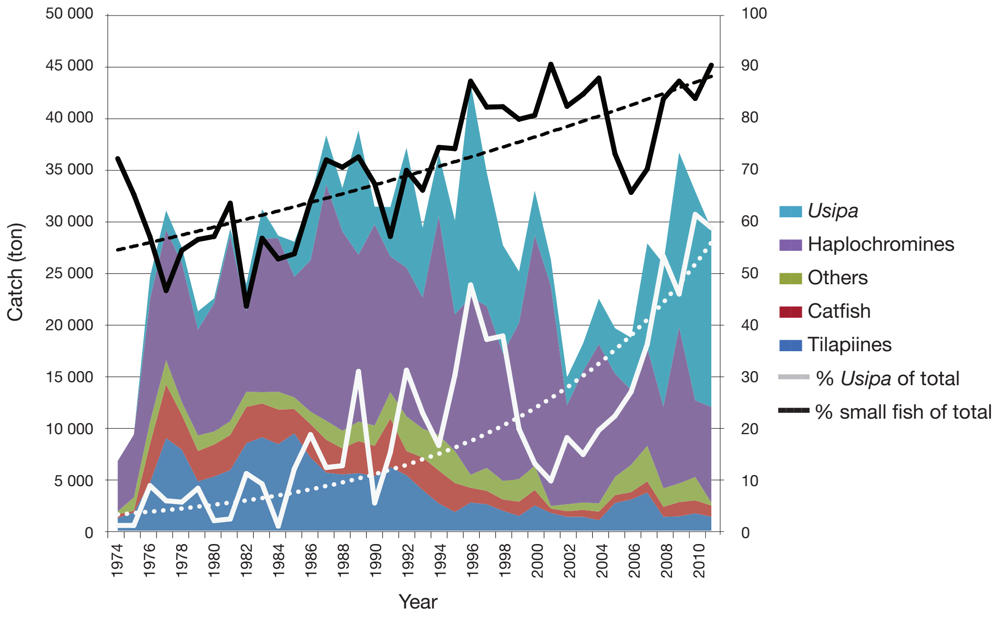
[11] The dense, bottom layer of water in a thermally-stratified lake.

[12] A seiche is a standing wave in an enclosed or partially enclosed body of water.

The total catch of Lake Malawi currently hovers between 60 000 tonnes.year^{-1} and 90 000 tonnes.year^{-1}, with a rapidly increasing contribution of *usipa* that in recent years comprised around 60 to 70 percent of the total catch (Figure 24). Catches in the Malawian part of Lake Malawi, mainly taken from the southeast and southwest arms of the lake, were always dominated by species from the highly diverse haplochromine community, from both the demersal and more pelagic areas of the lake. Most of these species were small and were sun-dried. A light fishery for the small pelagic species *Engraulicypris sardella*, called *usipa* locally, developed as early as the 1970s (Figure 24, 25).

FIGURE 25

Catch (in 1 000 tonnes) of the southeast and southwest arm of Lake Malawi by species category between 1974 and 2001; and proportion of the *usipa (Rastrineobola sardella)* and small fish (haplochromines + *usipa*) in the total catch

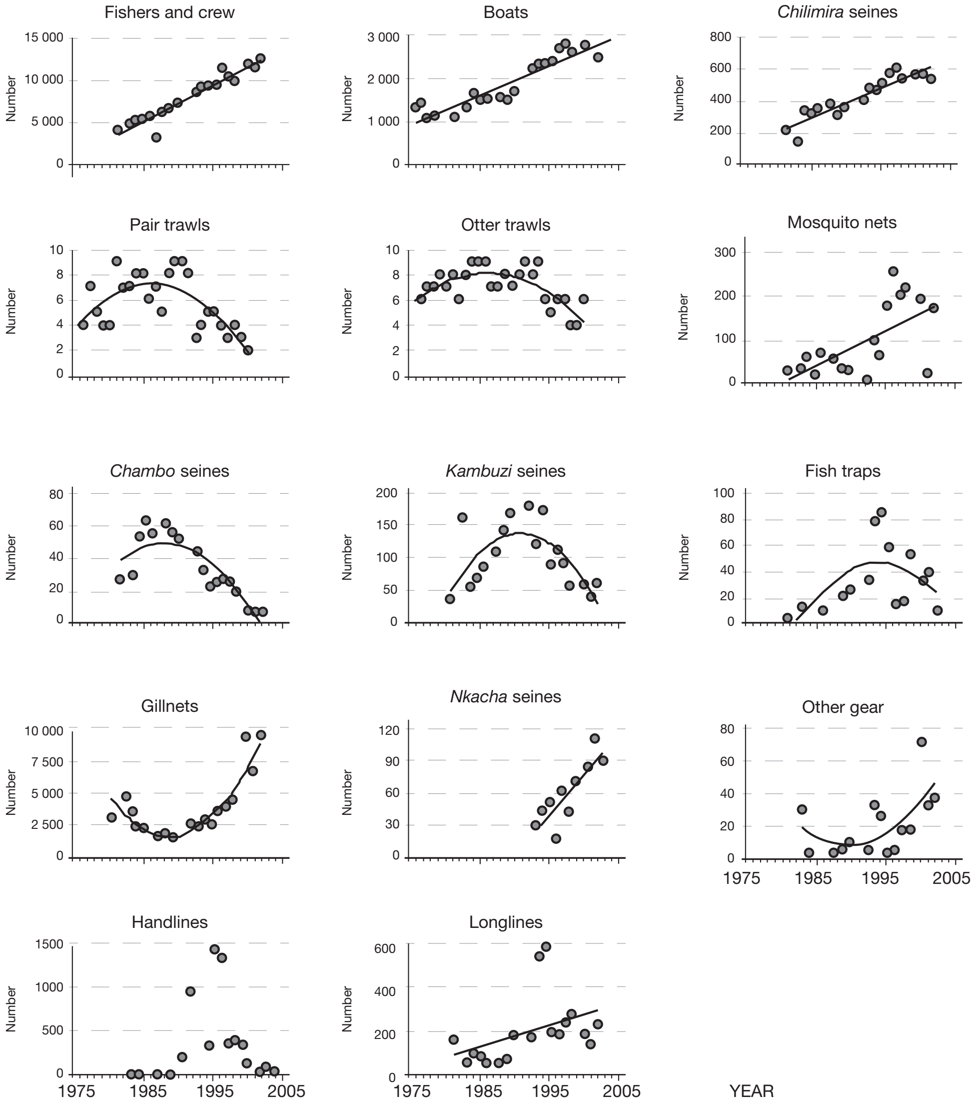


Source: Based on van Zwieten, Banda and Kolding, 2011; Hara and Njaya, 2016.

The developments in the artisanal catches of *usipa* were most likely severely underestimated in the period between 1974 and 2001, but specifically in the years before 1985. In the southern part of Lake Malawi an apparent overall stability in the total catch since 1985 (between 30 000 tonnes to 35 000 tonnes) can be noted. Next to that, catches feature a gradual species replacement, where larger species or groups (tilapiines, catfish, others) are replaced by smaller species (haplochromines and *usipa*), especially in the artisanal fishery. In southern Lake Malawi, by 2001 small species amounted to 80 percent and *usipa* to around 30 percent of the total catch (van Zwieten, Banda and Kolding, 2011). Data after 2001 are less reliable but estimates indicate that around 2011 *usipa* catches constituted about 60 percent of the total catch, and small fish up to 90 percent (Hara and Njaya, 2016), while the *usipa* fishery is still expanding.

FIGURE 26

Development of fishing effort on the southeast arm of Lake Malawi by numbers of fishers (owners and crew), boats (dugouts, plank boats with and without engines) and the most important gears as recorded in the Malawian catch and effort data recording system (CEDRS) during frame surveys (small-scale gears) and through licensing (trawlers)



Regression lines are shown to highlight trends and variability in the data, including outliers. *Chilimira* nets target *Engraulicypris sardella (usipa)*.

Source: Based on van Zwieten, Banda and Kolding, 2011; Hara and Njaya, 2016.

In the southeast arm, total effort of *chilimira* nets, the gear that targets *usipa*, steadily increased from 200 nets in 1980 to around 600 nets in 2005 (Figure 26). During the 2015 frame survey, 675 *chilimira* gears were counted in the southeast arm, while over the whole Malawian part of the lake a total of 3 124 *chilimira* nets were counted, indicating that the total catches are likely 4 to 5 times higher than reported.

Much less information is available for the Tanzanian (Nyasa) and the Mozambican (Niassa) parts of Lake Malawi. These parts of the lake have steep shores and their fisheries largely target pelagic haplochromines and *usipa*. The *Instituto Nacional de Investigação de Pesqueira* conducted surveys in two Mozambican districts between 2000 and 2015: of the total recorded catch of around 4 100 (+/- 900 CI) tonnes, 64.4 percent was *usipa*

(Olaf Weyl, pers. comm.). Between 2013 and 2017, in the Kyela district of Tanzania, landings of *usipa* were estimated to range between 2 284 and 5 611 tonnes. In 2015 the total catch of Lake Malawi was estimated to be 10 095 tonnes, but this figure did not include *usipa*, indicating that in this part of the lake *usipa* catches account for up to one third of the total catch.

PLATE 15
Drying of usipa (Rastrineobola sardella) on the shore of Lake Nyassa/Malawi

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With a long-term average annual catch per net, per year in the *chilimira* fishery amounting to 16 (+4 95% CI) tonnes, the total Malawian catch of *usipa* was estimated to be around 50 000 tonnes per year, which it currently appears to have reached (Figure 24).

5.3 LAKE TANGANYIKA

FIGURE 27
Lake Tanganyika and its catchment area

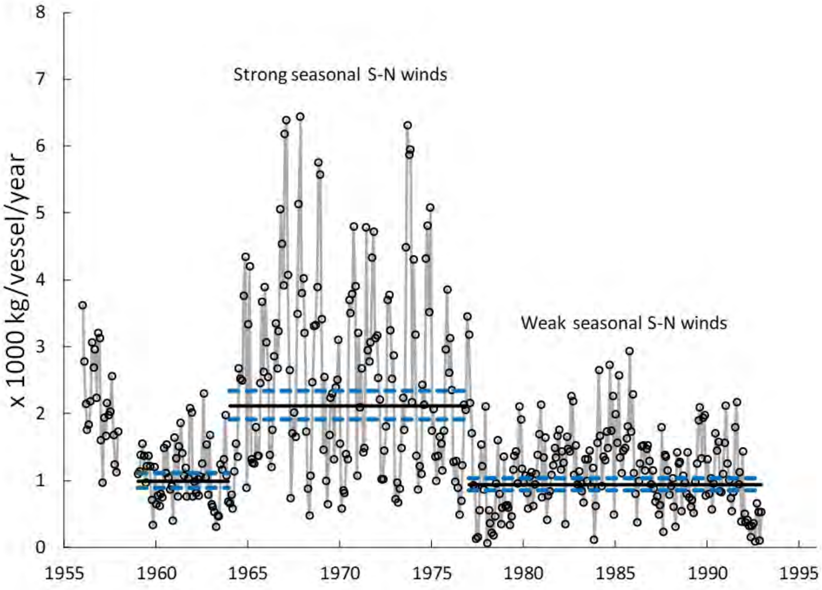
Lake Tanganyika is a large (33 000 km^2), deep lake shared by Burundi, Democratic Republic of the Congo, Zambia and Tanzania. The highly productive pelagic component of the lake forms the basis of a locally intensive fishery focused on a range of predatory *Lates* species as well as two small freshwater clupeids: *Stolothrissa tanganicae* and *Limnothrissa miodon*, which provide a vital source of livelihood and food supply to more than 10 million people living around the lake (Mölsä *et al*., 1999). Together they represent 60 percent (Mölsä *et al*., 1999) to 90 percent of the total pelagic commercial fish catches (Mulimbwa, Sarvala and Raeymaekers, 2014). In an earlier bioenergetic modelling study (Sarvala *et al*., 2002) the annual catch of *Stolothrissa tanganicae* was 18 percent to 35 percent of estimated production in individual countries and 25 percent in the whole lake. For *Limnothrissa miodon*, the corresponding ratio was moderately low (19 percent to 22 percent) in Tanzania and Zambia, but high (55 percent to 61 percent) in the Democratic Republic of the Congo and Burundi; in the whole lake, the exploitation rate was 30 percent. These figures suggest that the clupeid fishery by then was sustainable while the *Lates* populations were clearly over-exploited (Sarvala *et al*., 2002).

The most comprehensive study of the pelagic ecosystem was carried out during the FAO/Finnish International Development Agency (FINNIDA) Lake Tanganyika Research project (LTR), a lake-wide project to investigate the limnological processes governing pelagic fish production, aimed at providing advice on whether the fisheries could be expanded and managed on a sustainable basis. Studies included meteorology, hydrodynamics, limnology, plankton and fish, with 20 lake-wide hydroacoustic cruises conducted from the research vessel *Tanganyika Explorer*.

To understand the developments of the fishery in the lake it is important to understand the sources of its productivity. The relatively simple pelagic system consists of only two to three crustacean zooplankton species and four fish species. This should mean efficient utilization of primary and secondary production by the pelagic fish stocks (Lowe-McConnell, 2003). In earlier studies, Lake Tanganyika's overall fish yield appeared to be too high for the oligotrophic nature of its waters (Hecky, 1991).

FIGURE 28

Developments in monthly catch rates of small clupeids in the industrial fishery of Burundi in Lake Tanganyika between 1955 and 1993



The decadal-scale variations are possibly caused by a north–south seiche that occurs during periods of strong seasonal south–north wind, causing upwelling in the northern and southern tip of the lake during release of wind stress and high fluctuations in clupeid production, not seen during the period of weak seasonal south–north winds. Horizontal lines are the mean monthly catch rates over a period (continuous) and the 95% confidence intervals (broken).

However, the LTR project discovered "missing" primary production deeper than previously sampled (30 m to 40 m, or deeper). In addition, the LTR project revealed the importance of frequent upwelling and downwelling all over the lake from the mosaic of shifting wind patterns. The lake is permanently stratified, being the second deepest lake in the world (1 470 m), and seasonal mixing generally does not extend beyond depths of 150 m (Edmond *et al*., 1993). The mixing mainly occurs as upwelling in the north and south of the lake and is wind-driven, but to a lesser extent there are also upwellings and downwellings elsewhere in the lake, as well as locally. North–south winds over the length of the lake cause an internal seiche which, when wind stress is released, causes seasonal upwelling, increasing productivity of the waters in the two opposite tips of the lake (Plisnier *et al*., 1999; Plisnier *et al*., 2009). Possibly, this greatly increases the production of the short-lived, highly productive clupeids (Figure 28), but there may be other mechanisms that also play a role (Sarvala, pers. comm.). Paleolimnological evidence showed declines in fishery species and endemic molluscs that began well before commercial fishing started because of sustained warming during the last approximately 150 years. This warming strengthens stratification of the water column and makes it shallower as well. The resulting reductions in lake mixing have depressed algal production and shrunk the oxygenated benthic habitat by 38 percent, resulting in fish and mollusc declines. Climate warming and intensifying stratification have most likely reduced potential fishery production, helping to explain possible declines in fish catches (Cohen *et al*., 2016), next to or even overriding increased fishing pressure (Sarvala *et al*., 2006). Actually, O'Reilly *et al*. (2003) concluded that the impact of global climate change on this very deep lake is greater than that of any other anthropogenic activity, including fishing.

All parts of the lakes are fished but a semi-industrial pelagic fishery started in the mid-1950s in the northern (Burundi) and southern (Zambian) parts of the lake. An artisanal fishery utilizing lift nets from catamaran platforms and light attraction was developed around the same time. Limited data on effort development exist, but between 1995 and 2011, years in which lake-wide frame surveys were conducted, the total number of fishers more than doubled from 45 000 to 95 000. Over the same period, the fishery completely shifted from an industrial fishery, that was already in decline by 1995, to small-scale units using handlines from dugout canoes (3 585, increase +18 percent), gill nets, longlines, hook and line and beach seining operated from plank boats (17 381, +79 percent) and pelagic lift nets used on catamarans[13] (5 827, +79 percent). Catamarans are dominant in the light fishery for small pelagic fish, next to a small ring net light fishery in Zambia. While in 1995 there were still 184 industrial-scale vessels on the lake, also mostly targeting small pelagic fish and mainly operational in Burundi and Zambia, these had all but vanished in 2011 (van der Knaap, Katonda and De Graaf, 2014; LTA Secretariat, 2012).

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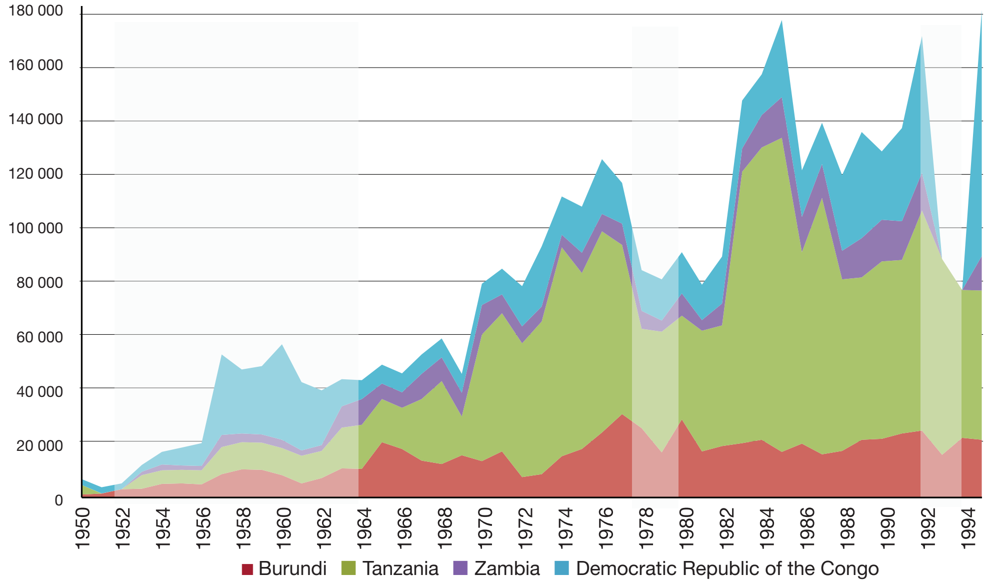
[13] These include the so-called motorized Apollo units used in Burundi and Democratic Republic of the Congo. Motorized catamarans are used in all countries except Zambia. Non-motorized catamarans are used especially in the northern part of the lake. In Zambia, 651 ring net vessels were counted; this is another light fishery that targets small pelagic fish.

FIGURE 29

Total recorded catch of Lake Tanganyika by country from 1950 to 1995



Grey areas are periods with less reliable data.

The total catch from the lake increased from the 1950s onwards to a maximum of around 170 000 tonnes in 1985 and has fluctuated around 145 000 tonnes since 1995 (Figure 29). Few reliable data exist after that period but recent estimates indicate that catches have now decreased to around 120 000 tonnes (Van der Knaap, pers. comm.). However, this may be an underestimate as the small pelagic fisheries alone may produce up to 110 000 tonnes (see below).

Over the period 1955 to 1995, the proportion of clupeids in the catch first increased and then decreased for the industrial and artisanal fisheries in Burundi (Figure 30), while in Zambia the industrial fishery shifted from a small pelagic fishery to a fishery on small *Lates stappersi*, before their demise halfway through the 1990s (van der Knaap, Katonda and De Graaf, 2014).

Because the southern stocks of *Lates stappersii* fed largely on shrimp and are thus approximately at the same trophic level as the planktivorous clupeids, this shift could represent a shift in fish community structure rather than a shift in production (Sarvala, pers. comm.) However, as the catches of the three important fisheries were highly positively correlated (Table 8) a significant component of environmental change that induced an overall decrease in the availability of the clupeids in the two regions, may also have contributed to the decline.

FIGURE 30

Proportion of clupeids in the total catch per fishery of the artisanal, industrial and traditional fisheries of Burundi, and the industrial fisheries of Zambia (1956 to 1997)

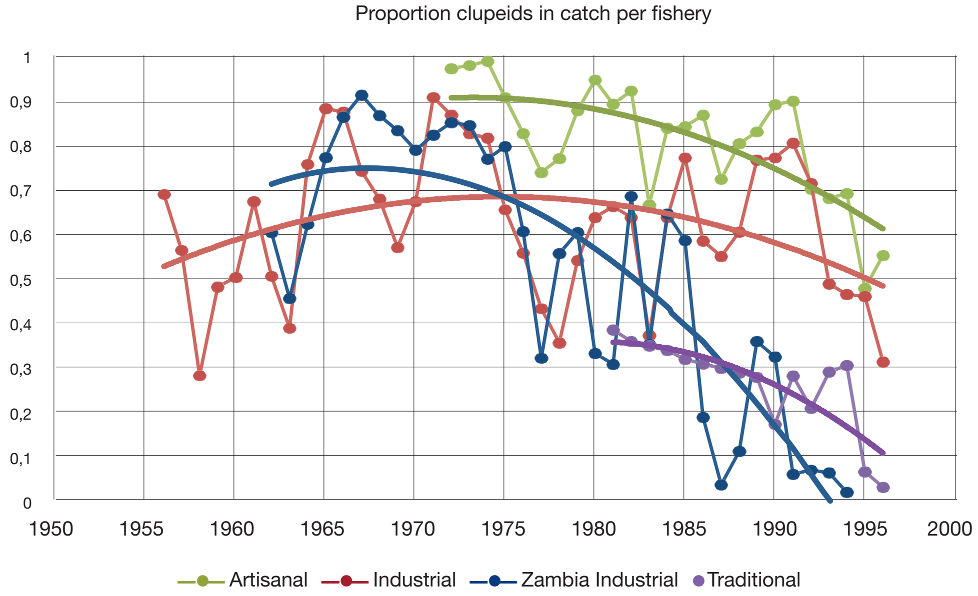


TABLE 8

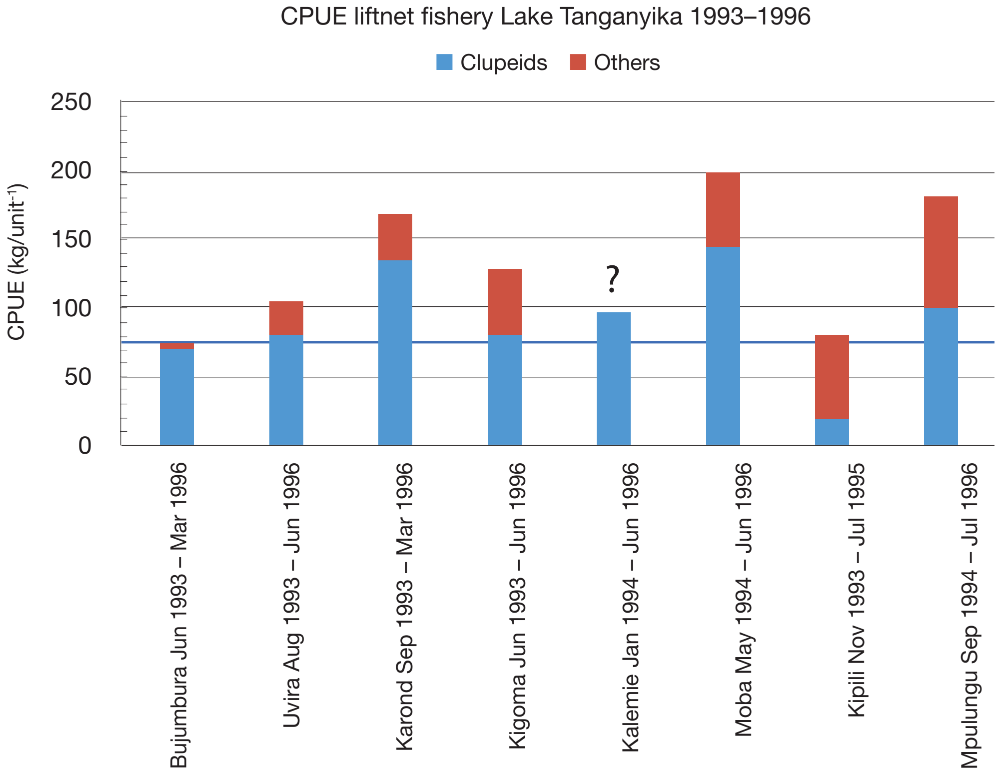
Pearson correlation coefficient between standardized catches (1962 to 1994) of the three important clupeid fisheries in Burundi and Tanzania

	Industrial Burundi	Artisanal Burundi
Industrial Burundi	1	
Artisanal Burundi	0.63	1
Industrial Zambia	0.42	0.74

Limited data exist after 1985, but the total catch of 2015 from the Tanzanian side of the lake amounted to 54 000 tonnes and it was suggested that the contribution of clupeids, mainly consisting of *Stolothrissa tanganicae*, was 40 percent.

FIGURE 31

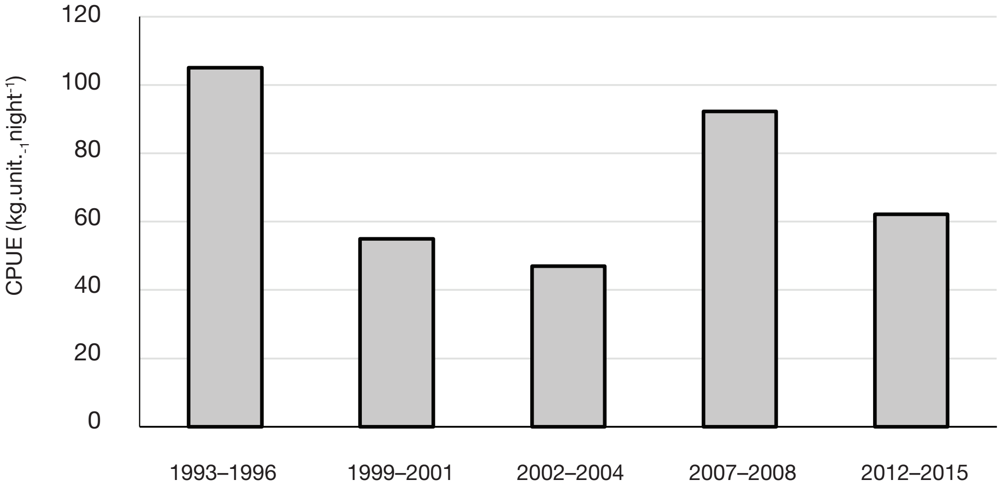
CPUE in lift net fishery, as recorded in the Lake Tanganyika Research project's fish biology sampling program (LTR data archives)



The question mark indicates a possible bias in recording. The blue line is the average CPUE (92.2 kg/unit/trip) over all fisheries taken over the periods and areas shown

FIGURE 32

Average CPUE of a lift net fishery from Uvira, Democratic Republic of the Congo



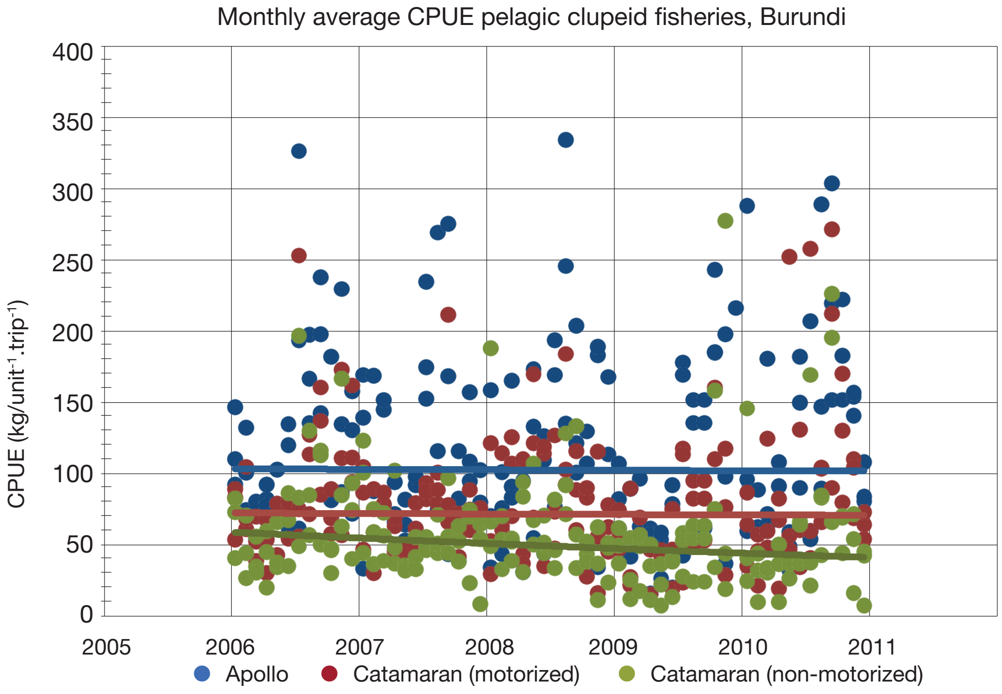
Source: Data for 1993–1996 FAO/FINNIDA Lake Tanganyika Research project; data for 1999–2001 FAO/FINNIDA Lake Tanganyika Fisheries Monitoring Program; data for 2002–2015 collected by N. Mulimbwa in a biological sampling program (Mulimbwa, Raeymaekers and Sarvala, 2014).

In different parts of the lake, the proportion of clupeids in the pelagic small-scale lift net fishery varies from 95 percent to 77 percent in the northern part of the lake, to 24 percent to 55 percent in the southern part of the lake (Figure 31). Clupeids formed around 70 percent of the average CPUE of 129 kg/unit/trip, but with a large variation between areas (CV=37%). The high variability in catches is also observed in a time series from 1993 to 2015 of a lift net fishery in Uvira where the average CPUE ranged from 47 to 105 kg/trip (Figure 32), the latter value already presented in Figure 31. In recent years CPUE in Uvira is around 62 kg/unit/trip.

No change or a slight decrease in catch rates for the three important light fisheries in Burundi was observed between 2006 and 2012 (Figure 33, Lake Tanganyika Authority (LTA) secretariat, data obtained through Martin van der Knaap). Catch rates differed between the three different gears where non-motorized and motorized catamarans on average caught respectively 50 percent and 30 percent less than the Apollo units that caught 121 kg/unit/night over the whole period averaged over monthly averages. Catches are highly variable with seasonal lows between March and June that are 30 to 40 percent lower than in the remaining months. Monthly variation in catch rates ranged between CV=53 and 66 percent for Apollo units and non-motorized catamarans respectively. With an average of 23 fishing days this translates into a daily variation of CV=253 to 314 percent (Jul-Larsen *et al.*, 2003) typical for small-scale light-fisheries on small pelagics (van Densen, 2001; van Oostenbrugge *et al.*, 2002). A highly variable but stable over the long-term CPUE indicates that the highly variable total catches in the fishery currently are driven by climatic factors.

FIGURE 33

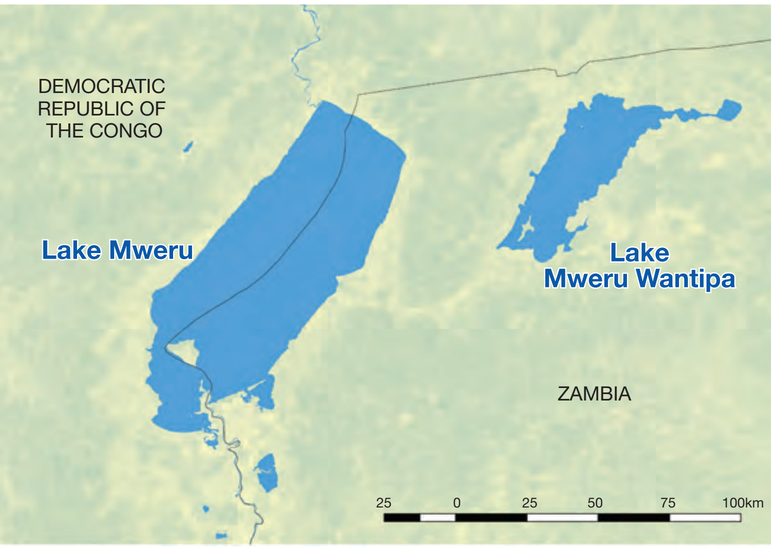
Trends in monthly average CPUE (kg/unit/trip) for three pelagic light fisheries from Burundi, collected from 2006 to 2012 in the catch assessment survey



Trend lines are power functions to account for the normality of residuals around the trend. Trends for Apollo gears and motorized catamarans are non-significant (resp: $F_{1,171}=0.009$. p=ns and $F_{1,173}=0.0247$, p=ns). Non-motorized catamarans show a slightly decreasing trend of 7 percent per year ($F_{1,176}=5.170$, $p<0.05$)

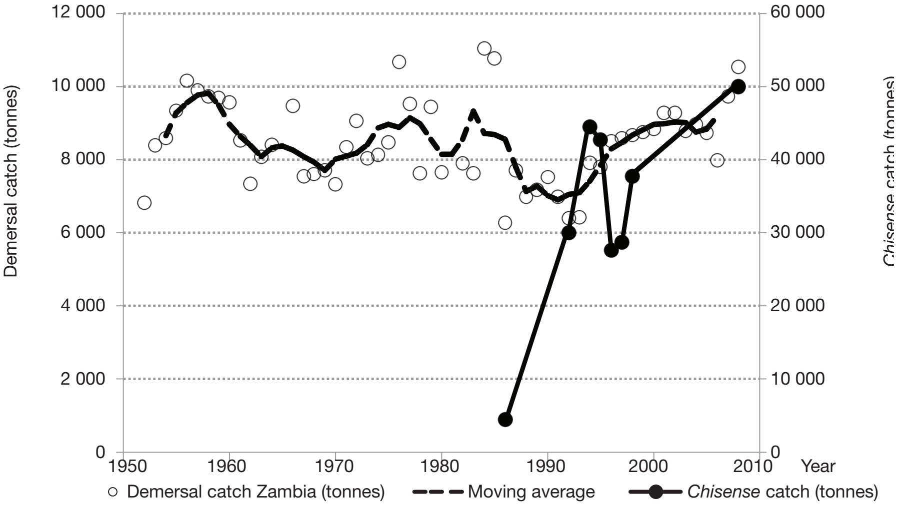
5.4 LAKE MWERU

FIGURE 34
Lake Mweru



Lake Mweru is an allotrophic riverine lake, where production is to a significant extent dependent on the nutrient pulses brought in with the annual floods. Annual fluctuations are around 2 m between peak and low levels, but highest and lowest recorded levels range between 4 m and 5 m (Bos, 1995) in a lake that is on average 7.5 m deep at intermediate water levels. Long-term demersal catches for the Zambian part of the fishery hover around 8 500 tonnes (N=55, CV=13%) (Figure 35).

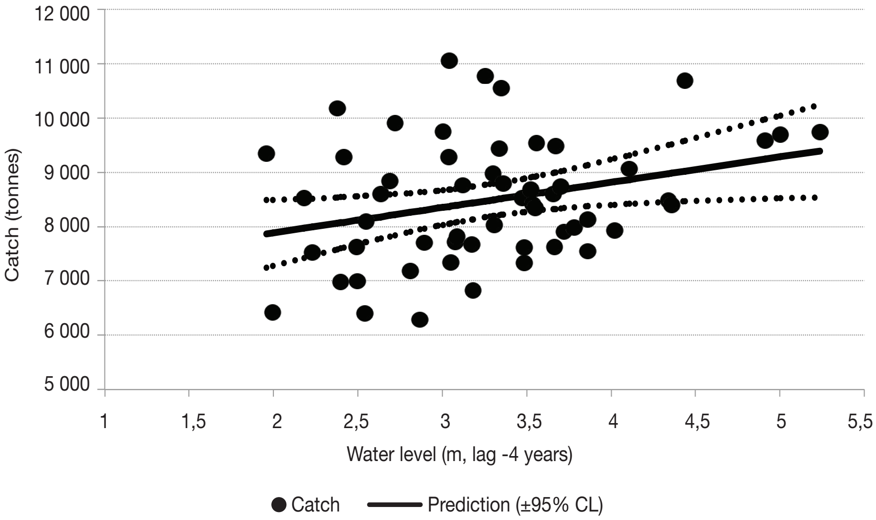
FIGURE 35
Total catch (tonnes) of the Zambian demersal (open circles, dotted line) and pelagic *chisense* (black circles, continuous line) fisheries of Lake Mweru-Luapula



Limited data exist for the Democratic Republic of the Congo side of the lake and they are also highly unreliable, but estimates range between 1 000 and 15 000 tonnes, with a long-term average of 5 500 tonnes (N=25, CV=67%). However, it is more likely that demersal catches on the Democratic Republic of the Congo side are as high as the Zambian catches (Greboval, Bellemans & Fryd, 1994). Despite representing only around half the fishery, Zambian demersal catches are correlated with the water level with a lag of four years (Figure 36). Therefore, peak aggregated catches follow high water levels four years earlier, with around 470 tonnes increase per meter of water level.

FIGURE 36

Regression of demersal catch (tonnes) of the Zambian side of Lake Mweru on the average water level four years previous ($F_{1,54} = 5.18$, $p=0.02$, $r^2=9\%$)



Fishing on Lake Mweru and its associated river, floodplains and floodplain lakes consists of many different methods, including gill nets used passively and actively, beach seines, longlines, hook and lines, traps, baskets, weirs, cast nets and a light fishery on the small pelagic species *Microthrisssa moeruensis* (*chisense*) carried out with various dip nets (Goudswaard, 1999; van Zwieten, Goudswaard and Kapasa, 2003; Mölsä, 2010). Nevertheless, the dominant gear in the lake is gill nets. Effort increased rapidly, especially since the 1990s. This was to some extent influenced by an influx of people fleeing from the war in the northern regions of the Democratic Republic of the Congo, but also because of normal population growth (Table 9) (Mölsä, 2010).

Prior to 1974, no specific fishery on the pelagic species *Microthrisssa moeruensis* was carried out, although it was reported from the lake. Small fish, including various barbs, small cichlid species, juveniles of larger species and *chisense* were, and still are, fished along the shore by women using baskets, but also in weirs in the floodplains during drawdown. During the second half of the 1970s, a light fishery started along the northeastern shore of the lake. By 1985 the fishery was carried out along the whole Zambian shoreline and to a lesser extent in the Luapula river. By then it supported around 1 700 fishers and workers, using 600 boats, 450 nets and around 1 000 lights, with an annual catch of around 4 500 tonnes fresh weight. Since then the fishery has developed rapidly, producing between 30 000 and 40 000 tonnes (equals 120–160 kg/ha/yr) annually between 1992 and 1997 (van Zwieten, Aarnink and Kapasa, 1995; Goudswaard, 1999). The frame survey of 2008 reports 1 960 fishers using the same number of nets and 9 803 lights. The fishery was estimated to catch around 50 000 tonnes by extrapolating from the average CPUE as recorded in the 1990s. This was deemed likely because average catch rates apparently had not decreased in the decade following 1997 (Mölsä, 2010). There are no regular catch estimates for this fishery because it is not included in the monitoring program (catch assessment surveys) carried out by the Department of Fisheries of Zambia.

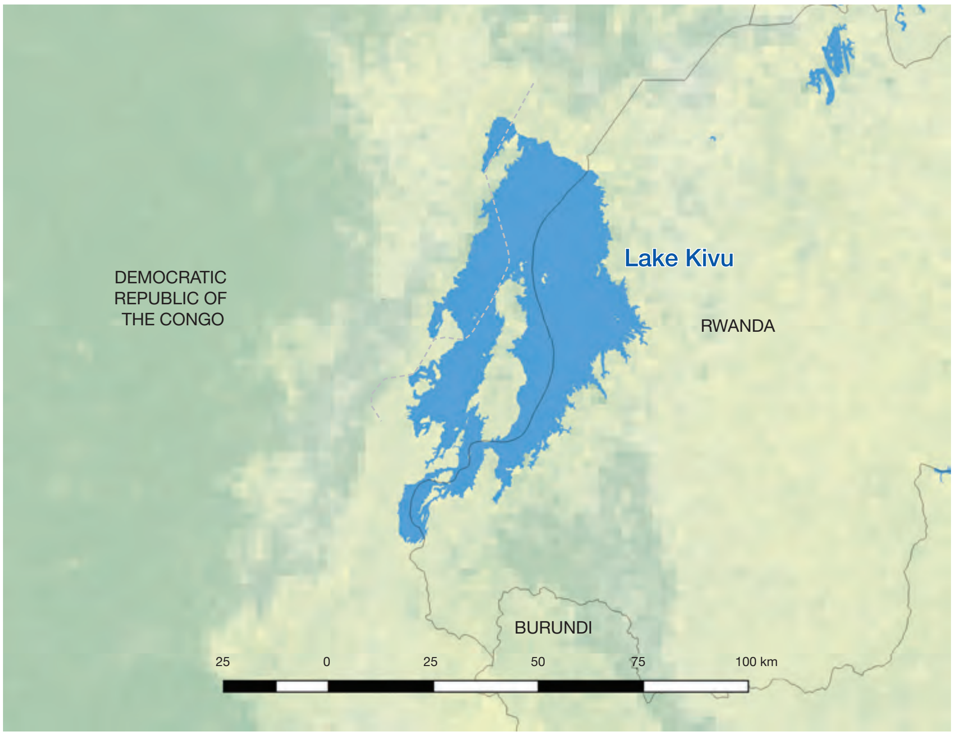
TABLE 9
Developments in fishing effort on the Zambian part of Lake Mweru since 1971

Year	Fishers	Gill nets	Chisense nets
1971	5 963		
1985	7 723		450
1992	9 301	45 057	1 426
1997	12 047	93 256	1 729
2008	21 222	435 848	1 960

No information exists on the size and extent of the pelagic fishery of the Democratic Republic of the Congo side of the lake, although it is likely to be much smaller than the Zambian fishery: after landing, *chisense* is dried mainly on the sandy beaches that are quite extensive on the Zambian side of the lake and more so in the southern and northern parts. The Democratic Republic of the Congo part of the lake has steep rocky shores with limited space to dry the fish. The dried *chisense* is traded to all the main population centres in Zambia, including the Copperbelt and Lusaka, and southeast Democratic Republic of the Congo, including Lubumbashi (van Zwieten *et al.*, 1996). Fishing pressure on Lake Mweru is high and has shown an early shift from a focus on larger species – mainly targeted by passive fishing methods using predominantly gill nets – to a fishery with highly diversified fishing methods and an increasingly important small clupeid fishery. This fishery, however, is not recognized in the official Zambian fishery statistics for the lake, while very limited information exists on the total catch of the fisheries in Democratic Republic of the Congo, including the pelagic clupeid fishery.

5.5 LAKE KIVU

FIGURE 37
Lake Kivu and its catchment area



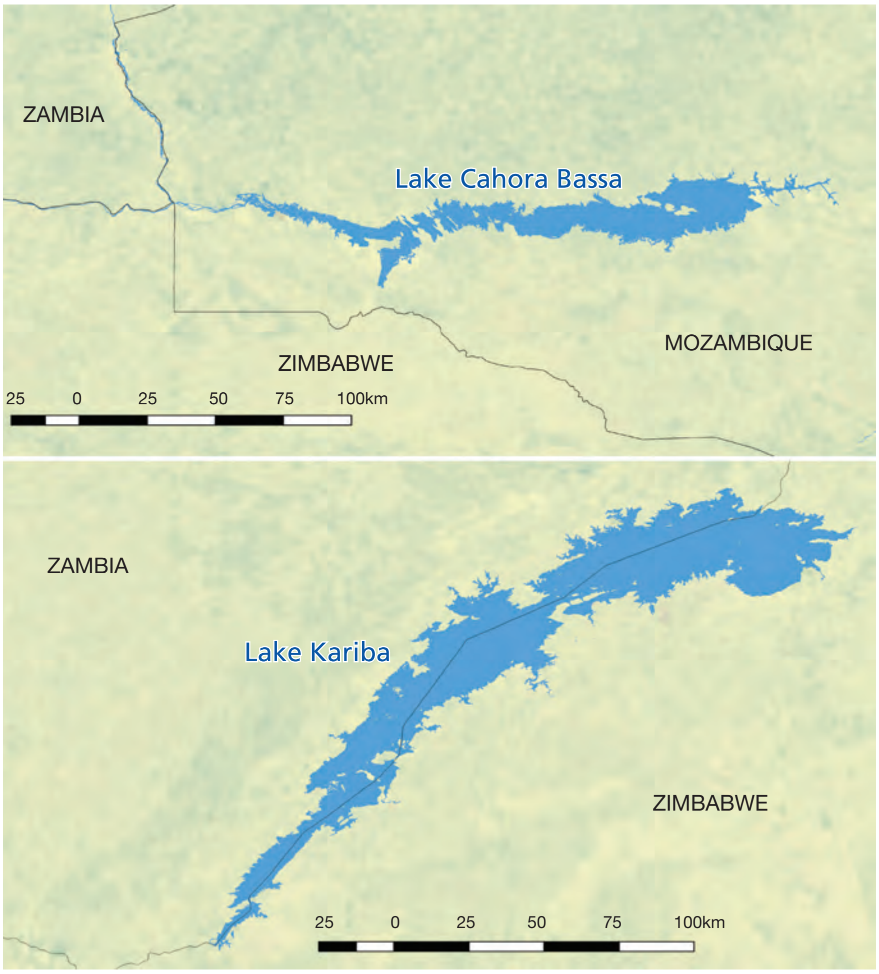
Lake Kivu (Figure 37) is shared by Rwanda and the Democratic Republic of the Congo. It has a surface area of 2 370 km² and a shoreline of about 860 km. The basin has a population of approximately 2 million people and represents one of the highest population densities in the African Great Lakes region, with high growth rates. The fishery supports about 500 000 people in Rwanda and the Democratic Republic of the Congo. The lake has a relatively low fish diversity of approximately 28 species, 50 percent of which are endemic cichlids, and four introduced fish species.

The Lake Kivu fishing ground on the Rwandan side of the lake is made up of five basins (districts) of different surface areas. These basins include, from north to south: Rubavu (47 km²), Rutsiro (542 km²), Karongi (200 km²), Nyamasheke (225 km²) and Rusizi (41 km²). Kivu is the biggest local source of fish in Rwanda and currently produces approximately 21 400 tonnes (equals 200 kg/ha/yr) of fish per year with the introduced Lake Tanganyika sardine (*Limnothrissa miodion*, *kapenta*) contributing 75 percent of total catches, followed by haplochromines (10 percent). The remaining 15 percent comprise tilapia (8 percent) and Clarias spp. (3 percent). The remainder of the catch is made up of other species. In 1990 and 1991 the catches of *Limnothrissa miodon* in Rwanda were 1 117 and 1 343 tonnes respectively (Mughanda and Mutamba, 1993). This means that in this lake the pelagic catches have increased by more than 1 000 percent in a couple of decades (Table 1).

5.6 LAKE KARIBA AND CAHORA BASSA

FIGURE 38

Lake Kariba and Cahora Bassa reservoirs on the Zambezi River, southern Africa

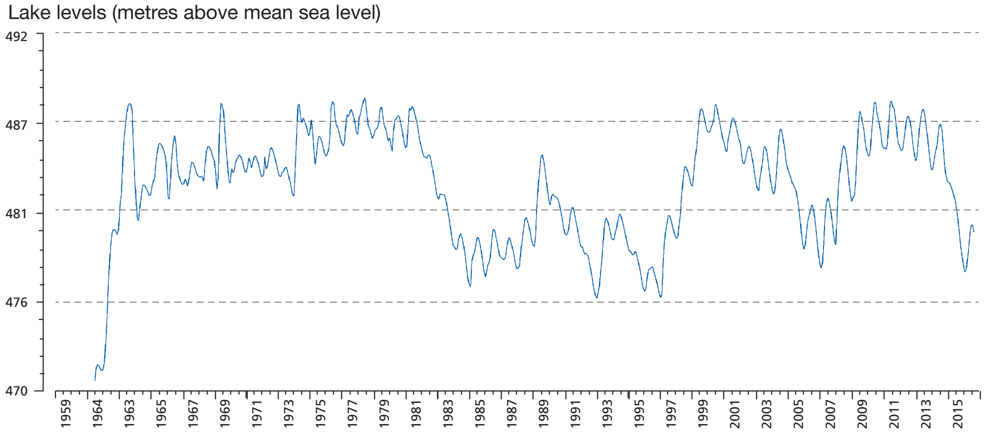


Lake Kariba (277 km long; 5 364 km^2; 160 km^3; 29 m mean depth and 120 m maximum depth), situated on the Zambezi River and shared between Zambia and Zimbabwe (Figure 38) was built in 1958 and is still the largest human-made lake in the world by volume (156 km^3). The dam wall (128 m x 580 m) was completed in 1960 and the filling phase lasted from December 1958 to September 1963 when the water reached the mean operation level of 485 m above mean sea level. The lake is almost equally shared by the two riparian countries Zambia and Zimbabwe, with 45 percent and 55 percent respectively (Kolding *et al.*, 2003). Lake levels fluctuate annually from 1 m to 5 m (mean = 2.9 m) as a function of inflowing floods between December and June and continuous drawdown through the turbines and (prior to 1981) spillage through the sluice gates. Since 1982 the lake levels have declined owing to a series of droughts and the lowest levels recorded were in December 1992 and January 1997 at 476 m (Figure 39).

The Cahora Bassa reservoir on the lower Zambezi River was filled in 1975. With a surface area of about 2 600 km^2 it became one of the fifth largest reservoirs in Africa. The limnology and selected aspects of the early fisheries were reasonably well studied under the FAO project GCP/MOZ/006/SWE on Mozambique – Fisheries Assistance to the FAO Nordic Programme (1985 to 1989) and summarized by Gliwicz (1984), Bernacsek and Lopes (1984) and Vostradovsky (1984).

The possibility of introducing *kapenta* into Lake Kariba was considered as early as 1956 although the first experimental attempts began in February 1962 following a recommendation from Jackson (1961), who predicted that the pelagic habitat of Lake Kariba would remain uncolonized because the fish species in the Zambezi River had evolved in a riverine habitat and would therefore only inhabit the shallow littoral zones of the lake. Under the supervision of Dr George Coulter, senior fisheries officer in the then Northern Rhodesia, a small brood of *Limnothrissa* fry were caught in February 1963, transferred to polythene bags and transported by road to Abercorn Airport (Mbala), by air to Kariba Airport and by road to the lake shore. Only a small proportion (14 individuals) survived the journey. These were placed in a keep net in the lake, where they lived and grew for more than three months until a storm wrecked the net and the fry escaped into the lake. Albeit accidentally, the first introduction of sardines to Lake Kariba, had taken place. Further experiments on the catching, handling, keeping and transportation of the sardines were also undertaken and a trial flight involving 12 000 sardine fry was made to Sinazongwe in December 1966. About

FIGURE 39
Mean monthly lake levels in Lake Kariba from 1962 to 2016



50 percent of the fry survived. Between July and November 1967, approximately 250 000 sardine fry were released into Lake Kariba from Lake Tanganyika. This involved 26 airlifts. In August and September 1968, a second series of flights took place and over 120 000 sardines were released.

The introduction was a success (Bell-Cross and Bell-Cross 1971; Junor and Begg 1971) and, although the then Rhodesian government was not informed about the introduction, the researchers at the Lake Kariba Fisheries Institute (LKFRI), some 200 km from the site of introduction, observed widespread presence of the species by 1969. Commercial offshore *kapenta* fishing began in July 1973 in Zimbabwe with a single purse seiner, but effort grew rapidly (Figure 40) and from 1976 this fishery changed to using lift nets from pontoons at night with light attraction (Plate 14), which considerably increased the catch rates. From 1978 the fishery started to expand along the Zimbabwean shoreline to six different bases and in 1981, after the termination of the civil war in Zimbabwe, the fishery started in Zambia.

The capital-intensive *kapenta* fishery susequently developed into a million-dollar industry, with between 20 000 tonnes and 30 000 tonnes landed annually, vastly outstripping the economic value of the inshore fishery and with theoretical potential for further expansion (Anon., 1992; Anon., 1996; Machena, Kolding and Sanyanga, 1993; Marshall, 1992, 1993; Kolding, 1994). The *kapenta* fishery alone, through its profitability, is according to Bourdillon, Cheater and Murphee (1985) directly responsible for most of the infrastructural development that has occurred on the Zimbabwean shoreline. Cheater (1985) gives a detailed account of the development of this fishery in Zimbabwe until the mid-1980s. From the early 1990s no new licenses were issued in Zimbabwe and fishing effort seemed to stabilize in Zambia around this time too (Figure 40), with a corresponding stabilization in catch rates of 100 kg to 150 kg per rig, per night in both countries. The standing biomass was estimated to range between 16 000 and 22 000 tonnes in 1995 (Ngalande, 1995) and this had not changed significantly in 2014 when a new acoustic survey estimated a standing stock of 16 277 ± 9 730 tonnes for the whole lake (Mafuca, 2014).

PLATE 16

Kapenta (Limnothrissa miodon) from Lake Kariba is sun-dried in two to three days and is ready for sale

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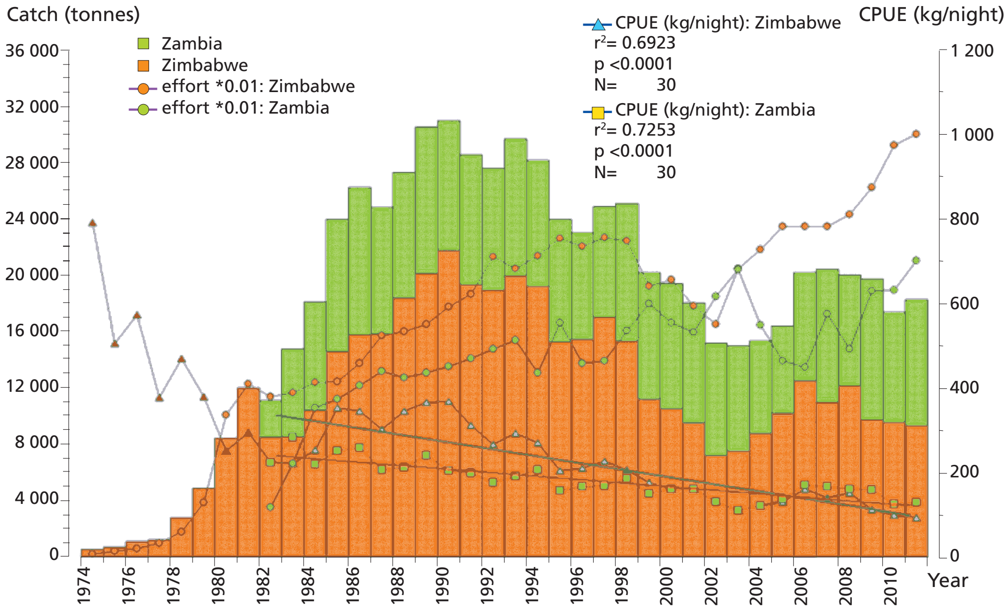
FIGURE 40

Total catch, effort (boat nights) and CPUE of *kapenta* in Lake Kariba from 1974 to 2011 for Zimbabwe and Zambia, respectively



Kapenta was not introduced to the Cahora Bassa reservoir in Mozambique but established itself there via the Zambezi River from Lake Kariba. It was first reported from Cahora Bassa in 1980 (Mikkola, 1982) and was abundant in the lake by 1982 (Gliwicz, 1984). Lindem (1983) surveyed the stock acoustically in 1983 and estimated the biomass to be 5 000 tonnes. Ten years later, by 1994, the biomass had grown to 22 000 tonnes (Ngalande and Mhlanga, 1994), which was as high as that of Lake Kariba in the same period, and it stayed more or less on that level until 2005 (Mhlanga *et al*., 2005). Presently, the standing stock has reduced to around 10 000 tonnes (Mafuca and Bettencourt, 2015). Some aspects of the ecology, growth, feeding and breeding in Cahora Bassa are given by Gliwicz (1984, 1986) and Vostradovsky (1984).

The fishery was started in 1993 by *kapenta* fishers from Zimbabwe settling in Mozambique and the number of registered rigs grew to 236 in 2016. There has been a slight decline in CPUE (catch per rig, per year, Figure 41), but the overall productivity fluctuates and is highly correlated with water inflow, as observed in Lake Kariba (Marshall, 1982; Karenge and Kolding, 1995b).

There is a strong seasonal variation in the catch rates of *kapenta* in both Lake Kariba and Cahora Bassa, with typically high catch rates during August to October, and low catch rates during December to February (Figure 42), which is related to lunar phases, hydrographic conditions and the mixing regime of the lakes (Cochrane, 1978; Gliwicz, 1986; Marshall, 1982; Karenge and Kolding, 1995b).

FIGURE 41
Total catch (bars, tonnes), effort (number of rigs) and catch per unit effort (tonnes*rig^{-1}) of *kapenta* in Cahora Bassa from 1993 to 2016

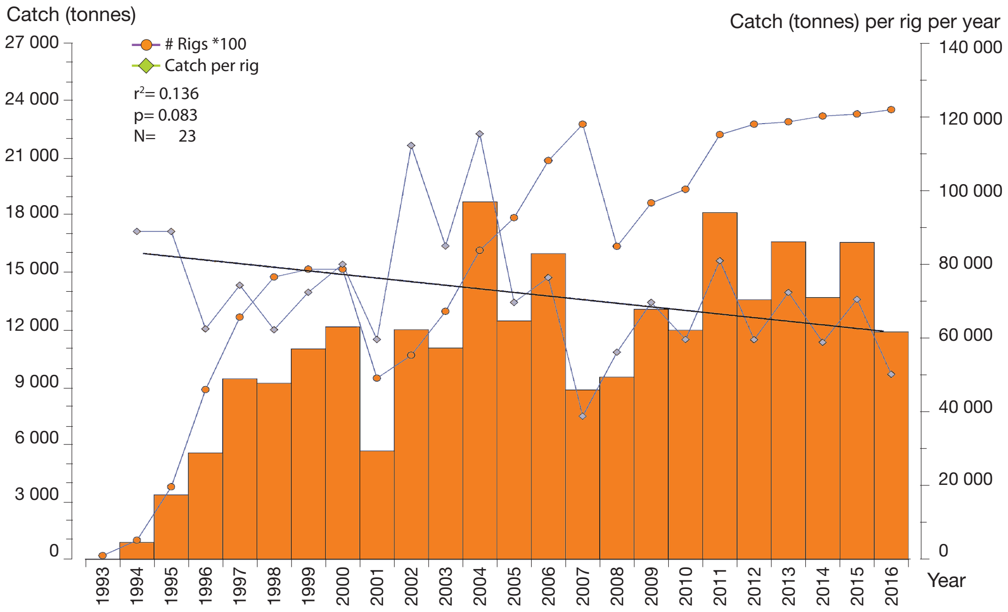
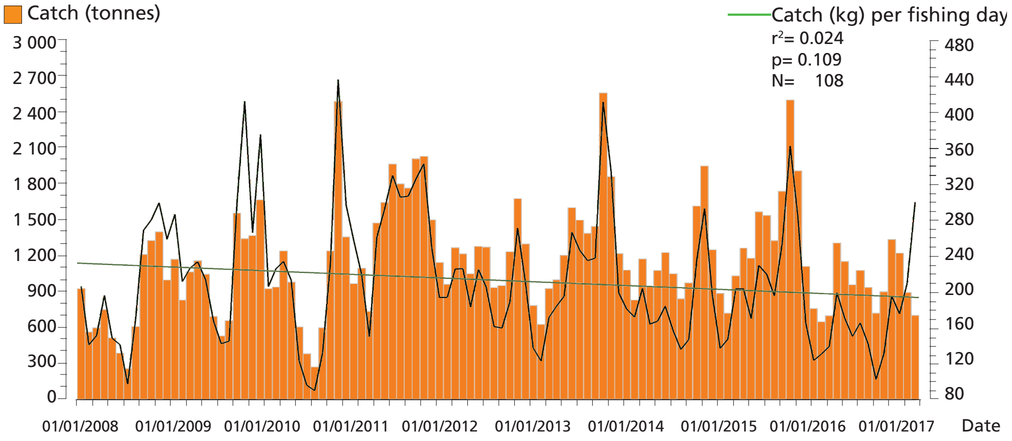


FIGURE 42
Total monthly catch, and CPUE (kg per fishing day) of *kapenta* in Cahora Bassa from 2008 to 2017



6. Value chains for small pelagic fish in Africa

6.1 THE REGIONAL IMPORTANCE OF DRIED SMALL PELAGIC FISH

According to preliminary FAO data for 2016, fish consumption per capita averaged 9.9 kg in Africa and about 8.6 kg in Sub-Saharan Africa. This compares with an average of over 20 kg at the world level. Within Africa consumption ranged from a maximum of about 14 kg per capita in western Africa to a mere 5 kg in eastern Africa. The lowest fish consumption per capita were recorded in Ethiopia and the highest in Gabon. In addition, to having a lower fish consumption per capita, most of the fish food supply in Africa is made of "lower value" fish[14] such as freshwater species and small pelagic fish. In 2016, freshwater species and small pelagic fish accounted for 76 percent of total fish food supply compared with 54 percent at the world level.

Fish consumption per capita in Africa grew over the last decade but at a slower pace than the world average. This trend is expected to worsen over the coming decade, according to the projections published in the OECD-FAO Agricultural Outlook 2018-2027. By 2027, fish consumption per capita in Africa is expected to decline by 3 percent as population growth should outpace increase in supply. A more substantial decrease is projected for Sub-Saharan Africa. Between the average period of 2015-2017 and 2027, trade is expected to be the main driver for growth in total fish food supply in Africa, with imports growing while exports are set to decline. However, the contribution of trade to total fish food supply (about 40 percent) is not expected to be sufficient to compensate for the growth in population, leading to a decline in fish consumption per capita. In fact, it is the only part of the developing world where fish supply has declined while production continues to increase (Béné, Lawton and Allison, 2010). This is attributed to the region's rapid population growth rates (Delgado *et al*., 2003).

A majority of countries in sub-Saharan Africa have a negative trade balance in terms of quantities of fish, despite the large revenues generated by international fish exports in some sub-Saharan countries. This trade therefore, seems to have failed to compensate for the increasing gap between fish demand and supply at the level of the African continent. When the distinction is made between high-value (large) and low-value (small) fish, there is even greater cause for concern: the study by Delgado *et al*. (2003) projects a 2020 trade balance level in quantity of small fish close to the value of 1973.

Béné, Lawton and Allison (2010) do not substantiate these fears at the macro-economic country level, while they also do not find evidence that the revenues generated from the export of fish and human development correlate, at least at a macro-economic level. They argue that, to cater for Africa's own very important current and potential fish market (Heck *et al*., 2007; WorldFish Center, 2005) policymakers need to refocus on intra-regional trade that is dependent on the activities of millions of people engaged in the production and trade of, in particular, so-called "low-value" fish products across the continent.

The low fish consumption is the result of a number of interconnected factors, including population increasing at a higher rate than food fish supply; limitations in expansion of

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[14] This definition includes fish used in fishmeal and other non-consumption uses (Delgado *et al*., 2003)

fish production because of pressure on capture fisheries resources and a poorly developed aquaculture sector; low income levels; inadequate storage and processing infrastructure; and a lack of the marketing and distribution channels necessary to commercialize fish products beyond the localities where they are captured or farmed. However, it is also important to mention that in Africa, actual values may be higher than indicated by official statistics in view of the under-recorded contribution of subsistence fisheries, some small-scale fisheries and some cross-border trade (FAO, 2018a).

Low consumption levels in sub-Saharan Africa are also attributed to inequitable distribution of fishery products because of poor infrastructure that limits the trade of highly perishable fresh fish. Most of the trade in the region, therefore, is in preserved fish, either dried, salted or smoked. Overfishing is also often mentioned as a limitation, but while individual catch rates by fishers are decreasing, overall catches from the region have increased almost linearly by around half a million metric tonnes per decade over the past 60 years (Welcome and Lymer 2012, Figure 10). Another, perhaps more important reason for the apparent low per capita consumption may lie in the increasingly poor recording of actual catches in commercial fisheries, and especially of small pelagic species, as well as non-accounting of subsistence fisheries in lakes, reservoirs, rivers and small waterbodies. For instance, Zimbabwe has around 1 150 small water bodies in which it is highly likely that fisheries are taking place, but these fisheries are largely unknown, much less how much fish is taken from these water bodies (Jennes *et al.*, 2007). This may also account for a distorted view of the actual fish consumption in many regions.

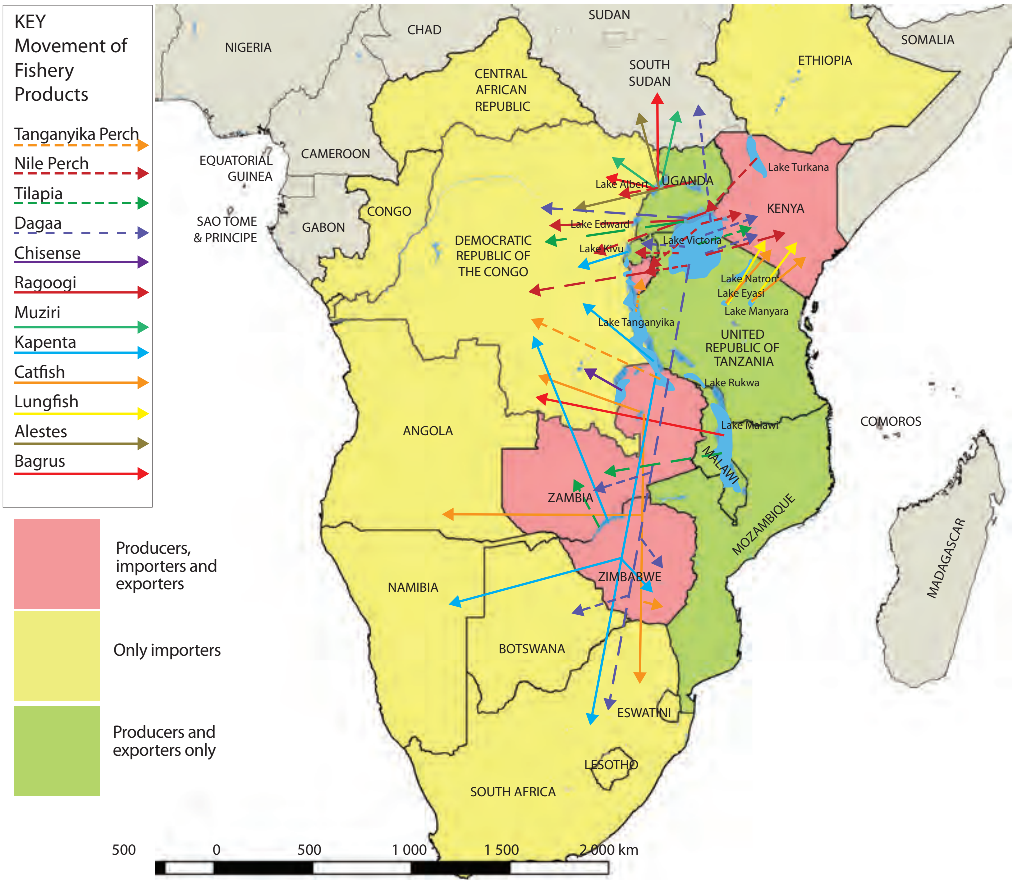
Focusing on the trade of small pelagic fish from large lakes in the region, it becomes clear how important these species are for regional food security (Figure 43) despite the limited and highly scattered information on source, destinations and volumes of traded fish and fish products. The next sections are taken from some of the few studies that have been carried out on the trade of small pelagic fish, focusing on East and southern Africa in general (IOC, 2012) and the *dagaa* trade from Lake Victoria (LVFO, 2016; Medard, 2015).

6.2 REGIONAL TRADE OF SMALL PELAGIC FISH

The most important small pelagic fishes for which some trade information exists include *Rastrineobola argentea* (*dagaa/omena/mukene*), *Stolothrissa tanganicae* and *Limnothrissa moidon* (*kapenta*), *Poecilothrissa mweruensis*, *Mesobola moeruensis* (both named *chisense*), *Neobola bredoi* (*muziri*) and *Brycinus nurse* (*ragoogi*) (Figure 43). The *dagaa* fishery contributes about 60 percent to the catch from Lake Victoria; the *kapenta* fishery contributes 60 percent of the catch from Lake Tanganyika and around 80 percent of the catches in Lake Kariba and Cahora Bassa; the *chisense* fishery contributes 60 to 70 percent of the catches from Lake Mweru Luapula and 10 percent from the Lake Bangweulu complex; and the *muziri* and *ragoogi* fisheries contribute over 80 percent to the catches from Lake Albert. Originally, the major export market destination for small pelagic fish was the animal feeds industry, in particular the chicken feed industry. However, regional trade for human consumption intensified with growing demand as the preserved products are relatively cheap, have a long shelf life, and are resistant to decomposition. There is also an increased awareness of the nutritional value of small fishes. Cross-border trade in small pelagic fishes is generally informal – contributing to the invisibility of the trade in national statistics. Numbers of traders and big consignments have increased rapidly over the past decades showing the need to record and regulate this trade (IOC, 2012).

FIGURE 43

Map showing regional trade movement of freshwater fishery products within East and southern Africa



Note in particular the trade routes of *dagaa (Rastrineobola argentea)* from Lake Victoria; *chisense (Microthrissa moeruensis)* from Lake Mweru – this species is also traded to Zambian and Congolese cities, the Copperbelt and Lusaka (van Zwieten, pers. obs.); *kapenta* from Lake Tanganyika *(Limnothrissa miodon; Stolothrissa tanganicae)* and Lake Kariba *(Limnothrissa miodon)*; *muziri (Neobola bredoi)* and *ragoogi (Brycinus nurse)* from Lake Albert and Edward.

Source: modified from IOC, 2012.

6.2.1 *Lakes Tanganyika, Kariba, Itezi-thezi, Cahora-Bassa: kapenta*

Canned *kapenta* products and frozen *kapenta* value packs from Lake Tanganyika target both local and export markets. Fresh *kapenta* is also traded around the lakes where it is produced. The sun-dried, smoked and salted products are sold locally and in neighbouring countries. Tanzania is a major exporter, whereas the other countries sharing Lake Tanganyika, namely Burundi, Democratic Republic of the Congo and Zambia are net importers. Zambia exports Lake Kariba *kapenta* to Zimbabwe, Botswana, Namibia and South Africa. Zambia also exports *kapenta* from Lake Tanganyika to Rwanda, while it imports *kapenta* from Lake Cahora Bassa in Mozambique.

Kapenta is relatively easily caught in commercial quantities using light attraction at night (see section on fishing methods), and the only processing required is a slight brining followed by sun drying for one to two days. Produced in this way it makes a cheap, tasty, highly protein and nutrition rich commodity which lasts for several months when it is stored in the dry form. *Kapenta* is widely consumed within the region, particularly among low-income earners and can be found in major markets in cities and towns, as well as in many smaller local markets. Unfortunately, in some areas, the name *kapenta* also carries negative connotations of "poor man's food". The local name *kapenta* originates from the Zambian coppermines where the dried fish imported from Lake Tanganyika first gained popularity in the 1960s. "*Kapenta milomo*" ("she who paints her lips", Epstein, 1968; Overå, 2003), was the colloquial Bemba term for women who visited local pubs and taverns because, at that time, "decent" women would never use makeup. Because *kapenta* is so easy to prepare, "an idle housewife can leave the beerhall just a few minutes before her husband comes home and still have a plate of tasty fish ready for his meal" – so it was said. This is how the fish name originated, but sadly it may have contributed to the low status among some consumers, despite its excellent taste and high nutritional value.

6.2.2 Lake Albert: muziri, ragoogi

Lake Albert's *Neobola bredoi* (*muziri*) resembles *dagaa* and is found mostly in East Africa. *Muziri* is a relatively new commercial fishery that emerged in Lake Albert around 2006. Initially, it was traded together with *dagaa* and mainly sold to the animal feeds industry. *Muziri* is processed through sun drying, salting and deep-frying. *Muziri* markets include: Democratic Republic of the Congo and South Sudan, which take the bulk of the deep-fried and sun-dried products. Domestic consumers and the animal feeds industry mainly take sun-dried products. Likewise, the *ragoogi* (*Brycinus nurse*) fishery on Lake Albert is driving an emerging commercial fishery. The post-harvest sector of *ragoogi* forms a major source of employement for women. *Ragoogi* is processed by sun drying, salting and deep-frying. Efforts are being made to improve fish handling and processing practices.

6.2.3 Lake Mweru: chisense

Trade in sun-dried *chisense* (*Microthrissa moeruensis*) products from Lake Mweru-Luapula, Zambia, is conducted by local and cross-border wholesalers who supply local markets in Zambia and regional markets focused on Democratic Republic of the Congo. Zambia exports *chisense* from Lake Mweru-Luapula to Democratic Republic of the Congo and other markets along the railway lines in Lusaka, the Copperbelt and Central Province. The fresh fish trade is dominated by men while trade in dried products is controlled by women (van Zwieten *et al*., 1996; Gordon, 2006). The main product is sun-dried *chisense*: the fish is dried on sandy beaches and mud slabs. The export trade in *chisense* has spurred improvements in fish handling and processing because of market demand for better quality products.

6.2.4 Lake Victoria: regional and national trade of dagaa

The main product from *dagaa* is sun-dried, but salted, smoked, deep-fried and milled/powdered *dagaa* is also traded. The latter is particularly important as an addition to baby food and is used in hospitals as a source of protein (A. Roem, Nutreco Africa, pers. comm.). In the region, only about 30 percent of the *dagaa* is utilized as human food, the remainder is transported to industrial feed mills and used as raw material to produce feeds for poultry, fish and livestock (LVFO, 2016; Isaacs, 2016). Sun-dried *dagaa* is exported to Kenya, Democratic Republic of the Congo, Malawi, Mozambique, South Sudan, Rwanda, Zambia, Zimbabwe and South Africa, and in recent years traded via Kenya to Malaysia (Medard, 2015). Tanzania is the biggest exporter of *dagaa* in the region, followed by Uganda. The *dagaa* from Lake Victoria has a specialized wholesale market, Kirumba Market, in Mwanza, Tanzania, the biggest *dagaa* wholesale market in East and southern Africa. Between 2009 to 2011, around 60 percent of the *dagaa* from

PLATE 17
Sun-dried dagaa (Rastrineobola argentea) being loaded and readied for regional trade

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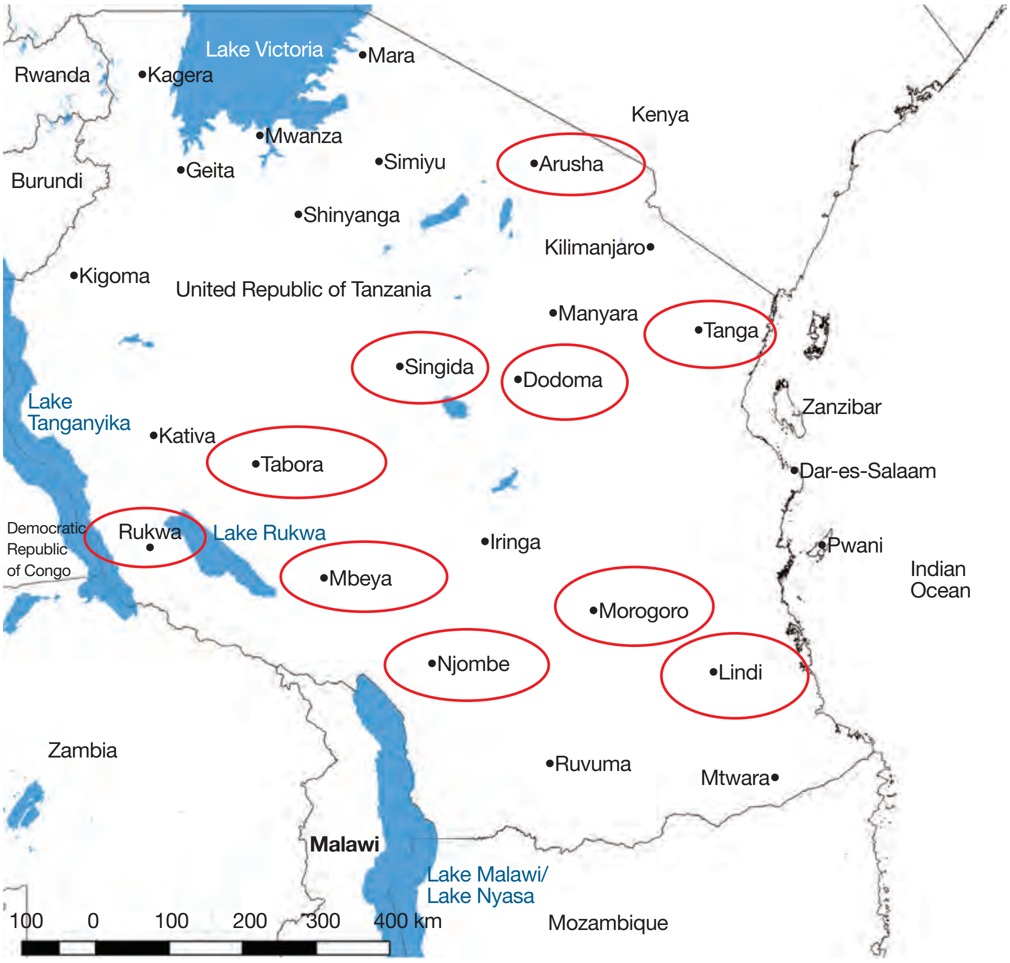
Kirumba Market went to animal feed factories in Kenya. The remaining 40 percent was used for human consumption, traded to the Democratic Republic of the Congo (30 percent), followed by Rwanda (20 percent), Burundi (10 percent) and Zambia (5 percent), while around 35 percent of the *dagaa* traded remains in Tanzania (Nayaro, Mbilinyi and Medard, 2004), both for animal fodder and for human consumption. Information from Kirumba Market shows that *dagaa* is destined for all regions in Tanzania but mainly Dar-es-Salaam (39 percent), Morogoro (16 percent) and Mbeya (11 percent) (Medard, 2015; Figure 44; Table 10).

TABLE 10
Official records of *dagaa* (tonnes) exported from Kirumba Market to the main domestic destinations, 2009 to 2011

Year	2009		2010		2011	
Region	*tonnes*	*percent*	*tonnes*	*percent*	*tonnes*	*percent*
Dar es Salaam	17 090	40.8	15 735	37.6	15 124	37.5
Morogoro	6 183	14.8	5 868	14.0	7 220	17.9
Mbeya	4 171	9.9	4 522	10.8	4 950	12.2
Mtwara & Lindi	2 046	4.9	4 014	9.5	3 205	7.9
Dodoma	1 964	4.6	2 513	6.0	2 025	5.0
Singida	2 129	5.0	1 719	4.1	1 532	3.8
Tabora	2 185	5.2	1 393	3.3	1 587	3.9
Ruvuma	1 895	4.5	1 048	2.5	1 664	4.1
Tanga	1 887	4.5	1 615	3.8	1 462	3.6
Iringa	1 282	3.0	1 566	3.7	778	1.9
Rukwa	1 032	2.5	1 839	4.3	698	1.7
Total	41 864	100	41 832	100	40 245	100

Source: Taken from Medard, 2015.

FIGURE 44
Main Tanzanian destinations for *dagaa* from Kirumba Market in Mwanza



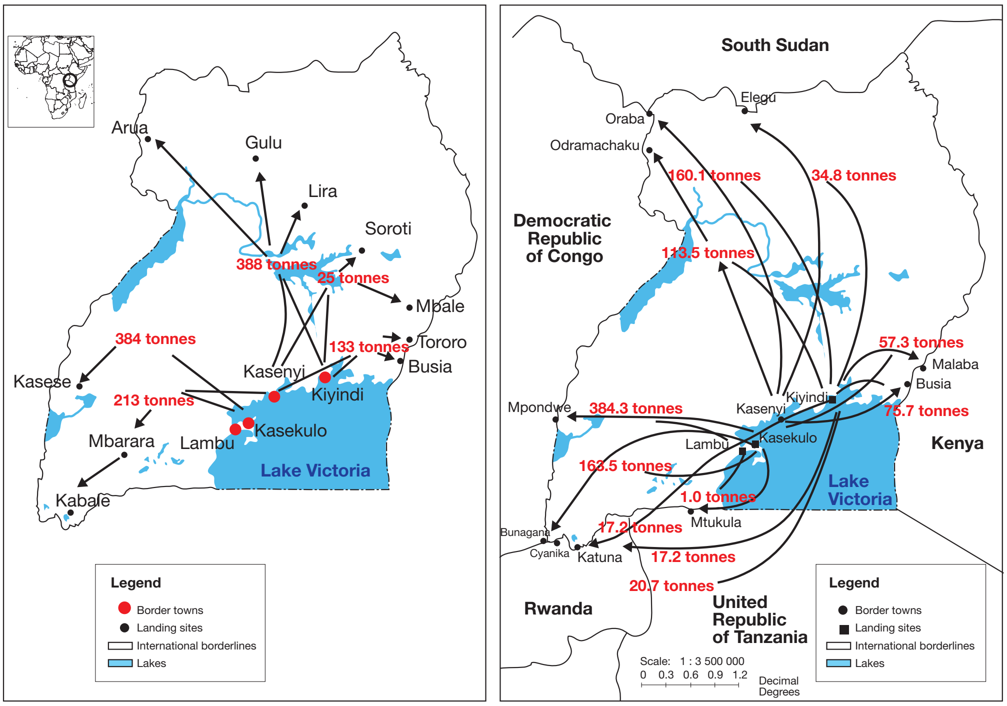
Reported volumes exported from Tanzania rose from 12 449 tonnes to 29 065 tonnes between 2010 and 2011 before falling to 18 196 tonnes in 2015. This was attributed to increasing domestic demand for *dagaa*, especially for industrial feed production. The main *dagaa* export destinations for Uganda between 2010 and 2015 were Democratic Republic of the Congo (15 015 tonnes), Kenya (4 374 tonnes) and South Sudan (4 069 tonnes). Kenya imported *dagaa* from both Uganda and Tanzania, the volumes rising from 6 199 to 7 809 tonnes between 2010 and 2011 and then declining to 4 228 tonnes in 2015.

Two-thirds of the traders in *dagaa* operate lake-wide within their own countries, one third process their merchandise and sell locally, while only around 8 to 9 percent of the traders operate regionally (Table 11).

Almost 90 percent of the traders deal in sun-dried *dagaa*, while a small proportion of *dagaa* is salted and then sun-dried, or deep-fried. Individual traders handle between 600 kg*month^{-1} to 1 700 kg*month^{-1}, depending on the season, leading to a seasonally fluctuating net revenue of between USD 3 000 to USD 8 000. Industrial feed producers produce poultry feed, fish feed and other animal feeds, pharmaceuticals and food supplements and sell at both domestic and regional markets. The main challenges in the *dagaa* trade are insufficient drying, contamination by sand and dust, losses during storage due to insect and mite infestations, and presence of infectious microbiological contaminants such as *Salmonella typhii*, *Escherichia coli*, and *Shigella*. Regional trade suffers from unclear quality control policies, tax and non-tax barriers to regional markets for feeds, and border entry restrictions. Supermarkets sell *dagaa* in various quantity packs, ranging from 200 grams to 1 kg, valued on average between USD 4 to USD 4.5 per kg. Supermarkets have difficulty controlling quality when *dagaa* is delivered ready-packed. Often labelled weights do not match actual product weight, and product quality is often low due to insufficient drying and microbiological contamination of *E. coli*, *Shigella* and *Ligula intestinalis* (LVFO, 2016).

FIGURE 45

Map showing regional (right) and national trade (left) routes of *dagaa* from the Ugandan part of Lake Victoria and known average annual tonnage for 2010 to 2015 for the various routes



Source: LVFO, 2016.

TABLE 11

Categories of *dagaa* traders and processed *dagaa* products traded

		Uganda	Kenya	Tanzania
Categories of *dagaa* traders	Fisher/processor/trader		7.9%	4.5%
	Processor/trader		60.5%	9.1%
	Traders who sold within the country	87.8%	31.6%	68.2%
	Traders who sold outside the country	12.2%		4.5%
	Others			13.6%
Processed *dagaa* products traders traded in most	Sun-dried	93.9%	100.0%	72.7%
	Salted and sun-dried	6.1%		
	Deep-fried			27.3%

Source: LVFO, 2016.

7. Governance and management implications

7.1 Catches of small pelagic fisheries are increasing in many African lakes

Notwithstanding the fact that the reported African inland capture fisheries have been steadily rising at about 3.7 percent per year (Figure 10), mainly due to catches of small pelagic fish, there is a generally pessimistic view of the future of inland fisheries because of the numerous threats to aquatic ecosystems posed by human activities (Welcomme and Lymer, 2012). This view that “inland fisheries are doomed” is supported by many individual studies and reports from all continents, including Africa (Allan *et al.*, 2005; Irvine, Etiegni and Weyl, 2018). Catches are perceived to be falling[15], species disappearing and many of the symptoms of chronic overfishing at the level of individual species or whole communities are being reported (Allan *et al.*, 2005; Welcomme *et al.*, 2010). Unfortunately, such perceptions generally cause a sense of hopelessness that leads to the neglect of the sector and encourages policymakers to focus on other, more optimistic, sectors for growth and development (Welcomme and Lymer, 2012).

As a result, the important and beneficial contribution of wild-caught inland fish to food security has been largely ignored and undervalued (Mills *et al.*, 2011). Priorities for food studies have switched to other sectors, and aquaculture is being promoted as the solution to sustain production in the face of the perceived inevitable decline and eventual disappearance of freshwater fish stocks (Welcomme and Lymer, 2012). This view is prominent in many African countries and together with a general lack of awareness of the importance of fish for human nutrition (HLPE, 2014), has led to a lack of means assigned to inland fisheries, a lack of informed approaches towards managing many aspects of the resources and their supporting habitats, as well as an apparent failure to include the sector in national and regional development policies (Welcomme and Lymer, 2012; FAO, 2012; HLPE, 2014).

However, as highlighted throughout this report, there are no evidence-based examples of small freshwater pelagic fish being overexploited in any system, and they are the main reason for the steadily increased total catches of African inland fisheries. In fact, their general very high biological turnover, with on average a reproduction of the standing biomass of around five times per year (Table 1), makes them extremely high yielding and very resilient to exploitation (Jul-Larsen *et al.*, 2003)

7.2 Fishery management in many African lakes is based on single stock management models that cannot address multispecies systems

While fishing and farming, and sometimes also fishing and pastoralism, are often integrated livelihood activities all over Africa, the governance, policies and management of these activities are mostly segregated (Kolding *et al.*, 2016a). Inland fisheries are often located under the same administrative umbrella as wildlife, tourism or game departments in (land-locked) African countries, or are small, isolated departments under agriculture or larger marine ministries. Inland fisheries are therefore considered more of an intermittent hunting activity than a stable supplier of food. The reason for

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[15] Note that the statement “catches are decreasing” rarely spells out whether this state of affairs concerns individual catches or catch rates (which will always decrease with increasing effort), or total catches (which in most cases are not decreasing, as this report shows). For the most part, statements on decreasing catches are based on individual catches (same as catch rates, CPUE).

this political separation is difficult to identify, but it appears to be partly historical and mainly inherited from pre-independence administrations (Malasha, 2003). It has also becoming increasingly evident that the management measures implemented in African freshwater fisheries are not adequately based on empirical knowledge (Jul-Larsen *et al*., 1997; Jul-Larsen *et al*., 2003).

Much of the current fisheries legislation in anglophone Africa can be traced back to pre-independence era and British game legislation, where hunting and angling were considered a sport, with the important principle of "giving the game a fair chance" (Malasha, 2003). This attitude has important implications for fishing methods that are thought of as "herding", "indiscriminate" and "unselective" and considered particularly unsporting when immature individuals are targeted. Thus, fisheries management in African freshwater lakes has from the beginning, and to the present day, primarily been about establishing operational rules for the fisheries-based preconceptions derived from sports fisheries and game hunting, rather than based on observed local practices[16]. There has been historic criticism of this management approach. C.F. Hickling, a fisheries biologist and adviser to the Colonial Office in London in 1953, wrote a memorandum in which he considered the effectiveness of most of the restrictions and prohibitions that had been in place in the colonies for almost 90 years as doubtful and unnecessary (Hickling, 1953). He pointed out that licensing of gear or nets requires a large and expensive enforcement staff. Other measures, such as closed seasons, mesh size regulation and fish size regulations were also questioned as general management instruments, due to their negative biological effects. Despite reservations towards most of the applied regulations, they have continued to form the basis for the management of freshwater fisheries in sub-Saharan Africa – even though regulations vary between countries. Furthermore, in 1957, during the last decade of the colonial period, a new and ground-breaking fisheries theory was developed in the United Kingdom, which rapidly became the doctrine of modern, rational fisheries management. The theory was based on single species mathematical yield-per-recruit models (Beverton and Holt, 1957), which stipulated minimum size limits on exploited species to maximize yields. This theory was soon exported to the colonial fishery administrations (Beverton, 1959) and underpins the widespread mesh size regulations and the condemnation of catching small and immature fish (Kolding and van Zwieten, 2011).

Lake Victoria is a case in point. Nile perch was introduced to Lake Victoria in the mid-1950s as part of an effort to improve sport fishing on the one hand, and bolster fisheries on the other (Pringle, 2005). Almost immediately after the Nile perch boom, in the late 1980s, and subsequent decrease in total catches and catch rates (Figures 19–21) the first concerns about overfishing were expressed and these have not subsided, despite stable or increasing total catches of most species. The Nile perch stock is generally considered overexploited (Kolding *et al*., 2008) and continuously heralded as being in danger of collapse; such announcements regularly making headlines in the major newspapers of the riparian countries. However, the fishery of Lake Victoria is one of the best monitored inland fisheries in Africa and the figures for current catches and standing biomass presented in this report (Chapter 5.1) indicate the considerable bias towards Nile Perch in the management discourse on Lake Victoria. Size, mesh size or hook size limits are the dominant management measure on which fisheries policies focus, largely directed at protecting the industrial export of large Nile perch, concomitant with a near neglect of the vital role that small fish, including juvenile Nile perch, play in the riparian communities, as well as for food security and nutrition in the wider East African region through exports to neighboring countries. Lake Victoria

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[16] This seems to have been much less the case in francophone Africa. See, for example, Carmouze, Durand and Lévêque (1983), Lévêque (1997) and associated literature that shows greater sensibility towards the fluctuating nature and successions within fish communities due to climatic variation, and the adaptive responses of fishers to such variation.

is in many ways a demonstration of how conventional fisheries management based on single species models and untested steady-state assumptions (Kolding *et al.*, 2008; Mosepele 2014; van Zwieten *et al.*, 2016) is unable to address multispecies fishing. It has resulted in a largely futile conflicting objectives between managers and fishers requiring an enormous, and expensive, enforcement effort if it is to be resolved under the present conditions. The narrative of overfishing because of "catching the young ones" is ubiquitous in most African lakes and the proposed measures to counteract overfishing invariably are textbook examples of the size prescriptions derived from Beverton and Holt's theory.

Traditionally, however, African fishers have always targeted all sizes of fish. This is because there is no preference for large size fish, as in Europe (Tsikliras and Polymeros, 2014). The overall outcome, and in particular under the "fishing down" scenario (Section 2.4), is increased conflicts and distrust between managers and fishers (Misund, Kolding and Fréon, 2002) and an increasing perception in the wider society that the traditional fishing pattern is destructive: fishers are seen as irresponsible law-breakers instead of good citizens providing essential, nutritious food to supplement the starch-based staples from the fields.

If African fishers had followed the current regulations and only fished selectively on the legal large fish sizes, there would inevitably be a concomitant decrease in individual catch rates and in the average size of fish caught. It is therefore a great paradox in fisheries governance, that the predictable result of fishing within legal requirements (a decrease in mean size and abundance) is simultaneously used as a diagnostic of unsustainability, irresponsibility and depletion (Kolding, Béné and Bavinck, 2014).

7.3 Co-management and beach management units

Instead of recognizing that the legislative framework needs informed revision, the suggested solution to the omnipresent "fishing down" problem and ensuing increase in illegal fishing methods (see Section 2.4) is the optimistic idea that co-management through understanding of the link between fishing effort and production, will turn fishers into law-abiding and responsible citizens. Fisheries co-management is in principle an arrangement in which responsibilities and obligations for sustainable fisheries management are negotiated, agreed, shared and delegated between government, fishers and other interest groups and stakeholders (Pomeroy and Rivera-Guieb, 2006).

The primary vehicle for co-management and co-responsibility in many African lakes is the Beach Management Unit (BMU) – local fisheries management bodies. Although co-management and BMUs have been, and still are implemented in many African fisheries, we will here use Lake Victoria as a case study because this is one of the best documented cases. In Lake Victoria, BMUs were first introduced from around 2000, under the Lake Victoria Fisheries Research Project (LVFRP) (Geheb, 2000; Medard, 2002; Kolding *et al.*, 2014) and Operational Guidelines were developed (Ogwang, Medard and Ikwaput-Nyeko, 2004) which have later been copied and used elsewhere in the region (e.g. Duvail *et al.*, 2016). BMUs are incorporated into the village government and are a sub-committee under the village committee for surveillance and security (Medard, 2015). The BMU has to prepare a "surveillance programme" and has a jurisdiction which typically corresponds to the area that is understood to be the village's land and its waters.

From the government's perspective, the primary duties of the BMUs are to take over the work of the fisheries officers, to curb illegal fishing in the fishing communities by enforcing the National Fisheries Act and its various supplements. BMUs are expected to generate lists providing details about all the fishers on the landing site: their boats, fishing licenses and fishing gear. Unlicensed fishers are supposed to get their licenses, while prohibited gears are supposed to be surrendered to the relevant authorities. The BMU is expected to maintain a daily record that summarizes "all illegal activities".

At the end of the month, records are to be submitted to the ward extension fisheries staff, who summarize the reports of all BMUs in their wards, and pass the report on to the district fisheries officer, and so on up the chain of command. Immigrant fishers and non-citizens are not be allowed to be "members" of a BMU. The BMU officers must be resident on a beach or landing site and shall be "ardent conservators of fishery resources" and should be able to work on a voluntary basis, be honest and truthful (Medard, 2015).

Nearly two decades after their initial introduction to Lake Victoria, the ideas behind BMUs and the accumulated experiences are still both remarkable and confusing (Kateka, 2010; Medard, 2015; Duvail *et al*., 2016). A central tenet of any successful co-management regime is the devolution and sharing of decision-making. However, a simple decentralization (or rather passing down) of national legislative tools from fisheries officers to fishing communities does not represent adequate sharing of decision-making processes. Many fisheries co-management arrangements in Africa, Lake Victoria included, are called "consultative", which means that mechanisms exist for government to consult with fishers. However, consultations around decision-making generally do not include consultations around problem definitions, goal setting and defining regulations: BMUs and other fishery co-management organizations are often relegated to executing management measures. The persistent power inequality and subsequent failure is also the general experience accumulated so far. According to Medard (2015) the major problems that face BMUs in Lake Victoria include reliance on donor project funds, lack of power transfer from the state and involvement in corruption.

BMUs without significant transformation, resources and capacity to plan and run local activities will continue to have limited power or incentives to effectively counteract activities which circumvent government regulations. In reality, BMUs have often only resulted in moving the management conflicts closer to the communities, which has exacerbated the likelihood of conflicts. In Lake Victoria, some BMU members have been injured, while others have lost their lives without compensation, while faithfully combating fishing illegalities (Medard, 2015). Similar incidents of violence have been reported from lower Rufiji (Duvail *et al*., 2016). This has lead to the majority of BMU members protecting their personal interests and the interests of their community members – to fish and use any gear – if they receive fish for food and money. BMU members also link with officials to maintain their position and often become entangled in corrupt networks (Medard, 2015; Nunan *et al*., 2018).

While the national or regional management institutions see BMUs primarily as their new implementation tools for centrally decided harmonized regulations, the fishers see them as a forum for solving local problems and conflicts, and particularly as instruments for reducing conflicts, theft, securing access to shared fishing grounds, fair and transparent price and enumeration systems, access to markets and government financing and lending schemes, and, not least, the curbing of corruption (Medard, 2010, 2015). The priorities of the communities are to solve their day to day problems including poverty, livelihoods and health-related issues and not just to address control measures that have been decided in a top–down fashion, which they do not necessarily believe in or agree with (Kateka, 2010).

7.4 The need for reassessment of assumptions

In most African inland fisheries (Nielsen and Hara, 2003; Nielsen *et al*., 2004), the ongoing conflicts between the harmonized gazetted regulations on fishing gears and legal fish sizes, and fishers' non-compliance have until now not been resolved by the introduction of co-management. On the contrary, the use of illegal fishing methods such as monofilament gill nets, beach seines, undersized mesh nets, mosquito nets and fish driving (*Katuli* or *Kutumpula*) are generally increasing. These methods are efficient and widely accepted by fishers (Medard and Ngupula, 2007; Okware, 2009;

Kateka, 2010; Kolding *et al.*, 2016a) and the implied negative effects causing their prohibition have never been empirically documented (Misund, Kolding and Fréon, 2002; Kolding and van Zwieten, 2014).

The result, however, of the persistent resistance among the fishers to curb illegal activities, combined with increased broadcast by the media of fears of imminent stock collapses, is increasing frustration among the managers. In Lake Victoria, the ensuing demands for increased government enforcement, and even military interventions (Uganda), are a strong indication of the deep void that still exists between the top and the bottom in the envisaged co-management structure. The result is that the mutual trust and respect, on which co-management hinges, deteriorates and ultimately breaks-up the arrangement.

So far the co-management processes are still a centrally controlled exercise where local communities are not involved in (co)determining the objectives of the fishery but are essentially expected to implement the existing regulations by self-policing (Abila *et al.*, 2000; Geheb, 2000; Medard and Geheb, 2000; Duvail *et al.*, 2016). It appears that the underlying assumptions for implementing co-management, i.e. a mutual common comprehension of problems, goals and measures, may not have been properly tested from the outset. According to Kateka (2010), the state has never tried to understand why illegal fishing is protected instead of being fought at community level. Instead, management has continued to be formulated at the national level and is sometimes heavily influenced by the high value of exports, the international development agenda and the global management discourses (Kolding and van Zwieten, 2011).

The biggest paradox, however, is that the "fishing down" process (see Section 2.4) with an increasingly diversified spread of the fishing pressure across the whole fishing community – mainly by the increasing use of illegal gears targeting small fish – is actually the best way to achieve the overall goal of maximizing yields (MSY) while maintaining the structure and functions of the ecosystems as required by the EAF (Kolding *et al.*, 2015b, 2015c). Together, this calls for a re-evaluation of the current legislation and a need for a paradigm shift in management (Mosepele, 2014; Kolding *et al.*, 2015c). However, the political and governance division between fishing as a hunting activity in the wild and farming as a domestic food supplier may not only prevent such changes, but also helps to explain the negative perceptions and recurrent management problems that African inland fisheries suffer from.

Ironically, there is now increasing evidence that the traditional African balanced fishing pattern focusing predominantly on small fish is much more ecologically sustainable and provides more food than predicted by the conventional Western fisheries theory (Kolding and van Zwieten, 2011, 2014; Garcia *et al.*, 2012, 2015). Thus, while the environmental and nutritional benefits of harvesting, marketing and consuming small (pelagic) fish are in many ways clear, economic, social and cultural barriers, in combination with legislation that focuses on mainly targeting large, adult fish, has to a significant degree impeded a common understanding and appreciation of the importance of small fish (Table 12). The constraints can be roughly divided into three main categories: harvesting, processing and marketing, and consumption.

7.4.1 Harvesting

As discussed above, the current management paradigm reflected in the legislative capture regulations are based on single species theory with a focus on large fish rather than more holistic multispecies management (Garcia *et al.*, 2012; Kolding and van Zwieten, 2011, 2014). In many lakes this prevents fishers from legally harvesting fish that are small and low down in the food web. While some pelagic fisheries have their own mesh and gear regulations, there are otherwise generally uniform regulations that *de facto* prevent the capture of small fish. A re-evaluation of such regulations is required in the light of an

EAF, taking into account current insights around fishing patterns that harvest whole fish communities.

7.4.2 Processing and marketing

The nutritional value of consuming small (sun-dried) fish whole is generally not recognized, which contributes to the notion that small fish are "low value" or "poor man's food". Such perceptions keep the value and quality of the processed fish low. There is a high market focus on fuelwood- and energy-demanding smoked and chilled/frozen products, and less on the development of high-quality, sun-dried products. The end result is substantial post-harvest losses and deterioration of nutritional content when fish reaches the consumer. Overall, the reduced profitability for fishers and traders becomes a vicious cycle that upholds the poor quality and impedes consumer preference.

7.4.3 Consumption

Seeing fish as food for the poor, consumer attitudes and preference for higher valued, large fish, together with increasing competition from the animal feed market (including aquaculture), limits the drive for policy action to ensure that the most nutritious food reaches the groups that need it the most. Malnutrition (hidden hunger) is one of the biggest health problems in Africa, which could to a large extent be alleviated if political and public awareness around the availability of the important small fish resources was improved.

All these factors require societal transformation. The challenges in transforming the utilization of "low-value" pelagic fish resources in a sustainable direction, where fisheries governance, marketing mechanisms and health policies ensure that these "vitamin fish" are accessible and available for human consumption and prevention of malnutrition, are profoundly social, economic and political in nature.

TABLE 12

Advantages of utilizing small fish, barriers to their sustainable utilization, and societal consequences of not utilizing small fish

	Advantages of utilizing small fish	Barriers and constraints	Societal consequences
Fish harvesting	Higher productivity (in volume) than larger fish, thus providing more food	Gear and size restrictions in nearly all fisheries. Management legislation focused on highly selective targeting of large fish.	Less food, income and nutritional security.
	Higher sustainable yield of fishery		
	More balanced harvest, leads to less disturbance to the ecosystem		
	Livelihood for large number of small-scale fishers, often in combination with farming	Management legislation sanctions common fishing methods (e.g. light fishing, small mesh sizes).	Conflicts between managers and fishers as targeting small fish is often illegal. Loss of income.
Processing and marketing	Livelihood for large numbers of fish processors and traders, mostly women	Women not included in fisheries governance.	Market value of small fish underestimated.
		Restrictions on small fish reduce processors/ traders' fish supply and income.	Loss of income reduce household food security and reduces fishers' access to credit (from fish traders) to finance fishing inputs.
	Often sun-dried, which requires less energy/fuel for preservation	High market focus on smoked and chilled/frozen products and less development of sun-dried products.	Deforestation for fuelwood. High energy costs and associated gas emissions for refrigeration and cooking.
	Less energy/fuel for preparation		
	Easier transport and marketing	Poor infrastructure (e.g. processing facilities, transportation and market infrastructure and credit facilities).	Post-harvest losses, less nutritional content when fish reaches consumer. Reduced profitability for traders.
Consumption	Higher nutritional value as whole fish is eaten, potentially more frequently served	Misinformed consumer attitudes and preferences. Small fish considered "poor man's food".	Malnutrition and lack of essential micronutrients for cognitive development and healthy immune systems.
	Affordable for poor consumers	Increasing competition from animal feed market (incl. aquaculture). Introduction of undesirable substitutes (meat stock cubes, etc.).	Less accessibility and affordability of proteins and micronutrients for poor consumers.
	Vulnerable groups' diets improve	Distributional challenges within households (age, gender), and between consumer segments (income, rural/urban).	The most nutritious food does not reach the groups that need it the most.
	Well suited as nutrient supplement	Inadequate focus on potential of small fish in health policy (e.g. maternal health and infant care, school feeding programmes).	Loss of potential health benefits and disease prevention among particularly vulnerable groups

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This Paper reviews the status and importance of the freshwater small pelagic fish and fisheries for sustainable and healthy livelihoods in Africa. The lack of recognition of the importance of small pelagic fish for sustenance, livelihoods and public health has prevented the necessary investments for improving the quality, shelf life and public awareness of this vitally important resource. This FAO Technical Paper has been prepared to fill this gap and enable policymakers and development practitioners to design and implement more effective policies, strategies and programmes that will contribute to reducing the food insecurity that currently affects the people of sub-Saharan Africa. The paper examines the biology and biological production of the most important pelagic species in the major lakes and reservoirs, as well as the impacts of environmental and climatic variation on stocks of these species. It discusses the various capture techniques and the potential for improving the fisheries and associated processing and national and regional trade within Africa.

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