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Fish population in Lake Kivu: review of recent advances on management and knowledge

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Abstract
Lake Kivu is one of the great East African great lakes, but has a very poor fish diversity face to the other ones. The introduction of the non-native *Limnothrissa miodon* at the end of the 1950's has led to develop a high fishery and is a benefit for the human population around the lake. Recent exploitation of gas conducts to numerous publications mostly focused on gas exploitation or physical and chemical properties, but publications addressing fish and fisheries in Lake Kivu from 2012 are limited. This document reviews the recent papers dealing on fish population and fishery and highlights the main conclusions to improve fish management in the future.

Keywords: lake kivu, *limnothrissa miodon*, tanganyika sardine, *lamprichthys tanganicanus*, east African great lakes

Introduction

Fish biodiversity in African great lakes has been widely studied, more specifically the mechanisms of speciation and adaptive radiation of endemic cichlid species in Lake Malawi and Lake Victoria region (Verheyen *et al*., 2003; Genner *et al*., 2015; Meier *et al*., 2017) [38, 11, 24]. Lake Victoria and neighboring lakes Edward, George and Kivu have been grouped in a 'superflock' of closely related haplochromine species, counting more than 700 species. The most recent common ancestor of the cichlids from these lakes existed about 4.5 million years ago (Witte *et al*., 2008), and important lineage diversification started 100-200 thousands years ago (Verheyen *et al*., 2003) [38]. Lake Kivu, with less than 30 fish species, including around 15 endemic haplochromines and a few non-native species, has a poor fish fauna compared to the other African great lakes (Snoeks *et al*., 2012) [33].

In 2012, the book '*Lake Kivu, Limnology and biogeochemistry of a tropical great lake*' (Descy *et al*., 2012) [35] has dedicated one chapter to '*Fishes: diversity and fisheries'* (Snoeks *et al*., 2012) [33]. This chapter reviewed the knowledge on fish diversity and fisheries in Lake Kivu, with a special emphasis on the introduced Tanganyika sardine, locally called Isambaza, *Limnothrissa miodon*, because of its importance in the ecosystem functioning and its important contribution for human alimentation. The introduction of the non-native *L. miodon* was analyzed and a review on its biology, its abundance and its contribution in the pelagic fisheries was done at the light of the available literature. The main conclusions were a relatively low fishery yield, amounting ~10,000 t year $^{-1}$ and a possible competition between *L. miodon* and the recently introduced *Lamprichthys tanganicanus* from Lake Tanganyika. A trophic niche overlap between the two species is likely, particularly offshore (Masilya, 2011) [22].

Lake Kivu, as other aquatic systems, faces to global change (Descy *et al*., 2015) [8] and amongst the main anthropogenic impacts, the increase of human population and the beginning of gas exploitation are of importance. Therefore, the lake is part of numerous publications referenced in the Web of Science® (WoS) and mostly focused on gas exploitation or physical and chemical properties (Hirslund, 2012; Borges *et al*., 2014; Vaselli *et al*., 2015) [12, 6, 37]. Conversely, publications addressing fish and fisheries in Lake Kivu from 2012 were mainly "gray" literature (scientific reports, government documents, theses) and articles from non-indexed journals in the WoS. This review aims to synthesize the main available contributions on this topic and the potential emerging threats on fish fauna. This document is divided into five main topics: waste management, fish community and fish ecology, fish consumption, aquaculture and fisheries management in Lake Kivu. The literature research was done using Google scholar and WoS, using key words 'Kivu' and 'fish'.

Waste Management

A few publications focus on waste management, increasing pollution loading being one of the main factors which threaten the survival of millions of people living around Lake Kivu (Majaliwa *et al*., 2012) [1]. Only very few river catchments are unaffected by people and pollution from domestic, industrial and agricultural activities. A global deterioration of the water quality in tributaries has been observed (Bagalwa *et al*., 2013) [5]. Aleke (2016) [4] underlined the urgent need to improve waste management and treatment. Agriculture is the most important sector of the Rwandan economy with a contribution of 47% to the GDP (12% for livestock) and 71% of export revenus (Twagiramungu and Ngendahayo, 2011) [36]. Crop cultivation remains the major farming activity in Lake Kivu Basin, while livestock rearing, fishing and small businesses activities have significantly declined after the war (Adidja *et al*., 2012) [1]. Therefore, use of pesticides increasing in Rwanda for agricultural and also urban uses (for structural pest control), pesticides are detected in tributary rivers and in surface water of the Rwanda lakes. In Lake Kivu, no contamination of the lower water layer (< 20m) was found, indicating that the groundwater that flows into has not yet been highly polluted (Houbraken *et al*., 2017) [13].

Fish community and fish ecology

Most of current knowledge on Lake Kivu fish diversity and fisheries are summarized in Snoeks *et al*. (2012) [33], who reported 15 haplochromine species in Lake Kivu. From a standardized gillnet survey of fish population in the area of Kibuye in 2012, Paris *et al*. (2013) [29] determined 9 non-haplochromine species and 32 different haplochromine species both in demersal and pelagic habitats. Among them, 9 were already identified by Snoeks *et al*. (2012) [33], and 6 were not captured. More surprisingly, 23 distinct other male phenotypes were observed and were likely to belong to other undescribed species (Tab. 1). However, the diversity in the cichlid family cannot be easily determined based on morphological traits and modern genetic methods should be applied to confirm the various different species identified (Paris *et al*., 2013) [29].

In accordance with previous studies (Snoeks *et al*., 2012) [33], Paris *et al*. (2013) [29] also observed the high prevalence of *L.miodon* in the pelagic zone. After its introduction in Lake Kivu, *L. miodon* has been rapidly adapted to its new environment and is now the most abundant species in the Lake. Compared to previous hydroacoustic surveys, results from 2012 (Guillard *et al*., 2012) [33] and 2014 surveys showed that the stock of *L. miodon* seems to have recently lightly declined, but a longer survey period is needed to confirm this assumption (Descy *et al*., 2015) [8]. *L miodon* does compete with *L. tanganicanus* adult for large zooplankton and has significant niche overlap, but habitat preferences differ: *L. tanganicanus* prefers the littoral and benthic zones and *L. miodon* the pelagic zone (Paris *et al*., 2013; Descy *et al*., 2015) [29, 8]. In the littoral zone, *L. miodon* was mostly found close to tributaries, whereas *L. tanganicanus* was predominant in rocks and helophytes habitats (Paris *et al*., 2013) [29].

Impact of anthropogenic climate changes on aquatic ecosystems is accumulating over the world, but must be evaluated from climate cycles and variability which have caused fluctuations in fisheries throughout human history (Brander, 2010) [7]. Zooplankton of Lake Kivu is different from that of the other Rift lakes, the grazing pressure being the result of a major anthropogenic change, the introduction of *L. miodon*. In this context, the peculiar morphology of *Tetraëdron minimum* in Lake Kivu can be explained by its advantage against grazing (Stoyneva *et al*., 2012) [35] as a device for reducing grazing losses, exploited consequently after the introduction of *L. midon* and then the human impact on the lake food web. A recent research paper faced with anthropogenic climate change and has compared climate variables and fisheries statistics (Akonkwa *et al*., 2015) [3]. The results showed variation of rainfall, increase in temperature, decrease in relative humidity and wind speeds, resulting in a decrease of water level of the lake, followed by periods of declines in catches of *L. miodon*. The paper predicted decline in Catch per Unit Effort in the future and claimed strategic policies should be made and adaptation measures be taken to prevent the climate change, in order to conserve the aquatic resources and avoid advert conditions in fisheries sector of Lake Kivu. Lake level variability has an impact on the littoral zone ecological functions and then on *L. miodon* which breeds and growth in this area. Hence, Muvundja *et al*. (2014) [31] highlighted the necessity to better monitor the hydrology of Lake Kivu and its basin, to be able to observe and quantify potential effects of climate change.

Table 1: Haplochromine species previously described in Lake Kivu and potentially new species defined based on their phenotypes according to Paris et al. (2013) [29]

Group	Name	Literature (Snoeks et al., 2012)	Paris et al. (2013)
Demersal	*P. graueri*	X	X
	A. scheffersi	X	X
	sp.1		X
	sp.2		X
	sp.3		X
	sp.4		X
	sp.5		X
	sp.6		X
	sp.7		X
	sp.8		X
	sp.9		X
	sp.10		X
Gracilior	*A. gracilior*	X	X
Littoral black	*N. olivaceus*	X	X
	sp.1		X
	Lithochromis-like		X
	Neochromis-like sp.1		X
	Mbipia-like		X
	Pundamilia-like sp.1		X
	Pundamilia-like sp.2		X
Littoral light	*P. paucidens*	X	X
	M. crebidens	X	X
	sp.1		X
	Blue and orange fin		X
	Haplochromis-like		X
	Paralabidochromis-like		X
	Red dorsum		X
Pædophage	*L. occultidens*	X	X
Piscivorous	*P. vitattus*	X	X
	sp.1		X
	sp.2		X
Pelagic	*Y. kamiranzovu*	X	X
Described species not found in 2012	*L. adolphifrederici*	X	
	P. nigroides	X	
	H. astatodon	X	
	H. microchrysomelas	X	
	A. rubescens	X	
	H. insidiae	X	
Total		15	32

Fish consumption

Africa's consumption levels of fish are low (Tab. 2), despite the rise in the world per capita food fish consumption from an average of 16.5 kg between 2001-2007 to 17.6 kg in 2010 (IOC, 2012) [14]. The production in African inland fisheries is mainly composed of small fish, weighing only one to a few grams as the *L. miodon* fishery in Lake Kivu (Kolding *et al*.,

2015) [20]. However, fish is popular for human alimentation, in part due to its moderate price, ranging between the chicken and beef prices (Spliethoff and Murasira, 2013) [34]. In Kigali, prices are highly variable, from FRw. 1250 for big Tilapia on ice from Uganda to FRw. 300 for fresh Tilapia from Rwanda lakes. For dried Isambaza consumers have to pay FRw. 3000 /kg at the market, while the similar fish from Lake Victoria and Lake Tangayika are more variable, from FRw. 2000 to 5.500 per kg. These small fishes are tasty, can be kept for a long time, are considered suitable family food and contribute to food security and improved nutrition (Spliethoff and Murasira, 2013) [34].

Despite the major role of fish in human alimentation, only a few papers focused on the nutritional benefit of Lake Kivu fish: *L. miodon* are sundried whole, with heads, bones and organs, and then concentrate 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 (Kolding *et al*., 2015) [20]. Kapepula *et al*. (2015) [19] have analyzed the variation of *L. miodon* nutritional value from Lake Tanganyika over seasons: the raw proteins in terms of nitrogen vary from 60.83 % in the rainy season to 56.06 % in dry season and the total lipids vary from 32.05 % in the dry season and 18.22 % during the rainy period. Compared analyses between the two pelagic species in Lake Kivu showed that *L. miodon* is more protein and calorie rich than *L. tanganicanus* (Riziki *et al*., 2015) [31], but both species are of high nutritional quality and are good sources of ω3 fatty acids (Masilya, 2011) [22]. They could contribute to food security in this area of poverty. However, despite a good nutritional value, the riparian population is reluctant to consume *L. tanganicanus*, probably because the fish is recent within the lake and not integrated in the feeding habits (Riziki *et al*., 2015) [31].

Table 2: Per capita fish consumption in selected East African countries (adapted from IOC, 2012) [14]

Country	Annual Fish Production	Fish for non-food uses	Fish Imports	Fish Exports	Fish Supply for human consumption	Population	Per capita fish Supply/ consumption
Area	**Tonnes in live weight**					**('000)**	**Kg/yr**
Burundi	14 200	0	98	11	14 287	7 606	1.9
D.R. Congo	239 078	0	96 474	3	335 851	60 800	5.5
Kenya	148 017	237	26 967	32 211	142 644	36 781	3.9
Malawi	66 794	1	3 002	313	69 483	14 045	4.9
Rwanda	10 025	0	3 310	74	13 285	9 219	1.4

Aquaculture

In Rwanda, the demand for fish increases and the catches from fisheries fluctuate due to stock variation. Nibeza (2015) [26] highlighted the problems of overfishing. Thus, the Government of Rwanda is investing considerable resources in revitalizing and expanding the fisheries sector. Several aquaculture projects have been licensed, and in the next 10 years, aquaculture and capture fisheries development are expected to increase (Nibeza, 2015) [26]. But in the same way than fish from fisheries, fish from aquaculture do not reach the domestic markets, being mainly sold locally at farm gates. Projects to develop fish farming and rehabilitation of fish ponds as well as the supply of fingerlings and fish feeds to fish farmers are planned, as well as pilot projects in cage farming in the various lakes of Rwanda, including Lake Kivu. Special attention will have to be paid for aspects like the impact of temperature and the quality and cost of the fish feeds on the fish growth (Spliethoff and Murasira, 2013) [34]. Tilapia cage culture is practiced in Lake Kivu, with large cage farms with more than 50 cages (33% of respondents from Lake Kivu). Plan production has estimated the optimum carrying capacity of 140 000 floating cages in the three main lakes of Rwanda; cages can be grouped in 28 cage-based parks of 5 000 cages each. The cage operators from these lakes were concerned with occasionally upwelling of natural gases (methane and sulfur compound) which lower the level of oxygne in the upper layers of the lake (Kampayana *et al*., 2016) [15].

Fisheries management and conservation

Fisheries activities are highly developed in Rwanda, mainly confined in lakes and at a global point of view, threats from overfishing appear minimal (Twagiramungu and Ngendahayo, 2011) [36], this point of view being opposite of Nibeza's one (2015) [26]. Searching for alternative livelihoods, fisheries are still considered as an 'open access' income generating activity (Spliethoff and Murasira, 2013) [34]. Fishery employes directly many people and sellers (mainly women) and a lot of unemployed youth, but the system is disorganized and the capital depreciation of the gear is not planned. Moreover, people from the two borders of the Lake Kivu cope with local constraints on both sides and manage their activities of sales regarding border laws and habits, leading to a fraud scheme (Doevenspeck and Nene, 2012) [9]. Fishermen have to pay a license but it is not always done (Nzibonera-Bayongwa, 2014) [27]. Local officials have suggested that most fishermen who grouped together into associations, are in general respecting net dimensions and appear to have a sense of responsibility (Twagiramungu and Ngendahayo, 2011) [36]. Fishing remains at the artisanal level; the contribution of the fishing industry to gross domestic product is negligible (less than 1 percent in 1998) (Twagiramungu and Ngendahayo, 2011) [36].

According to Kaningini (1995) [31] and Kaningini *et al*. (1999) [33], there is a lack of description of the fishery in Lake Kivu. Akonkwa *et al*. (2017) [2] published an attractive synthesis focused on the description and comparison in terms of species selection and total catches of fishing gears in Goma, Bukavu, and Kibuye fishing stations from March 2012 to February 2014. Gill-net, beach seine, lift net, trammel net, mosquito net, longline, single line, pots, and cast net are used on Lake Kivu. Longline was the most selective fishing gear in terms of species selection, the usual lift net provided the best catches, and the trammel net showed the highest CPUE (7.9 ± 6.1 kg/h). Cast-nets showed the largest mesh size (20 mm), while mosquito nets (1 ± 0.3 mm) were the smallest. Mosquito nets are still used (Twagiramungu and Ngendahayo, 2011) [36], despite the caveat already highlighted by Kaningini and Micha (1997) [33] around 20 years ago and reminded by Akonkwa *et al*. (2017) [2].

A survey of fisheries statistics in Lake Kivu was conducted from 2011 to 2013 (Descy *et al*., 2015) [8]. Fish catch data were collected in 59 sites identified in the field survey period, and catches were recorded on a daily basis for more than two years. During this period, a total of 340 fishing units were operating in Lake Kivu (Rwandan side), which corresponds to an average number of 6 trimarans per site. Five major fish taxa were exploited: *L. miodon*, *Haplochromis spp.*, *L. tanganicanus*, "Tilapia" (actually 3 species of *Oreochromis* and *Tilapia rendalli*) and *Clarias spp.* (*C. gariepinus* and *C. liocephalus*). *L. miodon* remained the dominant species in the catches the whole year round and across all basins, representing about 75% of total catches. The total fish production of Lake Kivu is low compared to other regional lakes, but accurate data and figures seem difficult to obtain, recent reports still showing old references (Tab, 3) (IOC, 2012) [14]. In general, correct fishery statistics are hard to get, in part due to the numbers of participants. There is a need of collaborative works. To rule on how to conserve fish, a platform from five districts bordering Lake Kivu, including traders, fishermen, the police and the army, district leaders, researchers, extension workers and drivers who ferry the fish to Kigali for sale, sellers, and consumers was composed in 2012. The main issue was an agreement between stakeholders to ban fishing in the lake for two months once a year, during the main spawning season. This decision was adopted as a permanent measure (Dusengemungu and Ndayisenga, 2012) [10].

Nzibonera Bayongwa (2014) [27] synthesized several propositions to optimize the management of fishery resources in Lake Kivu:

- New fishing methods should be initiated, in particular on the basis of their relevance to fleets, fishermen, fishing gear and the geographical area concerned.
- Scientific knowledge has to be strengthened on the state of fishery resources.
- Prospective and strategic advices should be planned on multi-years plans to reach a sustainable maximum yield.
- Create a fishing option in high school and in the universities.
- Accompany fishermen during periods of inactivity to avoid fishing during closing period.
- In line with the future plan for fisheries, the rationalization of marketing conditions will be sought through the search for economies of scale, harmonization of quality and enhanced hygiene and traceability.
- Help with the installation of young fishermen.

Table 3: Fish production from various lakes in East African region (from IOC, 2012) [14]

Lakes	Coverage (km^2)/Countries	Production in tons	Main species	Remarks
Victoria	68 800 km^2 Kenya, Tanzania and Uganda	900 000 (in 2010)	Lates niloticus (Nile perch) Rastrineobola argentea (Daaga), Oreochromis niloticus (Tilapia), Haplochromis, Bagrus, Clarias., Synodontis, Protopterus.	Dagaa (60%), Lates (30%, and Oreochromis, (7%). 194 172 fishers and 65 758 fishing crafts (2010.)
Tanganyika	32 900 km^2 Burundi, DR Congo (45%), Tanzania (41%), Zambia	200,000 (in 2011)	Stolothrissa tanganicae and Limnothrissa miodon (Kapenta) Lates stappersii (Bukabuka/Mukeke), Lates angustifrons (Capitaine), Lates marie (Ngonzi, Sangala), Lates microlepis(Nonzi/Nyunvi), Tilapiine	About 94 800 active fishers (2011). Kapenta contributes 60% to total catch and Lates stappersii 30%.
Malawi/Nyasa	29 600 km^2 Malawi, Tanzania and Mozambique	50 600 (in 2007)	Haplochromis spp. (Mbuna), Copadichromis spp. (Utaka), Preochromis spp. (Chambo), Rhamphochromis spp. (Ncheni), Engraulicypris sardella (Usipa), Barbus paludinosus (Matemba), Bagrus meridionalis (Kapango) and Clarias gariepinus (Mlamba)	About 50 000 fishers and over 350 000 fish processors, traders etc. in Malawi
Turkana (Rudolf)	7200 (7570) km^2 Kenya and Ethiopia	2 493 (in 2005)	Nile perch, Tilapia, Labeo, Bagrus, Barbus, Citharinus, Distichodus, Clarias, Synodontis, Hydrocynus forskalii	New supplier to regional trade for DR Congo.
Albert	5270 km^2 DR Congo 46% and Uganda 54%	More than 150 000 (in 2010)	Alestes baremose (Ngara), Hydrocynus forskahli (Ngasia), Lates niloticus, L. macropthalmus, Brycinus nurse (53%), Neobola bredoi (22%), Bagrus bayad	The small pelagic (Ragoogi) and Muziri) catch is over 60% of the Lake in Uganda. Production data is for Uganda only.
Mweru-Luapula	4 580 km^2 Zambia 58% and DR Congo 42%	2 2000	Poecilothrissa mweruensis andBangweluensis (Chisense), Oreochromis macrochir (Tilapia),Hydrocynus vitattus (Tiger fish).	About 25 000 fishers in Zambian waters
Edward	2 325 km^2 Uganda29% and DR Congo 71%	10 000 in (2010)	Tilapia, Bagrus, Barbus, Protopterus, Clarias, Haplochromis	516 fishers (No. Of fishers, boats and fishing gears are controlled/set in Uganda)

Kariba	54 00 km^2 Zambabwe & Zambia	23 226 (in 2001)	Limnothrissa miodon, Oreochromis spp., Tilapia rendalli, Labeo, Hydrocynus vitattus, Mormyrids, Clarias gariepinus	Lake Kariba is famous for Cage fish farming. Kapenta
Kivu	2370 km^2 Rwanda 42% and DR Congo 58%	7 000 (1991)	Oreochromis niloticus(Ingenge), Stolothrissa tanganicae and Limnothrissa miodon (Kapenta) Barbus spp., Clarias spp., Haplochromis spp.	About 6500 fishers. Kapenta (Limnothrissa) contributes over 80% of the total catch

Conclusion

Recent studies confirmed the dominance of *L. miodon* in fisheries and the potential for the exploitation of *L. tanganicanus* in Lake Kivu. As highlighted by the SmartFish program (Smartfish, 2015) [32], small pelagic fish are a major source for human alimentation in Africa and Lake Kivu fish resources is of main importance in the area. In the future, governments should plan to improve handling on board and development of landing site and market infrastructures. Increase of mobile phones in the population can lead to optimize fish landing and markets, boats being able to change destination if needed (Rabbaland, 2012). Better fishery organization is of importance to improve quality and maximize revenue. From an ecological point of view, catching small fish conserves the aquatic ecosystem structure, opposite to large predator fish and maintains the terrestrial ecosystem by reducing the cutting of firewood necessary for smoking and preserving large fish (Kolding *et al*., 2015) [20]. Furthermore, by primarily targeting large adult fish, such as e.g Nile perch in Lake Victoria, humans feed about two trophic levels higher in water than on land, which in terms of energy is a very inefficient utilization of available food (Kolding *et al*., 2015) [20].

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