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A century of drastic change: Human-induced changes of Lake Victoria fisheries and ecology

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ABSTRACT

Lake Victoria biophysical and geochemical status has changed dramatically within an unprecedentedly short time scale driven by human actions. These actions can be broadly classified as escalated fisheries exploitation, biomanipulation (characterized by species introduction) and catchment processes. A chronology of these activities since 1901 to present times is described and, where possible, related to changes in the ecology. The impacts of fishing are investigated using catch and effort data that have been consistently recorded for the past two decades. It is evident that water transparency in the offshore decreased from close to 8 m in late 1920s to less than 2 m in the 1990s before improving to about 4 m in the 2010s, a reflection of change in ecosystem functioning. The native tilapias that constituted the commercial fishery initially have since been replaced by introduced species and dagaa (*Rastrineobola argentea*) following biomanipulation events. Analysis of unified fishing effort index (*E*) reveals that in the last two decades fishing capacity has increased close to 8-fold in Kenya and Uganda and about three times in Tanzania. Illegal/prohibited gear have increased by 4.7 ± 1.9 folds whereas legal gear increased by 2.6 ± 0.8 times in the whole lake during since the year 2000. The catch per unit effort (CPUE) for Nile perch, tilapia and "others" declines with increasing effort while that for *dagaa* exhibits no clear trend. Haplorochromines catches and catch rates are increasing probably due to predatory release by the Nile perch. Tilapia and other fish catches and catch rates have declined with increasing harvesting capacity clearly indicating that they are over-fished. Catch and effort dynamics indicate that dagaa is still abundant in Lake Victoria. Overall, catches in Lake Victoria increase with increasing fishing effort but catch composition has shifted to one dominated by small pelagic species. It has been clearly shown that events leading to biomanipulation and processes in the catchment can fundamentally change a fishery in a different way as compared to fishing and hence the need for Ecosystem Approach to Fisheries Management (EAFM) in Lake Victoria.

1. Introduction

Ecosystems are ever-changing entities made up of several interactive biotic and abiotic components that determine their production and productivity levels (Jorgensen et al., 2007; Hooper et al., 2005). Equally complex are the ecological processes that govern ecosystem structure and function, the inherent variability in biophysical processes and the interactions between ecological, economic and social processes (Loreau, 2010). Understanding this complexity is a prerequisite for effective management (Bennett et al., 2013; Kelly et al., 2013; Acosta et al., 2010). Nevertheless, this is difficult when the said complexity is compounded with uncontrolled exploitation, introduction of invasive species, resource use conflicts and climate change (Hooper et al., 2005). This is especially so in large ecosystems where adequate data collection is expensive and logistically difficult (Petrovskii and Malchow, 2004). Lake Victoria, the largest (by surface area) among the African Great Lakes (Jean-Pierre, 2006), is a classic example of such ecosystems.

Lake Victoria, iconic in size and function, is an invaluable resource for East Africans who depend on it for food, transport, employment, water for domestic and industrial uses, climate regulation among other

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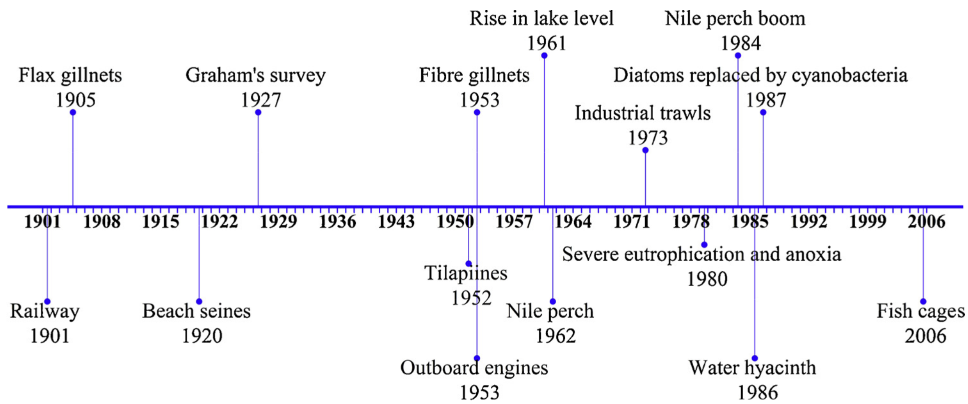

Fig. 1. A chronology of first arrival/introduction or observation of events in Lake Victoria.

ecosystem services (Nyamweya et al., 2016a; Crul, 1995; Anyah and Semazzi, 2009; Sun et al., 2014). The lake is the best example of the impact of anthropogenic activities on ecosystems having exhibited dramatic biophysical and geochemical changes within a relatively short time. Soon after British explorers set sight on the lake, there was an influx of settlers ostensibly to exploit its resources as well utilize parts of its catchment for agriculture. Inevitably, surrounding natural vegetation, forests and swamps were reclaimed to give way to cash crop plantations which have continued to grow in size and number over the years (Balirwa et al., 2003). As a consequence, there was a population irruption around the lake as migrants moved in to work on plantations. The unfolding development wrought pressures on several fronts; fishing pressure on the lake began to intensify (Graham, 1929) courtesy of population growth and efficient fishing.

A chronology of major anthropogenic events in Lake Victoria is depicted in Fig. 1. The arrival of the Uganda Railway in Kisumu in 1901 opened up the region for trade with the rest of the world but also set the stage for major events to beset the lake. As population grew, and with subsequent introduction of flax gill nets by the British in 1905 to replace the local villagers' papyrus nets and fish traps, overfishing soon became a problem: catches began to drop and fishermen turned to nets with ever smaller mesh sizes and thus decimated both the breeding adults and young of many native species (Graham, 1929). This was aggravated with the introduction of non-selective beach seine nets (1920s) that intensified fishing in littoral zones and damaged the breeding and nursery grounds of the indigenous cichlids (Graham, 1929).

The first comprehensive research survey in Lake Victoria conducted in the late 1920s (Graham, 1929), provided a baseline from which ecosystem change could be evaluated. At the time, Lake Victoria had clear waters that provided perfect conditions for feeding and spawning of the cichlid species that were abundant. *Oreochromis esculentus* and *O. variabilis* were the mainstay of the small scale fishery that was gaining vibrancy following the advent of efficient flax nets years before the survey. A diverse haplochromine cichlid stock existed, though exploited to a limited extent. Most of the shoreline was fringed with macrophytes and terrestrial vegetation. In the succeeding years popular species, such as Graham's tilapia (*O. esculentus*) diminished severely (Witte et al., 1992).

To remedy the situation, British officials introduced *Oreochromine* and *Coptodon* species (*O. leucostictus*, *Coptodon zillii*, *C. rendalli*, *O. niloticus* and *O. mossambicus*) in the early 1950s (Coulter et al., 1986; Hickling, 1961; Mann, 1969; Balirwa, 1992; Lowe-McConnell, 1987; Njiru et al., 2006). These introductions coincided with those of fiber gillnets and outboard engines. A decade later Nile perch were officially introduced (Pringle, 2005) whose impact on the haplochromine stocks, which it favored as prey has been widely documented (Marshall, 2018). Industrial trawling commenced in the early 1970s targeting haplochromines, which accounted for more than 80% of the fish biomass (Kudhongania and Cordone, 1974). This was however short lived as the Nile perch boomed in the early 1980s (Kayanda et al., 2009). Other notable events include Water hyacinth (*Eichhornia crassipes*) infestation and proliferation and the succession of diatoms by cyanobacteria that both occurred in the late 1980s (Opande et al., 2004; Taabu-Munyaho et al., 2016; Witte et al., 1992). Water hyacinth reproduces rapidly and covers large areas of the lake forming dense mats of plants that block sunlight needed for survival of life below the surface (Ongore et al., 2018). This paper examines fisheries and ecological changes against the backdrop of major anthropogenic events in and around Lake Victoria since the turn of the 20th century.

2. Materials and methods

2.1. Study area

Lake Victoria, occupies a shallow depression between the two arms of the Great Rift Valley (Fig. 2). It is the largest among the African Great Lakes by surface area and the only one not situated in either arms of the rift. The lake is trans-boundary (shared among three East African countries, i.e. Kenya, Ugnada and Tanzania) and its tributaries are the most distant sources of the River Nile (Penn, 2001). About 1 million tonnes of fish are landed from the lake annually making it the largest inland fishery in the world. The fishery is however largely artisanal, with the silver cyprinid *dagaa*, Nile perch and Nile tilapia currently accounting for most of the catch (LVFO, 2016).

2.2. Data sources and treatment

We examine biophysical and chemical, anthropogenic changes in Lake Victoria over the last century. Data from earlier years and in some cases current and future predictions are derived from published literature and reports. The data is presented to depict trends over time. Otherwise, recent limnological and fisheries information are derived from survey data (i.e. Regional Frame, Catch Assessment (CAS), Hydroacoustic and various biological surveys).

Frame surveys in Lake Victoria yield a variety of measures of fishing effort that broadly give the quantity of fishers, fishing crafts and gears. The influence of these parameters on catches of different fish species is investigated using a multiple linear regression. To have a clear indication of fishing effort all the parameters are standardized by comparing their current value with the base year. A unified fishing effort indicator E is then derived as a summation of all effort measures divided by the number of parameters (Eq. (1)):

$$E_i = \frac{\sum_{i=1}^{n} (e_i/e_b)}{n} \tag{1}$$

where E_i is the unified effort indicator for a particular fishery in the ith year, e_i is the effort parameter in the ith year, e_b is the effort parameter

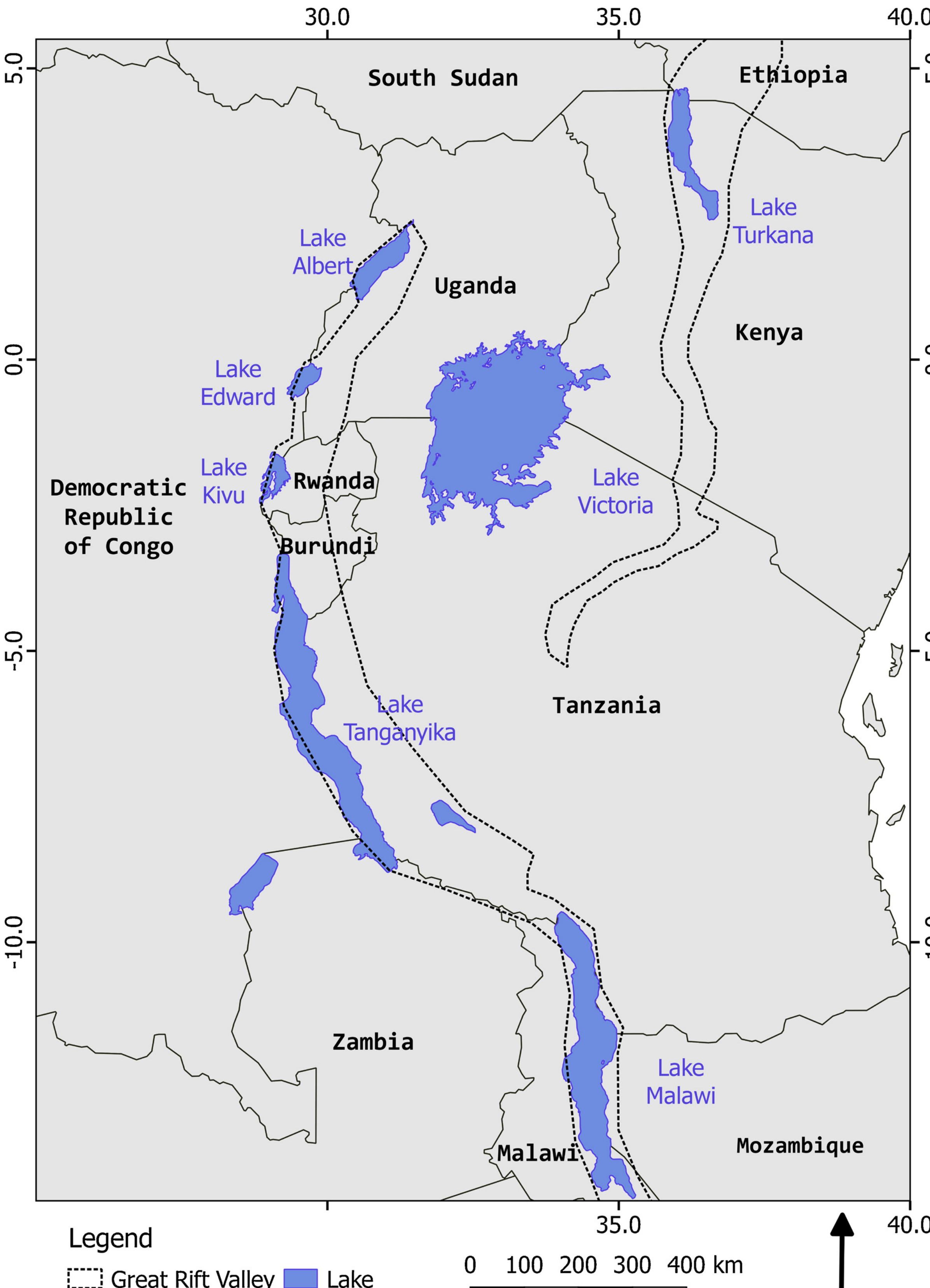

Fig. 2. Lake Victoria and other African Great Lakes.

Table 1
Human population trends in the Lake Victoria catchment.

Year	Population density	Population (millions)	Source
1960	45	8.7	UNEP
1970	61	11.8	
1980	84	16.2	
1990	115	22.2	
2000	159	30.7	
2010	218	42.1	
2010	220	42.4	Bremner et al. (2013)
2020	315	60.8	
2030	396	76.5	
2050	586	113.2	

in the *base* year and *n* is the total number of effort measures used.

Annual catches for the major commercial species were divided by the respective unified effort indicators resulting in catch per unit effort (CPUE) (Eq. (2)). This is an important means of estimating trends in stock abundance when independent survey data are not available. As CPUE decreases, it may reflect a decrease in stock abundance (Nyamweya et al., 2016b):

$$\text{CPUE} = \frac{\text{Catch}_i}{E_i} \tag{2}$$

3. Results

3.1. Human and limnological characteristics

The human population in the Lake Victoria basin has been steadily increasing (Table 1). In 1960, there were only about 8.7 million people living in the catchment. The population has since then increased more than 4-fold with over 42 million people living in the watershed. On average the population increases at a rate of 3.8% per annum.

Water transparency in Lake Victoria has exhibits remarkable variations on both temporal and spatial scales (Fig. 3). Since first recorded in late 1920s, water transparency (depicted as Secchi depth) has been higher in offshore areas (beyond the 20 m depth contour). The difference in transparency in offshore and inshore areas has however been decreasing overtime. Studies in the 1920s show that Secchi depth in offshore areas was over 7 m while it was only about 2 m inshore waters. In the latter years, the difference has been much reduced, with offshore Secchi depth declining to less than 4 m. Generally water transparency has declined significantly overtime with lowest Secchi depth being recorded in the late 1980s and early 1990s. Thereafter, a steady improvement in water transparency is evident in both offshore and inshore waters.

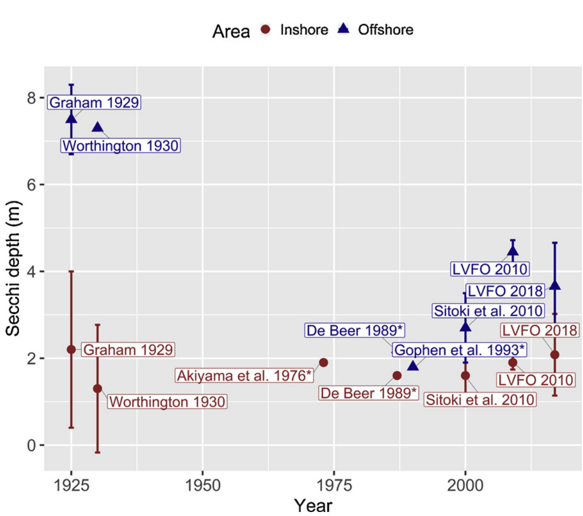

Fig. 3. Long term water transparency variations in Lake Victoria.

3.2. Fishing effort dynamics

Fig. 4 depicts the trends of fishing effort parameters from the year 2000 to 2016 in the three countries sharing Lake Victoria. The number of fishers and fishing crafts has increased steadily (more than doubling with reference to the base year) overtime especially in Tanzania and Uganda where the major portion the lake lie. In Kenya the numbers of fishers and crafts have remained fairly constant. Outboard engines have increased steadily in all the three countries whereas the reverse is true for inboard engines. Paddled crafts have slightly increased in Tanzania and Uganda but decreased in Kenya. Generally crafts with sails have remained constant but they are most prevalent in Kenya. The number of gillnets has no clear trend. Their numbers rapidly increased in the period preceding the year 2006 after which fluctuations are evident. Gillnets with a mesh size of less than 5 inches. However have been on a steady increase in Kenya. From the year 2000 to 2006, lift nets were recorded in Tanzania whereas they were virtually absent in the other two countries. Afterwards, they decreased steadily in Tanzania whereas a huge increase is recorded in Uganda in 2016. Overall small seines that usually target small pelagics in Lake Victoria have increased over the years in all the countries. This increase has been more pronounced in Kenya which recorded the highest number in small seines in latest Frame Survey. The number of small seines of mesh size more than 5 mm increased over 10 folds in the considered period. Scoopnets on the hand decreased about three times from the levels observed in the base year. The number of handlines has decreased in Kenya from more than 34,000 to about 2800. The handlines increased in Uganda (from 4500 to 37,700) but remained stable in Tanzania over the years. Longline hooks have increased about five folds in all the three countries with Tanzania having the highest number. The observed increase is consistent with the rapid increase in longline hooks number 10 and above that are legally not allowed in Lake Victoria. The converse is observed in longline hooks number 8 and 9. Other longline hooks show no clear trends as is cast nets and basket traps. Seine nets operated from either the beach or boats have doubled, increasing from 2393 in 2000 to 4665 in 2016. Monofilament nets were barely observed in the base year but their number rapidly increased to over 72,000 in 2016.

Multiple regression model results show that Nile perch catch is significantly correlated with the number of fishing crafts, outboard engines, paddled crafts and crafts using sails. Tilapia catches are significantly related to the number of fishers, both inboard and outboard engines, paddled crafts and crafts using sails. Dagaa and haplochromines catches show no significant relationship with any of the effort parameter (Table 2). The regression model significance results are detailed in S1.

To decipher changes in overall fishing capacity over the years, key effort parameters (number of fishers, crafts and propulsion mode, and gear) were amalgamated with reference to their levels in the year 2000. The unified fishing effort index (*E*) thereof shows that harvesting capacity has increased over the years (Fig. 5). This proxy of fishing capacity has increased close to 8-fold in Kenya and Uganda and about three times in Tanzania. A further look into the unified fishing capacity index revealed that illegal/prohibited gear have increased much more (by 4.7 ± 1.9) as compared to the legal gear that increased by 2.6 ± 0.8 in the whole lake during since the year 2000 (Fig. 6).

Fish catches and catch rates (CPUE) were determined for the different effort index levels (Fig. 7). Varied trends are observed for the different fish groups. Nile perch catches generally increase with increasing fish effort. The catches for this species however decline when the effort index is beyond 2.6. On the other hand CPUE for Nile perch declines consistently with increasing effort index. Catches for dagaa increase with increasing effort index but CPUE exhibits no clear trend. Both catches and CPUE for tilapias and "others" generally decrease with

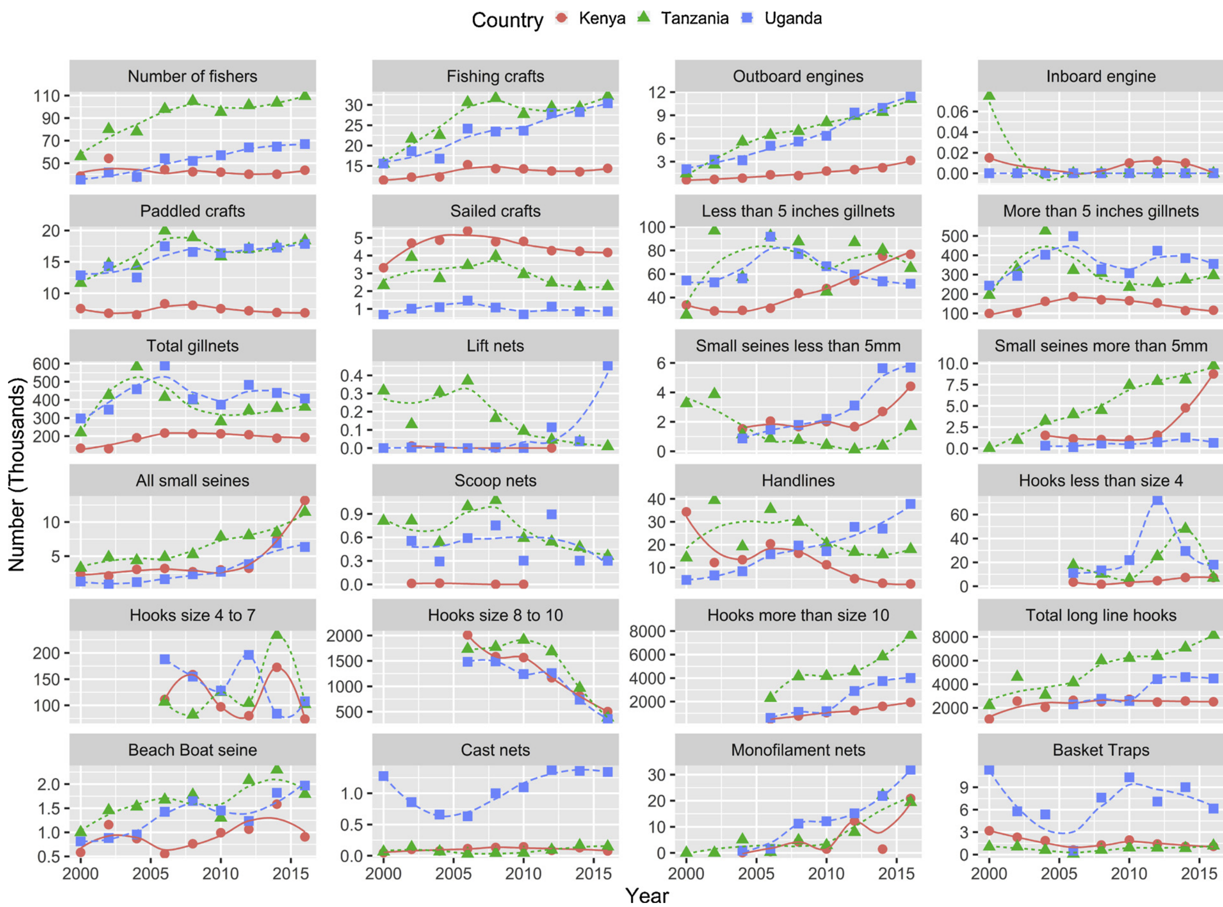

Fig. 4. Changes in fishing effort parameters in Lake Victoria since the year 2000.

Table 2
Multiple regression model results of catch and fishing effort parameters in Lake Victoria. Significance codes: α = 0.001 '***', α = 0.01 '**', α = 0.05 '8' and α = 0.1 '.'.

Parameter	Nile perch	Tilapias	Dagaa	Haplochromines
Number of fishers		**		
Fishing crafts	*			
Inboard engine		*		
Outboard engines	*	*		
Paddled crafts	*	.		
Crafts using Sails	**	*		
Gillnets				
Long line hooks				
Beach Boat seine	.			
Monofilament nets				
Cast nets				
Lift nets				
Small seines				
Scoop nets				

increasing effort index. Haplochromines catches and CPUE on the other hand increase with increasing effort index. Overall fish catches in Lake Victoria increase with increasing fishing effort but CPUE exhibits a contrary trend.

4. Discussion

In the last century, Lake Victoria ecosystem has changed on a scale seldomly observed elsewhere (Marshall, 2018; Goldschmidt et al., 1993). A detailed chronology of events reveals that major changes in the ecology and fishery of the lake have been preceded by major anthropogenic actions. Thus observed biota and water quality changes are just responses to anthropogenic activities that escalated in the considered period as discussed hereafter. The effect of fishing is investigated using catch and effort data that has been consistently recorded for the past two decades.

Native and endemic fish (Oreochromines) constituted the commercial fishery in the 1920s in abundances that attracted investment in fish harvesting with signs of overfishing quickly setting in thereafter (Graham, 1929). The initial decline of commercial species triggered biomanipuation (Pringle, 2005) of the ecosystem with the aim of boosting fishery. Although this was achieved as evidenced by the eventual boom of the introduced Nile perch and Nile tilapia in the 1980s, the diverse haplochromine cichlids were decimated with far reaching ecological consequences that have been compounded by developments and land use changes in the catchment (Balirwa et al., 2003; Goudswaard et al., 2011; Goldschmidt et al., 1993; Nyamweya et al., 2016b). Although commercial species showed signs of over-exploitation due to increase in human population and development of trade infrastructure in the region, the complete change of commercial fish species is easily attributed to the introduction of new species in Lake Victoria. Negative correlation between introduced and native fish species through predation and competition mechanisms in Lake Victoria has been highlighted variously in scientific literature (Nyamweya et al., 2016b).

Water transparency in Lake Victoria has drastically over time. The observed changes could be related to catchment processes. Heightened exploitation of the lake's watershed has resulted in clearing of the surrounding natural vegetation, denuding of forests and draining swamps increasing soil erosion and siltation. Sitoki et al. (2010) link siltation to decreasing water transparency in Lake Victoria. Additionally, agricultural chemicals and municipal waste end up in the lake, providing nutrients for massive algal blooms that also decrease

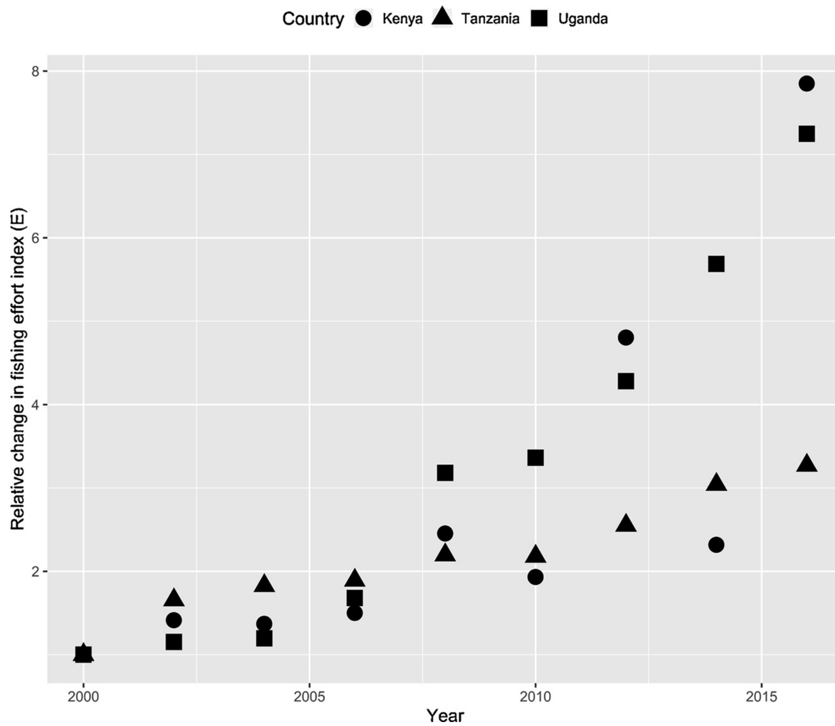

Fig. 5. Changes in effort index (*E*) over time in Lake Victoria per country.

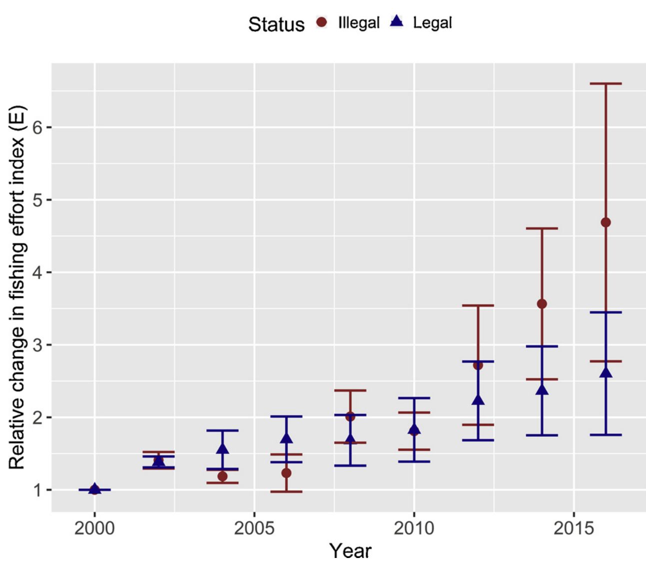

Fig. 6. Relative change of fishing effort (legal and illegal) in Lake Victoria.

water transparency (Balirwa et al., 2003). The recent improvement water transparency is however intriguing and indicative of yet to be fully understood processes. That notwithstanding, the changes may be related to Nile perch boom that reduced algae eating haplochromines (Seehausen et al., 1997) with the recent improvement in water transparency coinciding with the recovery of haplochromines (Sitoki et al., 2010).

Fish harvesting dynamics in Lake Victoria are reflected in Frame Survey data (LVFO, 2017). The surveys enumerate fishers, fishing crafts, fishing gear and other infrastructure associated with fishing. The increase in the number of fishers is concomitant with the population increase. Over 30 million people reside in the Lake Victoria watershed with an estimated increase of 3% per annum (UNEP, 2006). Across the African Great Lakes, poverty levels are high and a majority of the population living along the lake shores rely directly or indirectly on the fisheries. Other fish harvesting parameters take various trends. Only number of crafts (and propulsion modes) and beach/boat seining are significantly related to either Nile perch or tilapia catches. This information is important as it highlights points of intervention for regulation of fishing effort. The unified fishing effort index however indicates that harvesting capacity has increased tremendously in the last two decades especially in Kenya and Uganda. This increase is more pronounced in prohibited fishing gear (i.e. under size nets and hooks, beach and boat seines, and monofilament gillnets). The shift to lower mesh sizes and other illegal fishing is probably triggered by the changing population structure of fish.

Changes in fishing effort index levels have an impact on catches and CPUE. Nile perch catches initially increase with fishing effort. Beyond a certain level, the catches decline an indication that the species is beginning to exhibit signs of over-fishing. This is further corroborated by CPUE which declines consistently with increasing effort index. Catches and CPUE for haplochromines (Nile perch main prey), on the other hand, increase with increasing effort index. This is indicative of increasing abundance of haplochromines due to predatory release occasioned by the declining Nile perch stocks. Tilapias and other fish species generally decline in catches and CPUE with increasing effort index clearly showing these groups are over-fished. Dagaa dominates catches in Lake Victoria in recent times (LVFO, 2016). Its catches increase with increasing effort index, a sign that the species is still abundant in the lake. Considering all species together, catches are still increasing with increasing harvesting capacity. The catch composition is however shifting towards one dominated by small pelagics – an emerging trend in the AGLs. It is worth noting that even though the overall catch is increasing in Lake Victoria, the high value species are declining and CPUE is also declining. A consequence of this is reduced income for fishing communities unless more value is harnessed from the abundant small pelagics.

It has been clearly shown that events leading to biomanipulation and catchment processes can fundamentally change a fishery in a different way as compared to fishing. It is therefore imperative for players in the management of the Lake Victoria ecosystem to pay much attention to such activities. For instance, cage culture in the lake is

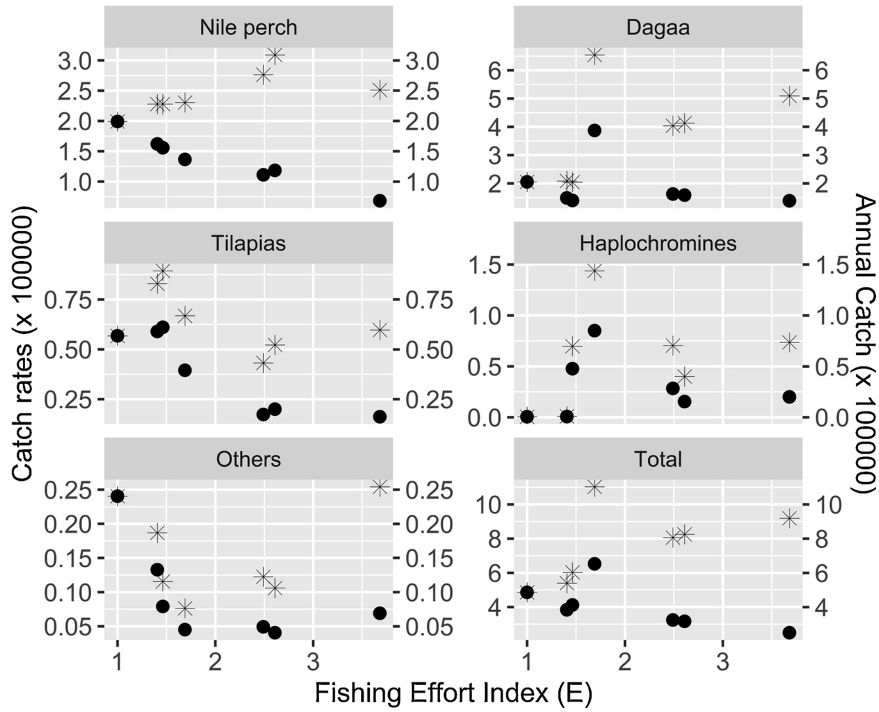

Fig. 7. Trends in annual fish catches (*) and catch rates (•) with increasing effort index in Lake Victoria.

growing rapidly and, just like preceding anthropogenic activities, it has a potential to alter the ecology of Lake Victoria in an unpredictable way. Measures should be set in place to guard against adverse effects of the practice on the ecosystem. Going forward, activities of the nature like the ones that drastically changed Lake Victoria should be subjected to rigorous evaluation. This is possible in an ecosystem approach to fisheries management setting.

5. Conclusion and recommendations

Lake Victoria has witnessed a century of change characterized by major anthropogenic activities and dramatic changes in its biophysical environment. A part from water transparency reducing several folds, its fisheries have completely changed from one dominated by native tilapias to one constituted majorly by introduced species and dagaa. Fish harvesting capacity has increased several folds since the turn of the millennium affecting fish catches and CPUE in Lake Victoria. Nile perch has only recently shown signs over-fishing but for most of the considered period its catches increased with increasing harvesting capacity. Haplochromines (Nile perch prey) abundance increased with increasing fishing effort suggesting a stock under recovery probably due to predatory release. Dagaa catches increase with increasing effort indicating that the species is still abundant in the lake. Tilapias and other species catches and CPUE decline steadily with increasing fishing effort. Overall, landing in Lake Victoria increase with increasing fishing effort but catch composition has shifted to one dominated by small pelagics. Fishing crafts (of various propulsion modes) and beach/boat seines are the only parameters that significantly affect catch. Consequently the said parameter should be the focus of fishing effort regulation. Analysis of diverse data sets shows that fishing may reduce abundances of target species but predator-prey relationships have a bigger impact. On the hand, biomanipulation wrought unintended consequences on the biogeochemistry of Lake Victoria.

Authors' contribution

Chrispine Sangara Nyamweya: conceptualization, methodology, investigation, formal analysis, writing – original draft; Vianny Natugonza and Anthony Taabu-Munyaho: conceptualization, investigation, writing – review & editing; Christopher Mulanda Aura, James Murithi Njiru, Cyprian Ogombe Odoli, Zachary Ogari and Robert Kayanda: writing – review & editing; Collins Ongore: investigation, formal analysis; Richard Mangeni-Sande and Benedicto Boniphace Kashindye: investigation.

Conflict of interest

None declared.

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