FOOD, FEEDING HABITS AND POPULATION STRUCTURE OF “NINGU” (*Labeo victorianus,* BOULENGER, 1901) IN FOUR SELECTED RIVERS OF THE LAKE VICTORIA BASIN, KENYA.

BY

NAKANGU FURAHA NELLY

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DECLARATION

DECLARATION BY THE STUDENT

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NAKANGU FURAHA NELLY

______________________________ ______________________________

SNAT/FAS/M/004/18 **DATE**

DECLARATION BY THE SUPERVISORS

This thesis has been presented with our approval as University supervisors.

______________________________ ______________________________

Dr. James E. Barasa **DATE**
School of Natural Resource Management
Department of Fisheries and Aquatic Sciences
University of Eldoret

______________________________ ______________________________

Dr. Geraldine Matolla **DATE**
School of Natural Resource Management
Department of Fisheries and Aquatic Sciences
University of Eldoret

______________________________ ______________________________

Prof. Mbalassa Mulongaibalu **DATE**
Faculty of Sciences
Official University of Bukavu

DEDICATION

To Mike and Rose Cikuru, my beloved parents

To René N. Makungu, my best friend and husband

To Jemimah, Michael and Joel, my most precious progeny

ABSTRACT

“Ningu” (*Labeo victorianus* Boulenger, 1901) is one of the endemic fishes in Lake Victoria Basin (LVB), but is now threatened by multiple stressors caused by human activities. This study investigated spatial and temporal variability in food composition and condition of *Labeo victorianus* in Awach, Mara, Nyando and Sondu-Miriu rivers of Lake Victoria, Kenya. Sampling was done during the dry and wet seasons by electrofishing. Food composition analysis showed that *Labeo victorianus* is a benthophagus and omnivorous species whose diet is dominated by detritus, plant material and insects. There were differences in food composition among rivers, with significant river X season interactions (PERMANOVA F = 11.6, df = 4, p = 0.001), suggesting that the diet depended on prevailing environmental conditions. In turbid rivers the diet was dominated by detritus while in less turbid rivers it was dominated by insects and periphyton. Sand and mud also formed a significant part of the diet, which was an indication of limited preferable food items. There were ontogenetic shifts in food composition (PERMANOVA F = 4.6, df = 3, p = 0.001), but also with a spatial interaction (PERMANOVA F = 5.6, df = 7, p = 0.001), further indicating the role of environmental conditions in determining the diet for different size classes. Interestingly, fish condition did not differ among rivers. *Labeo victorianus* population size structure was unimodal (7-15cm) in Awach, Nyando and Sondu Miriu rivers while bimodal in Mara River. This study shows that turbidity and organic matter and nutrient loading determine the diet of *Labeo victorianus* in LVB Rivers, and provides further justification for maintenance of water quality as a conservation measure for threatened species. The findings from this study can inform efforts to culture the species for restocking and/or food production. The findings also have greater implications for other fish species threatened by human activities, and can be used to inform sustainable management of riverine fisheries and conservation of threatened of *Labeo victorianus* in the LVB. Further studies to incorporate use of stable isotopes may be used to provide historical information on the food of the species.

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

CPN: capture per net

EAC: East African Community

GDP: Gross Domestic Production

IUCN: International Union for Conservation of Nature

KSh: Kenyan Shillings

LVB: Lake Victoria Basin

LVEMP: Lake Victoria Environmental Management Program

LVFRP: Lake Victoria Fisheries Research Project

LVFS: Lake Victoria Fisheries Service

LWR: Length-Weight Relationship

SL: fish standard length

SWB: Satellite Water Bodies

TL: Fish Total Length

UOB: Official University of Bukavu

UOE: University of Eldoret

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CHAPTER ONE

INTRODUCTION

The Lake Victoria Basin is among the richest of the Great lakes of Africa, characterized by a high degree of biological diversity and endemism (Ogutu-Ohwayo, 2001). It contains one of the largest number and diverse freshwater fish species in the world, producing more than 500,000 tons of fish per year and contributes to the livelihood of the surrounding population by the supply of a high-quality protein food, water for domestic use and irrigation, transport, hydropower, employment, and mining (Balirwa *et al.*, 2003; Wakwabi *et al.*, 2006; Obiero *et al.*, 2019; Nyamweya *et al.*, 2020). Since the past century, several changes have occurred to the lake and its basin which have impacted aquatic biodiversity and degraded the water quality.

The main causes of the changes were anthropogenic activities, climate change, fishing pressure, agricultural development and industrialization that have resulted in habitat degradation, fragmentation and pollution (Witte *et al.*, 1992; Aloo, 2003; Ojwang, 2007). Introduction of non-indigenous species led predation and hybridization with native species, accasioning decimation of native fish species, and loss of fish diversity in the lake (Ogutu-Ohwayo *et al.*, 1997). Similarly, overfishing in the lake as well as the influent rivers of the lake basin caused the decline of native fish species (Balirwa *et al.*, 2003; Njiru *et al.*, 2008). This situation was followed by the reduction in fish diversity, especially the endemic species (Ogutu-Ohwayo, 1997).

Labeo victorianus, known locally as “Ningu” is a cyprinid species endemic to the Lake Victoria basin (Kibaara, 1986).   Considered to be a delicacy, the fish species has greatly contributed to the food fish supply of the riparian communities due to the least effort and cost to capture the fish as well as the high market demand (Ochumba and Manyala, 1992; Orina *et al.*, 2018). *Labeo victorianus* is potamodromous, so the fish migrates from the lake to the rivers for spawning during the rainy season, which predisposes them to overexploitation (Rutaisire *et al.*, 2004). Over the years, the landings of the species have declined drastically (Cadwalladr, 1965; 1969), from a high of 14.7 in 1957 to 0.5 metric tons by the year 1963 (Cadwalladr, 1969; Balirwa *et al.*, 2003), making the species to be classified as threatened (Maithya *et al.*, 2012; IUCN, 2018). Overfishing, use of unsuitable fishing gears (small size gill nets) to catch juveniles, expansion of agriculture and destruction of breeding shelters through clearing of vegetation and logging have negatively affected the breeding patterns of the species because the fish were caught in large quantity when schooling at the mouth of rivers (Ochumba and Manyala, 1992; Ogutu-Ohwayo, 2001; Shoko *et al.*, 2007). Consequently, the decline in the number of *L. victorianus* has also affected the Catchment Rivers of Lake Victoria and could not support a productive fishery (Cadwalladr, 1965; Ochumba and Manyala, 1992).

Due to the seasonal changes of the environmental conditions in the Lake Victoria Basin (LVB), the dry and wet seasons are accompanied by fluctuation in the catchment river flow regimes (Masese and McClain, 2012). However, some fish species have the ability to adapt to those fluctuations and food resources available in the ecosystem when the preferred conditions and food resources are rare and to switch to the preferred ones once they become abundant. This ensures survival of the fish during the harsh periods (McKaye and Marsh, 1983). For instance, *L. victorianus* ascends large rivers and streams during the flood for spawning purposes in floodwater pools or inundated grasses at margins of rivers. This may bring insight into how the fish species copes with the fluctuating environment during its migration (Ochumba and Manyala, 1992; Esteves and Lobón-Cerviá, 2001). Understanding the biology and the interaction between *L. victorianus* and its environment is crucial in the management of fisheries resources, though the abundance of the fish species is related to the type of habitat and habitat suitability (Fayazi *et al.*, 2006). Therefore, ecological and biological patterns affecting the riverine fisheries resources in the LVB rivers need to be well understood (Huissman and Richter, 1987; Rutaisire and Booth, 2004; Aruho *et al.*, 2018).

Studies report that food and feeding habits in fishes are influenced by changes in the environment and their diet may change as they grow (Welcomme *et al.*, 2006; Winfried and Nelson, 2012; Mboya, 2012). Ontogenetic shifts in the diet have been reported in *L. victorianus* (Owori-Wadunde, 2004). This is an important finding, which can inform choice of diet, as well as the quality and size of the diet, formulation of diets by farmers in the domestication of *Labeo*. Therefore, if well understood, the feeding habits of *L. victorianus* in natural habitats give an insight into the nutritional requirements for better growth (Abwao *et al.*, 2014). The fish rely on a variety of food which provides the necessary energy for its entire metabolism.

Several studies have examined the biology and the ecology *L. victorianus*, including length-weight relationships, size at first maturity, growth performance reproductive biology; feeding and food composition. Earliest studies on the feeding habits of the fish in the Lake Victoria and its affluents rivers (Kagera, Nzoia, Sondu- Miriu, Sio) include those of Corbet (1961), Ochumba and Manyala, (1992); Owori-Wadunde (2004, 2009). According to these authors, the fish species is an omnivorous bottom feeder grazing rock surfaces, feeding on detritus, diatoms, plant material (macrophytes) and insects. Furthermore, the food varied depending on the age and the location of the fish (Cadwallard, 1965; Rutaisire and Booth, 2004; Owori -Wadunde, 2004). Such observations have also been made for the cyprinid *Barbus altianalis* (Ojwang, 2007) and other potamodromous species in the LVB including *Schilbe mystus* and *Synodontis.* Recent efforts to domesticate *L. victorianus* for aquaculture production as a strategy to improve the conservation of natural populations include Oenga *et al.,* 2010; Abwao *et al.,* 2014; Orina *et al.*, 2014, 2018 focused on hatchery and grow-out manipulations. However, there is little information about the diet and feeding habits of the fish species in the influent rivers of the Lake Victoria Basin.

1.1.Statement of the problem

Rivers of the LVB play an important role as they provide fish food and other services to the surrounding population than the lake basin. Despite the prominence of *Labeo victorianus* in the riverine fisheries of the LVB, contributing about 204 tonnes annually in the 1960s and 70s (Ochumba and Manyala, 1992), there is limited landings currently, with only 0.5 tonnes being landed annually (Cadwalladr, 1969; Balirwa *et al.*, 2003; Mokoro *et al.*, 2014) yet the species accounts for about 17.12% of the riverine fishes in the Kenyan waters (Masese *et al.*, 2020a). This clear decline in the *L. victorianus* fishery has been occasioned by several factors, including the construction of fishing barriers (weirs) and dams, the use of gillnets at the mouth of the rivers which prevent gravid females to move to the flood pools to spawn as well as the hatched larvae from moving back to the lake, the catching of juveniles, and the destruction of breeding habitats have seriously contributed to the decline of the fish species (Cadwallard, 1965; Shoko *et al.*, 2007).

Rivers of the LVB face environmental degradation that also affects extant fish species (Masese *et al.*, 2020a). The riverine habitats are subjected to seasonal variation in the hydrological regimes and food resources available for the fish that may influence the feeding patterns and prevalence (Adite *et al.*, 2005; Welcomme *et al.*, 2006; Masese *et al.*, 2020a). The decline in *L. victorianus* fish stocks in the riverine waters of LVB is now a threat to food and nutritional security of local communities who used to depend on the species for livelihoods. One way of addressing this decline in the abundance and catches of *L. victorianus* is domestication of the species, in order to increase its production for food, while simultaneously conserving natural populations through reduced fishing pressure. However, domestication requires a suitable diet in terms of quality and type of ingredients to be incorporated, for use by the fish.

Long-term studies are needed to understand the food and feeding habits of *L. victorianus* over a temporal and spatial scale, with a focus on the variations, especially as may arise because of different seasons (dry and wet), as well as in different sites (different rivers and the main Lake Victoria), in the LVB of Kenya. It is unclear if the species maintains the same diet or varies the diet in different environments and seasons. Therefore, despite the numerous studies over the years (Ochumba and Manyala, 1992; Owori-Wadunde, 2009), no clear pattern of the food and feeding habits for the species has been discerned to inform formulation of high-quality diets necessary in the domestication of the species.

1.2.Justification of the study

This study intends to examine the variations in the food composition and feeding habits of *L. victorianus* in riverine ecosystems of the LVB to understand the food dynamics of the species in response to the changes in the biotic and abiotic factors in the ecosystem. The spatial-temporal variations in the feeding habits give an insight into the food web, the resilience of the species to the changing environment (Leonhardt *et al.,* 2020). Understanding the resilience of the fish species to environmental conditions is crucial to support the recovery of the species in the Lake Victoria Basin, since this is an important goal for conservation of biodiversity as well as boosting the *Labeo* fishery in LVB, a precious food resource for local community (Mwangi *et al.*, 2012).

Furthermore, knowledge on food and feeding habits in changing environments and seasons helps to understand if the species is a specialized or generalized feeder. This is important in feed formulation to support domestication of the species. Feeding of farmed fish is the costliest activity in commercial aquaculture (El-Sayed, 2014; Schumann and Brinker, 2020), and it is desirable to feed the fish on high quality diet for better production. However, knowing if the fish is a generalist or specialized feeder will have a bearing on the quality and therefore cost of the diet to be formulated. Generalist fish will survive on feed of lower quality, while specialized feeders will need high quality diets in aquaculture. Therefore, comprehensive knowledge of the fish feeding ecology is important for the successful management, conservation of the fisheries biodiversity and commercial farming for food fish and to provide seeds for restocking the indigenous fish into the lake and rivers to meet the demand of the growing population.

1.3. Objectives

1.3.1. General objective

The study aims to assess the effects of environmental and seasonal changes on the food composition and feeding habits of the *Labeo victorianus* in the Lake Victoria Basin of Kenya.

1.3.2. Specific objectives

1. To determine the seasonality of water quality and nutrients in the selected rivers of the Lake Victoria Basin.
2. To determine food composition and feeding habits of *Labeo victorianus* under varying seasons and environments in selected rivers of the Lake Victoria Basin
3. To determine ontogenetic shifts in food composition of *Labeo victorianus* under varying seasons and environments in selected rivers of the Lake Victoria Basin
4. To determine the length-weight relationship and condition factor of *Labeo victorianus* in the selected rivers of the Lake Victoria Basin
5. To determine the population structure of *Labeo victorianus* in the selected rivers of the Lake Victoria Basin

1.3.3. Hypotheses

- H_{O1}. There are no changes in the seasonality of water quality parameters and nutrients in the selected rivers of the LVB.
- H_{A1}. The seasonality influences the water quality parameters and nutrients in the selected rivers of the LVB.

- H_{02}. There are no differences in the food composition of *Labeo victorianus* in response to the seasonality and environmental conditions in the selected rivers of the LVB
- H_{A2}. The seasonality and environmental conditions influence the food composition of *Labeo victorianus* in the selected rivers of the LVB
- H_{03}. There are no ontogenetic shifts in the diet and condition factor of *Labeo victorianus* in the selected rivers of the LVB.
- H_{A3}. Ontogenetic shifts in the diet and condition factor of *Labeo victorianus* differ in the selected rivers of the LVB.
- H_{04}. There are no differences in the length-weight relationship and condition of *Labeo victorianus* in the selected rivers of the LVB
- $H_{A4.}$ The length-weight relationship and condition factor of *Labeo victorianus* differ in the selected rivers of the LVB
- H_{05}. There are no differences in *Labeo victorianus* population size/structure in the selected rivers of the LVB.
- $H_{A5.}$ The population structure of *Labeo victorianus* differs in the selected rivers of the LVB.

CHAPTER TWO

LITERATURE REVIEW

2.1. The Lake Victoria Basin and its aquatic biodiversity

Lake Victoria is the largest lake in Africa sharing its waters with Uganda, Tanzania, and Kenya (43%, 51%, 6% respectively) and the second in the world located between latitudes 0°20'N, 3°0'S and longitude 31°39'E, 34°53'E with nine affluent rivers (Kagera, Nzoia, Yala, Sio, Sondu-Miriu, Nyando, Awach, Mara and Kuja) and the River Nile, the outlet (Ogutu-Ohwayo, 2001). The lake is a square saucer-like shape, with 400 km length, 320 km width, and 92m maximum deep. The Kenyan portion of Lake Victoria represents about 47, 709 km^2 and has diverse water bodies like rivers, satellite lakes, flood plains, ponds, and dams. These water basins harbour unique and endemic genetic resources (Barasa *et al.*, 2014, 2016) and play the role of shelter for the endemic species, providing feeding and breeding habitats for numerous species while have highly contributed to their biodiversity and fish production (Wakwabi *et al.*, 2006; Shoko *et al.*, 2007). Currently the ichthyofaunal biodiversity is threatened due to changes in environmental conditions in the LVB as a result of anthropogenic impacts (Balirwa *et al.*, 2003, Masese *et al.*, 2020a).

2.1.1. The Kenyan catchment of the Lake Victoria

The Kenyan catchment portion of Lake Victoria is composed of water bodies made of several small lakes, rivers, dams, and streams also known as Satellite Water Bodies (SWBs). The main rivers include Sondu-Miriu, Yala, Nzoia, Kibos, Sio, Awach, and Kuja-Migori (Wakwabi, 2006). The satellite lakes include Lake Kanyaboli, Sare, Namboyo at the northern side of Lake Victoria, and the saline Lake Simbi at the South. The majority of endemic fish species that disappeared from Lake Victoria found refuge in these rivers, dams, and wetlands. (Masai *et al.*, 2005). Besides satellites lakes have contributed to the livelihoods of the local communities and also add significance of the lakes in conserving LVB genetic and trophic diversity (Abila *et al.*, 2004, 2008; Barasa *et al.*, 2014, 2016). The majority of these water bodies are made of rocks with coarse surfaces and covered with embedded leaf in decomposition in their upper slopes (Raburu and Masese, 2012). Also, they are particularly dominated by emerged and submerged aquatics macrophytes which create a natural fence preventing the migration of some fish species to low oxygen and high turbidity level tolerance (Masai *et al.*, 2005).

2.1.2. Ecological changes in the Lake Victoria Basin

Lake Victoria is facing changes in the physical and chemical conditions of its waters which occurred since the 1960's due to eutrophication. Water column mixing and seasonal stratification in the lake ecosystem are influenced by intensification of winds (El-Niño-Southern Oscillation cycles) during wet season (Ochumba *et al.*, 1994; MacIntyre *et al.*, 2014). Progressive stratification in the water column has caused the formation of seasonal anaerobic zones in the hypolimnion while long term water resilience (23.4 years) has increased the lake vulnerability to environmental changes that have affected the biodiversity (Ochumba *et al.*, 1994).

The growth of the population was estimated to >3% per year in the basin region (Witte *et al.*, 1992, Ojwang, 2007; Hecky *et al.*, 2010; Njiru *et al.*, 2018; Nyamweya *et al.*, 2020) accompanied by a huge demand for hydropower (Awange *et al.*, 2013). It was estimated that 90% of the total river inputs to the Lake Victoria comes from Kenyan, Rwandan and

Burundi drainages basin where the highest population and agricultural activities were recorded (Verschuren *et al.*, 2002). The nutrient loading is mainly caused by denuding of forests, agriculture expansion, the discharge of untreated municipal sewage associated to industrial activities have caused soil erosion and siltation, chemical overflows into the lake and its catchment rivers leading to high nutrient inputs causing eutrophication, algal bloom, and anoxic bottom layers (Njiru *et al.*, 2018; Nyamweya *et al.*, 2020). Knowing that 80% of the water source in the LVB comes directly from precipitations (Morgan *et al.*, 2021) and more than 70% is taken away through evaporation, the vegetation losses caused by agricultural activities has impacted the amount of rainfalls (Sewagudde, 2009; Liu *et al.*, 2014).

The blooming of phytoplankton has also resulted in the decrease in water transparency and doubled phosphorus concentration in the lake (Ogutu-Ohwayo, 2001; Nyamweya *et al.*, 2020). The role of climate change is important as it governs rainfall patterns and temperature variabilities and also affects the water reservoir in the LVB (Awange *et al.*., 2013). Its potential outcomes are nutrient inflows to have increased two to three-fold since this century (Mungai *et al.*, 2019), rise in temperature (3 to 4 ºC) is projected by the end of this century (Sewagudde, 2009; Awange *et al.*, 2013). The shallow bays especially for those near urban settling have recorded high levels of Electrical conductivity, Total Dissolved Solid, heavy metals, chloride, and ammonia during the dry season while pH levels were low (Awange *et al.*, 2013).

2.1.3. Algal and macrophyte diversity

The lake is rich in algal species composition widely distributed in the lake basin. In riverine ecosystems, the basal energy is supplied by plant material which comes from a foreign source (Masese and McClain, 2012). The alterations in chemical, physical, and hydrological largely observed throughout the lake are affecting the qualitative and quantitative algal community. The blooming of phytoplankton biomass, largely nitrogen-fixing cyanobacteria in replacement to diatoms (*Melosira*) (Ogutu-Ohwayo, 2000; Verschuren *et al.*, 2002), is believed to be the result of climate change, anthropogenic influence, and predation by Nile perch (Wakwabi *et al.*, 2006, Njiru *et al.*, 2018). This situation was believed to be the main reason for the decrease in tilapiine species *O. variabilis* that used to feed on it abundantly (Outa *et al.*, 2020). The decrease in oxygen concentration and water transparency in the lake was also due to the decomposition of algal biomass in the lower layers of the lake (Witte *et al.*, 2012). The floating mats of water hyacinth (*Eichhornia crassipes*) also invaded the shoreline habitats of the Lake Victoria basin in the late 1990's however, it was later successfully controlled by the weevils *Neochetina* ssp. and washed away during El Nino warm and wet weather (Aloo, 2003; Williams *et al.,* 2007).

Macrophytes or aquatic plants are used to assess the environmental health, their distribution, and community patterns are related to their tolerance to various humidity levels (Tiner, 1991 cited in Achieng *et al.,* 2014). Their growth and abundance vary with ecological conditions and nutrient level prevailing in the wetlands, the wet season is favored than the dry, less disturbed ecosystems that have abundant macrophytes biomass (Thenya, 2006; Raburu *et al.*, 2017). It is believed that primary and secondary consumers are the original fish fauna of the lake (Witte *et al.*, 1992). Macrophytes species are abundant on the littoral wetlands and river mouths of the LVB. Over 300 species of phytoplankton and diverse macrophytes communities, sources of primary production are important food for fish larvae (Wakwabi *et al.*, 2006). Macrophytes are important as thatch materials, flood mitigation items, building material and grassland suitable for pasturage. The most important are *Cyperus, Phragmites, Nymphea, Ceratophyllum, Typha, Echinochloa,* and *Potamogeton,* (Thenya, 2006).

2.1.4. Aquatic invertebrate community

The community of aquatic invertebrates is composed of zooplankton (microplankton) and macroinvertebrates, not restricted to the Lake Victoria basin but also to other habitats (Ogutu-Ohwayo, 2000). Macro-invertebrates do not migrate and spend their entire life in a small area; hence they play an important role as water quality bioindicators in aquatic environments (Raburu *et al.*, 2017). They feed on suspended detritus, algae, and aquatic macrophytes and supply the fish food chains with animal protein (Corbet, 1961; Mwebaza-Ndawula *et al.*, 2013). They are made of several taxonomic groups; however, the Diptera (Chironomid, chaoborid) and *Caridina nilotica* are the most abundant (Ogutu-Ohwayo, 2000). Macroinvertebrates are used in different parts of the world in wastewater management and water quality bioassessment protocols (Raburu *et al.*, 2017).

The zooplankton community is mainly composed of *Copepoda*, *Cladocera*, *Rotifera,* and another small group of acarid mites colonizing both the littoral and pelagic zone (Mwebaza-Ndawula *et al.*, 2013). The Cyclopod copepods have replaced the calanoid copepods and Cladocerans, reducing the grazing pressure on the algae (Hecky, 1993 cited in Rutaisire and Booth, 2004). The freshwater shrimp *Caradina niloticus* is abundant in the lake and represents 80% of the diet of the juvenile Nile perch (Cornelissen *et al.*, 2018). Over 54 species of molluscs' diversity (of which one fifth is endemic to the basin), arthropods, odonates, arachnids, crustaceans, reptiles, amphibians and mammals are found in the lake (Wakwabi *et al.*, 2006).

2.1.5. Natural distribution of *Labeo victorianus*

Rivers, dams, and flood plains remain the refuge, breeding and feeding habitats to the endemic species which are now scarce in the main lake (Wakwabi, 2006; Shoko *et al.*, 2007). *Labeo victorianus* inhabits the shallow inshore waters of the lake and rivers and spend part of its life cycle in the LVB (Owori Wadunde, 2004; 2009; Wakwabi *et al.*, 2006). The fish migrates upstream of both permanent and temporary rivers, streams and floodplains to spawn during rainy season when the rivers are flooded (Orina *et al.*, 2014; Masese *et al.*, 2020a). Other *Labeo* species are found across the African continent: *L. gregorii* and *L. cylindricus* in the River Tana while *L. horie*, *L. coubie* and L. *cylindricus* are found in Lake Turkana, Albert, Baringo and Albert Nile (Kibaara, 1986; Lysell, 2009; Kembeya *et al.*, 2019). Similarly, the *Labeo* population is also found in Lakes Edward and George *(L. fuelleborni* and *L. forsakii*), Rukwa, Tanganyika, and Malagarasi River (Ogutu-Ohwayo and Wandera, 1997; Lysell, 2009).

2.1.6. Abundance, landings and economic importance of *Labeo victorianus*

Agriculture including fisheries and aquaculture have contributed up to 38.1% of employment in Kenya in 2016 (FAO, 2018; Obiero *et al.*, 2019). According to the Ministry of Agriculture, Livestock and Fisheries, capture and marine fisheries have contributed at 87.3% of the annual national fish production and have generated KSh 24.546 billion in 2019. Aquaculture production was 18.542 metric tons and contributed 12.6% of the total production.

The migratory species *L. victorianus* supported an important regional fishery in the 1930 to mid-50's and economy of the surrounding population (Cadwalladr, 1965; Ochumba and Manyala, 1992, Owori-Wadunde, 2009; Oyoo-Okoth, 2011). In the 1987-88, the annual yields reached 576 kg/hour in the lower reach of the River Sondu Miriu floodplain (Ochumba and Manyala, 1992). *Labeo victorianus* was one of the most abundant migratory fish species caught by fishermen (Owori-Wadunde, 2009). *Labeo victorianus* (Boulenger, 1901) together with *Clarias gariepinus* (Burchell, 1822), *Barbus altianalis* (Boulenger, 1900), *Schilbe intermedius* (Ruppell, 1832), *Bagrus docmak* (Forsskal, 1775), *Synodontis victoriae* (Boulenger, 1906), and *Synodontis afrofischeri* (Hilgendorf, 1888) are the riverine potamodromous fish species that dominated a commercial seasonal fishery in the LVB in the 1950's (Ojwang *et al.*, 2007; Balirwa *et al.*, 2003) (**Table 1**).

Table 1. Annual summary of fish species found in landings (gill net data) for Lake Victoria at recording stations in Kenya, Uganda and Tanzania in 1957 (LVFS 1958 cited in Balirwa *et al.*, 2003).

	Percentage of total catch (by number)		
Species	**Kenya (7stations)**	**Uganda (10stations)**	**Tanzania (16stations)**
Oreochromis esculentus	46.7	52.5	18
Oreochromis variabilis	14.9	20.2	3.9
Haplochromines	2.6	1.9	12.7
Labeo victorianus	14.7	2.4	31.9
Bagrus docmak	8	9	5.9
Barbus altianalis radcliffi	1.5	1.3	0.5
Mormyrus spp.	6	3.7	3.3
Clarias gariepinus	1.5	1.8	0.9
Schilbe intermedius	2.4	0.2	4.7
Brycinus jacksonii	1.1	5.8	2.6
Synodontis spp.	0.1	0.2	4.8
Protopterus aethiopicus	0.5	1	0.5
Other species	0	0	0.2

Labeo victorianus started disappearing from the catches in the 1960’s (Cadwalladr, 1965). In Tanzania, catches ranged from 10% of the catches in 1958 to 0% of the total fish landing

(Shoko *et al.*, 2007). Uganda has experienced the same reduction in the Kagera River catches ranged from 11.5 cpn in 1936 to 0.5cpn in 1963 **(Fig 1)** (Cadwalladr, 1969; Ogutu-Ohwayo, 2001, Lysell, 2009). The fish species is now restricted to rivers of the LVB where it is facing several threats. *Labeo victorianus* and *Labeobarbus altianialis* contributed to more than 65% of fish biomass per unit effort in the rivers of the LVB (Masese *et al.*, 2020a). Masese *et al.*, (2020a) also reported that *L. victorianus*, *Labeobarbus altianalis*, *Clarias gariepinus* and Mormyrids can sustain a commercial riverine fishery.

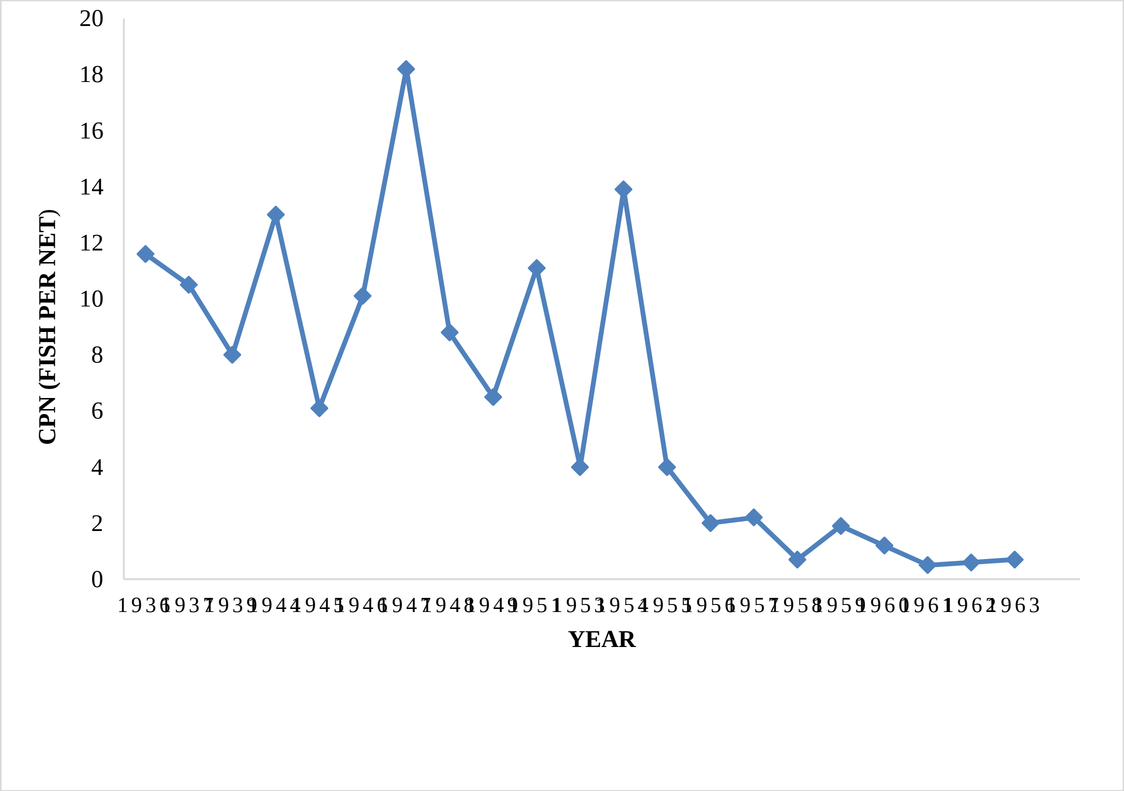

Figure 1. Annual records of *Labeo victorianus* in Kagera River (Cadwalladr, 1965).

2.3. The Biology of *Labeo victorianus*

2.3.1. Morphological features of *Labeo victorianus*

Figure 2. Sexually mature male *Labeo victorianus* from Kagera River (A) and Sio River (B) (Rutaisire, 2003).

Labeo is a genus of carps and belong to the family of Cyprinidae, a pan-African group of species more than 80 species (Weyl and Booth, 1999; Lysell, 2009) found in the freshwater environments of tropical and subtropical Africa and Asia but absent in Europe and America (Rutaisire, 2003). *L. victorianus* measures up to 41 cm long (Ogutu-Ohwayo and Wandera, 1997), a migratory fish species is found in inshore shallow waters and migrate to rivers to breed during wet seasons (Corbet, 1961; Kibaara, 1986; Wakwabi *et al.*, 2006).

Owori-Wadunde (2004), described the fish species as followed: the mouth is formed of soft and retractile lips and located on the ventral side of the body. The buccal cavity is formed of soft teeth and a hard upper palate pad. The oesophagus is a muscular tube measuring 1cm made of epithelial cells that excrete mucus to ease the swallowing of the food. “Ningu” has no true stomach; the digestive system is an extension of the gut and intestines which length can be 11.8 times the body length. The species possesses pharyngeal jaws in their throat that crumbles the food into unidentified gut content (Ojwang, 2007). Its protractile mouth is similar to other cyprinid species (Mboya, 2012).

2.3.2. Feeding habits of *Labeo victorianus*

Cyprinid’s species feed on a diverse diet including zooplankton, phytoplankton, and detritus macrophytes, bacteria, fish remains, insects (Ochumba and Manyala, 1992; Owori-Wadunde, 2004; Oenga *et al.*, 2010; Orina *et al.*, 2018). Corbet (1960) highlighted that the clear understanding of the progressive decline of the fishes and the complex habitat ecology as the main reasons for investigating the feeding habits of non-cichlid fishes in Lake Victoria.

According to Mboya (2012), the feeding regime of a fish species vary with the age of the fish, the habitat and is dependent on other fish species. It can change with the moon phase, size of the fish or the feeding ground where the fish was caught. Though, many fish species feed on more than a single type of food.

In their early stage, after the absorption of the yolk sac the fish species feed on rotifers, then slowly switch from animal-based to plants food items. The shift in diet during the growth stage has qualified the fish species to experimental studies in fish farming. Due to the seasonal change of the environmental conditions in the LVB, the dry and wet season are accompanied with fluctuation in the catchment river flow regimes (Masese and McClain, 2012). *Labeo* sp. were reported as algal grazers, feeding on epilithic and epiphytic algae (Corbet, 1960; Owori-Wadunde, 2009). The species *Labeo victorianus* is a bottom feeder and omnivorous, consuming mostly detritus of plant material. The species have different feeding habits which allow a wide range of food available. This is due to the position and the structure of its mouth well adapted for scraping surfaces and filtering detritus submerged (Owori-Wadunde, 2009).

2.3.3. Spatial and temporal variation in the feeding habits of *Labeo victorianus* in the Lake Victoria Basin

Investigations carried out by Owori-Wadunde (2009), in the Lake Victoria Basin suggests that there is variation in the feeding habits of *L. victorianus* based on the adaptability of the fish species to different habitats. The fish species only feed during day time. According to the same author, the fish feed on detritus, fine sand particles, *Cladocerans, Baciliophyta* (diatoms), and *Cyanophyta* (84,6% of the gut content) in the River Sio while in the River Kagera, 90.5% of the gut content was made of detritus, fine sand, plant tissue, *Chlorophyta*, and *Baciliophyta*.

Before they can start feeding, the post hatched larvae depend on the yolk sac for at least 5 days, the time when the digestive system is developing to start external feeding. The smaller gut length of the juvenile “Ningu” compared to the adult confirms that the juvenile feed on animal-based diets (zooplankton) to later divert to plant diets as they grow, preferably when they are two weeks old. Adult ‘Ningu’ was found to be omnivorous, mainly feed on plant-based detritus (Owori-Wadunde, 2004).

2.3.4. Breeding and behaviour of *Labeo victorianus*.

Cadwalladr (1965) reported that the fish species exhibit a migratory behaviour up to the river Kagera and Sio (Uganda) likely to spawn during March-April and September-November as shown in Fig 3, and is associated to rainfall season. In the Mara river, the gravid females are obtained during the bi-annual breeding migrations (April, May, and September) in Kenya (Kembeya *et al.*, 2017).

However, variations in peak breeding activity implied that the spawning started before the rainy season and continued after it (Ochumba and Manyala, 1992). This phenomenon is also related to the fullness of the gut content and the mesenteric fat, suggesting that the fish feed intensively before breeding (Owori-Wadunde, 2004, Ochumba and Manyala, 1992, Rutaisire and Booth, 2004). Other factors related should be taken into consideration to activate the breeding and the gonad maturation like the flood regime and water quality parameters (Whitehead, 1959a, cited in Ochumba and Manyala, 1992). Fry return to the lake when they are 3 to 4 weeks old (Cadwalladr, 1969). The fecundity, fertilization, and hatching rates are high and correlated to the length of the fish. A single female can produce up to 70 000 eggs under controlled conditions (Rutaisire and Booth, 2004; Kembeya *et al.*, 2017). According to Rutaisire and Booth (2004), female length *L. victorianus* at maturity was between 11.8 and 21.9cm while for the male it ranges between 12.8 and 22.1cm.

In the natural habitat, suitable conditions patterns are necessary for the fish to spawn including the size at sexual maturity, duration, and periodicity of breeding while in culture systems, nutrition, temperature, and environmental conditions should be considered (Rutaisire and Booth, 2004). The larvae are transparent and minuscule (Kembeya, 2017).

They quickly develop swim bladder and pectoral fin after two days to escape from threat and search for food (Owori-Wadunde, 2004).

Labeo victorianus is unable to breed naturally under captivity; hence artificial breeding methods are imperative for aquaculture perspectives (Maithya *et al.*, 2012). Recent investigations on the breeding of *L. victorianus* include those of Rutaisire and Booth, (2004; 2005) and Kembeya *et al.* (2017). However, there is need for studying breeding behaviour of the fish species in different environments of the LVB.

2.3.5. Habitat preference for *Labeo victorianus* growth

Habitat classification might be based on different characteristics like depth, vegetation, or nearest shoreline type. However, Corbet (1960) classified three types of habitat based on the bottom deposit: hard (made of rock, gravel or sand), soft (made of Humus, clay, mud, or silt) or Mixed (a combination of hard and soft features). In the Lake Victoria, rocky shores and islands harbouring shallow waters are known to be shelter for endemic fishes (Wakwabi *et al.*, 2006).

Labeo victorianus, for instance, inhabits shallow water (0-20m deep) on substrate habitats like rocks, stones, logs and sand or aquatic animals (Lysell, 2009; Owori-Wadunde, 2009). The species have different habitats preference, lives near the river mouth on submerged rocks and coarse cliffs and shelves and is well adapted to flowing waters, with a foraging habit on periphyton algae (Cadwallard, 1965; Rutaisire and Booth, 2004, Maithya *et al.*, 2006). According to Ojwang *et al.*, (2007), there are piece of evidence that *L. victorianus* has 2 subpopulations, the potamodromous population which migrates and, the riverine population which completes its entire life in the river.

2.2. *Labeo* in aquaculture

The growing world population is accompanied by an increasing demand for food, whereby fish culture plays an important role as a global perceptive to meet the demand for quality and affordable food products after the collapse of the yield of the wild stock in most developing countries where the population density is increasing (De Silva, 2001; Kuria *et al.*, 2012; Obiero *et al.*, 2019). The projective demand for fish production in Kenya reaches 51.320 tonnes while the demand was estimated to 261.462 tonnes in the early 2020's (Obiero *et al.*, 2019). There is a high preference for riverine fishes including *L.victorianus* and their market value is high (Mwangi *et al.*, 2012). Aquaculture perspectives become more attractive for farmers.

Several investigations were carried out to understand the biology of the *L. victorianus* to be introduced into fish farming and to restore the declining wild stock. The domestication and captive propagation are practical and the most used alternative for endangered species for their conservation (Rutaisire, 2003). It is also effective in improving the livelihood of rural populations (De Silva, 2001). For the long-term culture of the fish, studies made by researchers yield positive outcomes in terms of growth, successful artificial reproduction, stress resistance and adaptation to exogenous diet to produce a hatchery-raised population intending to produce a large amount of juvenile, to respond to the increasing demand, supply of the fish and protein (Huisman and Richter, 1987; Rutaisire, 2003; Rutaisire and Booth, 2004; Maithya *et al.*, 2012; Owori-Wadunde, 2009; Kuria *et al.*, 2012; Abwao *et al.*, 2014; Orina *et al.*, 2014; Kembeya *et al.*, 2017).

The shift in diet during the growth stage and the omnivory feeding behavior is important in formulating suitable artificial diets for the domestication of the fish species in the aquaculture industry (Oenga *et al.*, 2010; Kuria *et al.*, 2012; Abwao, *et al.*, 2014). Owori-Wadunde (2009) found that *L. victorianus* larvae fed on zooplankton has shown a high growth and survival rate than those fed on plant-based diets. However, though the culture of the native fish species is important, its sustainability depends on the ecosystem stability and requires scientific knowledge and elaborated programs that must include rural populations (Maithya *et al.*, 2012).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study area

The study was conducted in the Nyando, Nzoia, Sondu –Miriu, Awach, Yala, Mara Rivers and some shoreline streams of Lake Victoria, Kenya (Figure 3). Most originate in the Mau Forest Complex and the western escarpments of the Great Rift Valley. The Nzoia River, which is the largest of the LVB Rivers in Kenya, also has its source in Mt Elgon.

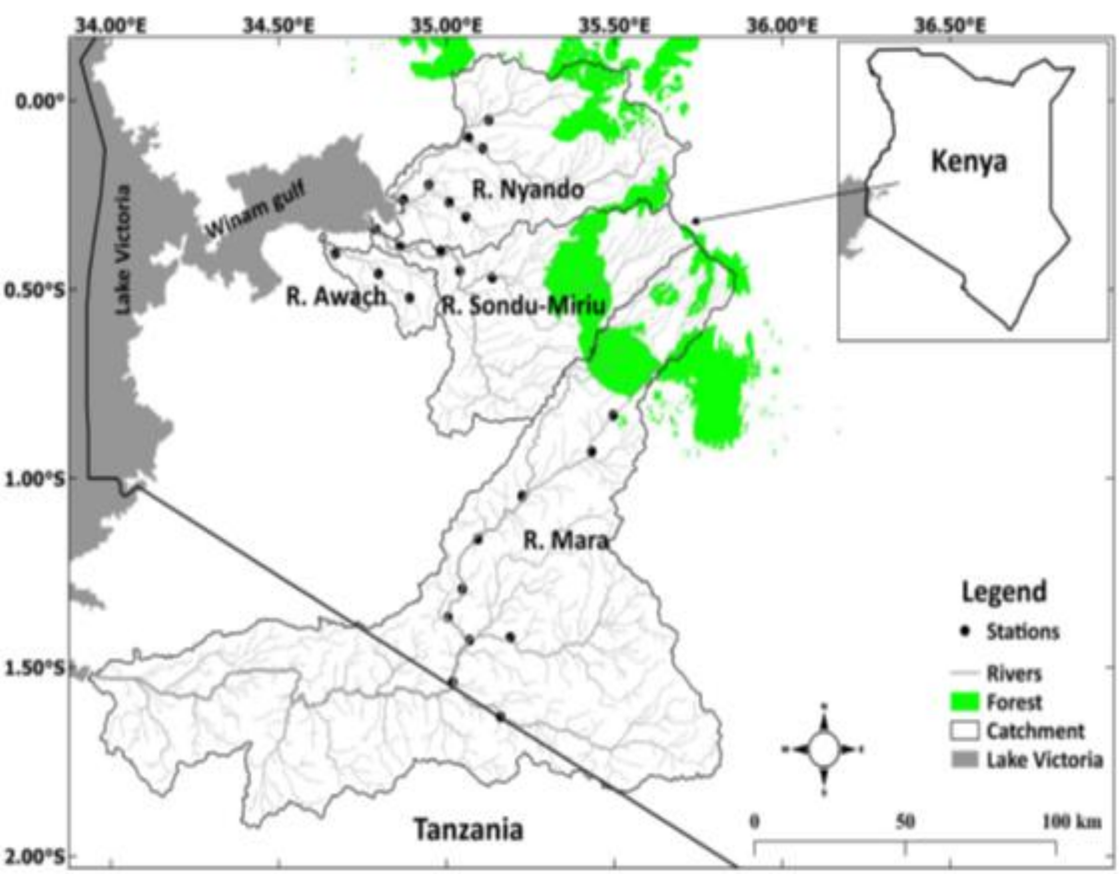

Figure 3. The sampling sites in the LVB, Kenya Rivers. The points in black represent sites in the Nyando, Awach, Sondu-Miriu and Mara Rivers where *Labeo victorianus* samples used in this study were collected from (Source; Achieng *et al.*, 2020)

The rivers have witnessed land use and land cover changes in their catchments over the years, characterized by expanding agricultural and declining indigenous forests (Mati *et al.*, 2008).The growth of human population and waste disposal from urban areas and agro-industrial activities- pan paper mills (Nzoia), sugarcane processing (Nzoia and Nyando) are multiple sources of pollution which contribute to the poor water quality. Primary source of energy assured by plant material depend on the coverage vegetation surrounding, expected to increase with the river size and the reduced canopy (Masese and McClain, 2012). The allochthonous materials from different sources carried by the river flow are discharged in the river system allowing ecological and productivity differences between the rivers (Kanda *et al.*, 2015; Achieng *et al.*, 2020).

The climate in the LVB shows the same characteristics to that of the East African region, varying from tropical in the savannah to wet tropical in the mountain areas (Masese and McClain, 2012). The annual rainfalls ranging from 800 mm/year (in the lowlands and south side of the lake) to 2200 mm/year (in the highlands) occur twice a year, between March and June and between September and November (Masese *et al.*, 2020a). The riparian features, used as buffers to the ecosystem play an important for physical and biological quality of the streams and rivers by minimizing the nutrient and sediment loading, promotes vegetation cover and lower water temperature and negatively affect the fish assemblages. Therefore, the connection between riparian in stream features and fish and food availability are used to assess the aquatic habitat disturbance in the tropics (Junk *et al.*, 1989; Fischer *et al.*, 2010; Masese and McClain, 2012).

Ceratophyllum, phragmites and Cyperus papyrus are the vegetation found in the lower regions of the river banks (Omondi and Ogari, 1994). From the river mouth to Odino Falls, the substrate is mostly silty mud, sand, stones and rocks with a variety of vegetation dominated by Papyrus swamps and *Phragmites sp.* (Ochumba and Manyala, 1992) while most of the tributary catchments are made of rocks, covered with coarse surfaces with leaf litter in decomposition (Raburu and Masese, 2012).

3.1.1. Study design

Site selection in the rivers: sites selected in least impacted and impacted sites for comparisons. Sites were located upstream and downstream of point sources of pollution (Webuye Paper Mills, Chemelili and Muhoroni Sugarcane Processing). Sites were also selected in seasonal streams and rivers (Awach and Talek tributary in River Mara). Other sites were selected for spatial coverage of LVB Rivers. Sampling was done during the dry (January-March and July-August) and wet (April-June and October-December) for temporal comparisons of food composition and condition.

3.1.2. Physical and chemical variables

Data on physico-chemical water quality variables were collected from March 1998 to February 2020 during sampling for the fish. Dissolved oxygen (mg/l), pH, electrical conductivity (µScm^{-1}), turbidity (NTU) and temperature (°C) were collected in-situ using YSI multi-probe water quality meter (556 MPS, Yellow Springs instruments Ohio, USA).

3.1.3. Fish sampling

Labeo victorianus was obtained from the river by electrofishing. Fish sampling was done using a generator-powered bank electrofisher (Honda GX240 8HP; 400V and 10A). During fishing, the power of the electrofisher was calibrated based on the water conductivity on the sampling sites (range 34-572µScm^{-1}). Sampling was carried out during daytime hours through which the dazed fish were collected using a 17mm mesh-size hand net (Achieng *et al.*, 2020).

The total length (TL) was measured from the tip of the mouth to the caudal fin. The standard length (SL) was measured from the tip of the mouth to the base of the caudal fin. TL and SL were measured using a caliper calibrated in centimeters. The weight was immediately measured using a portable weighing scale model CY 220.

3.1.4. Laboratory analysis

Total Nitrogen, Total Phosphorus, Soluble Reactive Phosphate, Nitrate, Nitrite, Total Ammonia) at different sites were determined at the laboratory. The laboratory analysis procedures used for this study are those adopted by the APHA (1998) standards.

3.2. Stomach contents

A total of 277 fish specimen were obtained for this study. The fish was gutted and the stomach contents labelled indicating the site collected and the date of collection. The fish samples were fixed using 5% formaldehyde. The stomachs were opened and the food contents removed and spread on petri-dishes where water was added for separation of small particles before examination on microscope (OPTIKA WF X10/20).

Food items were separated into five (5) broad categories: sand and mud, insects and Mollusca, plant material, algae/periphyton and detritus. The proportion of each food category was estimated and compared between the stations and seasons.

Food composition

A number of parameters were determined to capture food composition of *L. victorianus*. These included:

3.2.1. Frequency of occurrence (% N)

The record of stomachs containing each food items was recorded and expressed as a percentage of all stomachs. The following formula was used: **$\% N = (Ni / \Sigma Ni) * 100$** where Ni is the percentage of occurrence of a food item recorded in the stomach,

Σ Ni is the total number of food items recorded in the stomach (Hyslop, 1980).

3.2.2. Ontogenetic shifts in food composition.

The importance of different food items for different size of fish was determined by dividing the fish samples into four size classes (A = fish TL 5.0 -10.4 cm, B = 10.5-20.4 cm, C = 20.5-30.4 cm, and D = >30.5 cm).

3.3. Relative condition factor (K_n)

A total of 277 fish samples were used for this study collected from August 2009 to February 2020.To minimize error arising from seasonal fluctuations in body weight due to feeding, fish total weight obtained in single sampling regime for calculating relative condition factor was used to determine the length-weight relationship (Ondhoro *et al.*, 2016).

Relative condition factor was used to compare the conditions of fish populations among rivers and seasons. Relative condition factor is the ratio of observed individual fish weight to expected or predicted weight of a given individual of a given length.

$K_n = W_i / aL^b_i$ (Le Cren, 1951) where K_n is the relative condition factor, W_i is observed individual fish weight, L_i is observed individual fish total length and ***a*** and ***b*** are species-specific constants. The regression constants were obtained from the overall length-weight relationship ($W = aL^b$) derived by pooling data for each river system per season (Ondhoro *et al.*, 2016).

3.4. Determination of sexual maturity and sex ratio

The stage of sexual maturity was based on microscopic morphological appearance of the gonads followed by anatomic dissection and/or external characters and classified according to a five-stage scale described by the method of Rutaisire and Booth, (2003). Gravid males and females were easily identified upon gently squeeze of the stomach (Abwao *et al.*, 2014).

The length-at-maturity was determined as the length at which 50% of the fish samples are sexually mature fitting a logistic function to the proportion of mature fish (Rutaisire and Booth, 2004). The proportion of mature fish (PL) was predicted using a model in each group of individuals (L) as followed: $\mathbf{PL= (1+exp\ (L - L_{50})/\delta)-1}$ where L_{50} is the length at maturity and δ is the rate at which maturity attained (King, 1995). Sex ratio was determined from the collection of the mature fishes using Chi square test.

Table 2. **The Microscopic description of various stages of gonadal recrudescence of *Labeo victorianus* (Rutaisire and Booth, 2003)**

Stage	**Male**	**Female**
Juvenile	Testes threadlike translucent strap	Ovaries not distinguishable from testes. Also appears as a thin translucent stap
Maturing (including virgins and recovery spent fish	Testes thick, straight and translucent	Ovaries straight. Ova white in colour and visible through the capsule
Late maturing	Testes enlarged, begin to form lobes and turn white. Mesenteric fat present around the testes	Ovaries increase in size, form lobes, is the largest organ in the abdominal cavity and is covered with mesenteric fat. Ova greenish in colour.
Ripe	Testes white convoluted and is the largest organ in the abdominal cavity. Mesenteric fat layer less than in stage 3	Ovaries are fully distended and fill the abdominal cavity. Oocytes olive green ad easily shed on application of slight pressure on the belly
Ripe running	Testes appeared as straight, thin, largely translucent strap on either side of the swim bladder ventral to the kidney	Ovaries flaccid and often haemorrhagic if spawning was successful. Few oocytes visible, giving the ovary a speckle appearance

3.2. Statistical analysis

We used two-way analysis of variance (ANOVA) to test for differences in water physical and chemical variables among rivers (Awach, Mara, Nyando and Sondu-Miriu) and seasons (dry and wet) with rivers and seasons as main factors and rivers × season interaction term.

Principal Component Analysis (PCA) was used to reduce the dimensionality of the physico-chemistry data. We included two PCs to describe water quality. PCAs were statistically assessed using permutational analysis of variance (PERMANOVA) based on Bray-Curtis dissimilarity matrices (Anderson, 2001; McArdle & Anderson, 2001).

Two-way nested analysis of similarities (ANOSIM) was used to compare average rank similarities in food composition among rivers and between seasons, with rivers nested within seasons. This analysis was performed to check if *L. victorianus* shifted its diet and food composition spatially “rivers” and seasonally “season”. Further One-way ANOSIM was used to test for ontogenetic shifts in food composition in *L. victorianus*, with size classes (4 in number) used as response variable. ANOSIM calculates a test statistic, the R-statistic, which varies between 0 and 1; higher values indicate greater differences between factors.

Non-metric multidimensional scaling (NMDS) was used to visualize food composition in different rivers and with seasons. Dissimilarity matrices based on the Bray–Curtis coefficients (Bray and Curtis, 1957) were derived arcsine transformed data using the R function “vegdist” (Gardener, 2014). Goodness of fit of the ordination was assessed by the magnitude of the associated stress value, with a value of <0.2 corresponding with a good ordination (Kashian *et al.*, 2007).

Permutational multivariate analysis of variance (PERMANOVA) was used as implemented in the “adonis” function of the vegan R package (Oksanen *et al.*., 2018) to test for significant differences in food composition with rivers nested within seasons. Pairwise differences in food composition between rivers were run for all pairs of rivers and seasons using “adonis.pair” function of the EcolUtils R package (Salazar, 2018), and used Bonferroni correction to set significance levels for p values. In all the aforementioned tests, statistical significance was determined by 999 permutations.

CHAPTER FOUR

RESULTS

4.1. Water physico-chemistry and nutrients

There were significant differences in water physico-chemical variables among rivers (ANOVA F=8.4, df = 3, p <0. 001), and between seasons (ANOVA F=45.1, df= 1, p <0. 001), with a significant rivers X season interaction (ANOVA F =13.7, df = 1, p <0. 001) (**Table 3**). There were significant differences in water quality between seasons (PERMANOVA F=16.6, df= 1, p=0. 001), among rivers (PERMANOVA F =17.9, df = 3, p=0. 001), and with a significant season X river interaction (PERMANOVA F =13.7, df = 1, p =0. 001). The PCA (PC 1) axis explained 40.6% of the total dataset variance, while the second PCA axis (PC 2) explained 21.5% of the total variance in water physico-chemistry (**Figure 4**). The PCA summarized relationships among water quality variables in the rivers (**Figure 4**). The first two PCA axes explained 62.1% of total variance in water physico-chemistry among the rivers. Sites in the Mara River recorded high electrical conductivity, turbidity and temperature during the dry season (**Figure 4**). The other rivers (Awach, Nyando and Sondu-Miriu) recorded higher nutrient concentrations than the Mara River. Higher nutrient concentrations were recorded during the wet than the dry season (**Figure 4**).

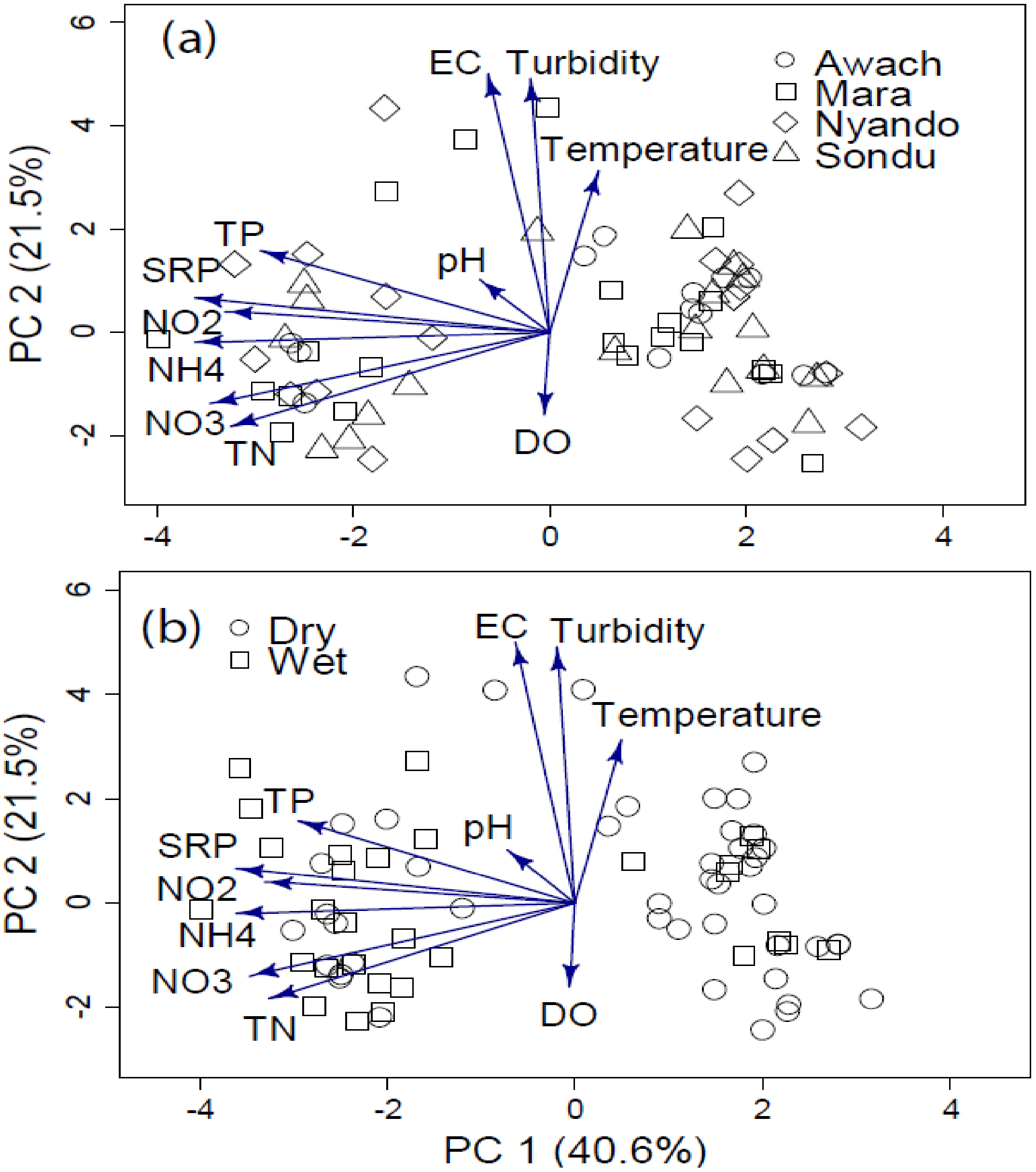

Figure 4. Principal Component Analysis (PCA) biplots for water quality physico-chemical variables for the Awach, Mara, Nyando and Sondu-Miriu (Sondu) rivers. The upper panel (a) displays loadings for rivers defined by water quality, and the lower panel (b) shows loadings for seasons.

Table 3. Means (±SD) for water quality physico-chemical variables and nutrient concentrations in Awach, Mara, Nyando and Sondu-Miriu Rivers during the dry and the wet seasons

Variables	**Season**	**Awach**	**Mara**	**Nyando**	**Sondu-Miriua**	**F-Value**	***p*-value**
Temperature (°C)	Wet	19.82±2.49	19.17±2.64	21.5±3.72	19.57±1.77	1.45	0.215
	Dry	--	23.37±1.32	--	21.8±2.6		
EC (µS/cm)	Wet	121.3±49.3	66.3±13.41	273.2±130.3	60.51±10.76	2.50	0.037*
	Dry	--	403.4±142.1	--	65.47±10.44		
Dissolved oxygen (mg/L)	Wet	6.57±1.58	7.5±0.47	8.29±0.9	6.82±0.9	2.07	0.077
	Dry	--	5.85±0.57	--	7.98±0.32		
pH	Wet	6.96±1.21	7.5±0.15	8.09±0.87	7.43±0.29	2.19	0.063
	Dry	--	7.3±1.46	--	7.49±0.26		
Turbidity	Wet	176±205	16805±69.1	178.3±84.7	39.36±7.04	3.19	0.011*
	Dry	--	135.4±38.9	--	49.37±15.15		
Total nitrogen	Wet	10641±6711	1599±294	8476±5813	12793±2138	11.66	0.000***
	Dry	--	2528±351	--	2341.3±331.3		
Total phosphate	Wet	3458±52.3	559.4±210.6	758±244	410.2±58.6	19.04	0.000***
	Dry	--	326±86.3	--	87.37±26.11		
Soluble Reactive phosphate	Wet	145.8±52.3	62.67±20.45	558±244	210.2±58.6	23.17	0.000***
	Dry	--	35.44±19.38	--	14.36±2.26		
Nitrate (NO3)	Wet	6755±5443	47.87±5.08	6560±4164	10605±1997	9.88	0.000***
	Dry	--	100.0±46.1	--	216.1±61.7		
Nitrite (NO2)	Wet	1180±558	24.08±11.44	621±613	444.5±203.8	5.44	0.000***
	Dry	--	425±38.9	--	60.7±54.2		
Ammonium (NH4)	Wet	2506±2563	24.22±9.16	1095±1414	1543±1297	5.89	0.000***
	Dry	--	122.7±83.7	--	13.43±5.62		

* Asterisks on p values are for significant differences: *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$

4.2. Diet and food composition of *Labeo victorianus* in the four rivers of the Lake Victoria Basin, Kenya

Non-metric multidimensional scaling (NMDS) based on diet and food composition showed a clear differentiation between rivers (PERMANOVA F = 10.2, df = 3, p = 0.001) (**Figure 5**). Further differences were obtained between river X season combinations (PERMANOVA F = 11.6, df = 4, p = 0.001) (**Figure 6**). There were also differences in food composition between size classes (PERMANOVA F = 4.6, df = 3, p = 0.001), indicating an ontogenetic shift in diet of *L. victorianus.* *Labeo victorianus* larger than 30cm fed largely on insects (43-57%). The consumption of detritus decreased as the size increased (47-28%) while consumption of sand inversely increased with the size (0-14%) in Mara and Sondu Miriu River (**Figure 7**). There was an influence of seasonality on food composition among the size classes; (PERMANOVA F = 3.29, df = 3, p < 0.001) (**Figure 8, Table 4**) river X season combinations was not significant. There were no clear patterns of association between food composition, seasons and size classes.

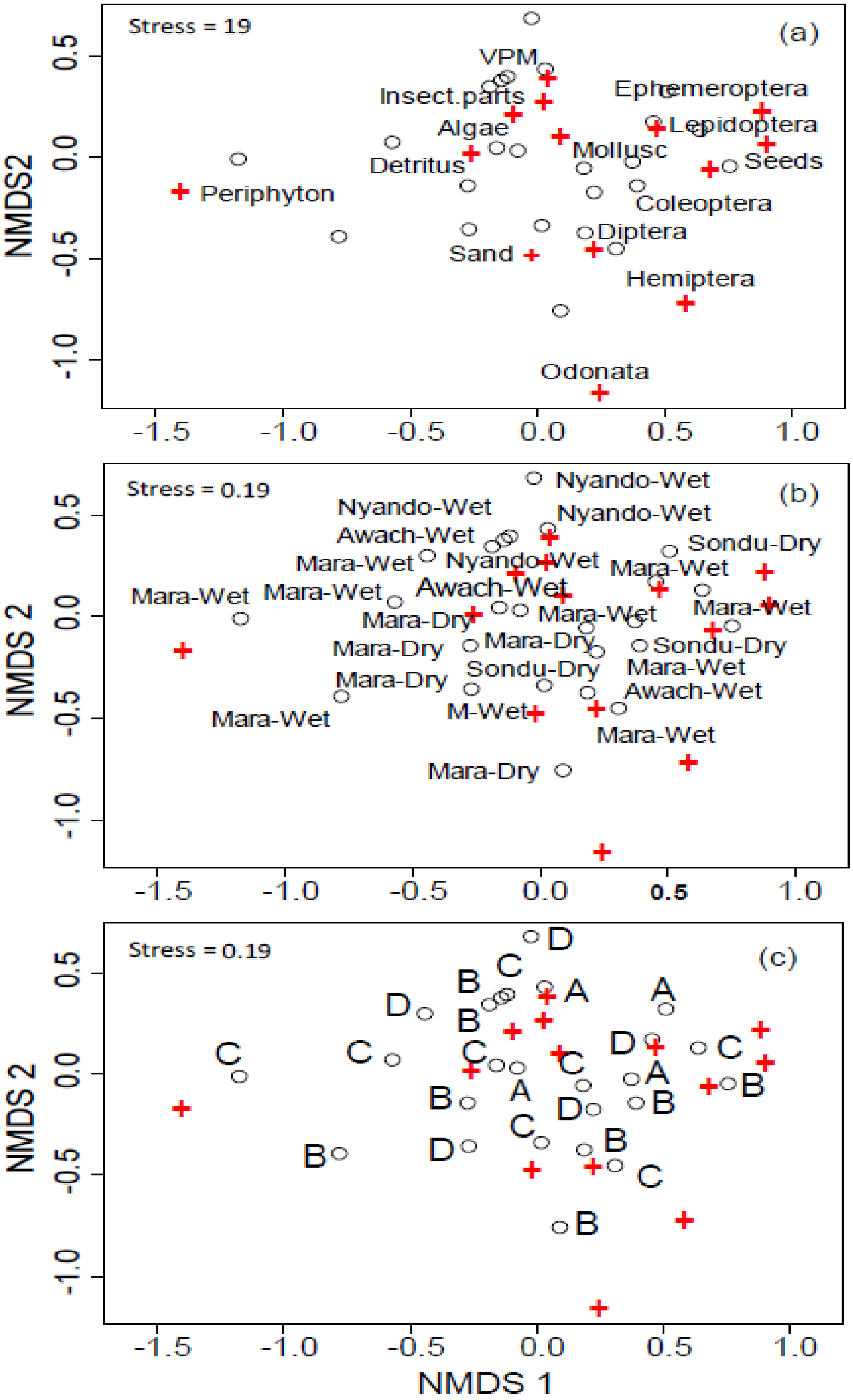

Figure 5. Non-metric Multidimentional Scaling (NMDS) based on the diets and food composition of *Labeo victorianus*.

The three panels are the same ordination with different loadings for (a) food composition, (b) rivers, and (c) size classes in terms of length (cm): Rivers and seasons: Awach-W = Awach wet, Mara-D=Mara dry, Mara-W=Mara wet, Nyando-W = Nyando wet, and Sondu-D = Sondu dry. Size classes: A = fish total length: 0.5-10.4 cm, B = 10.5-20.4 cm, C = 20.5-30.4 cm, and D = >30.5 cm.

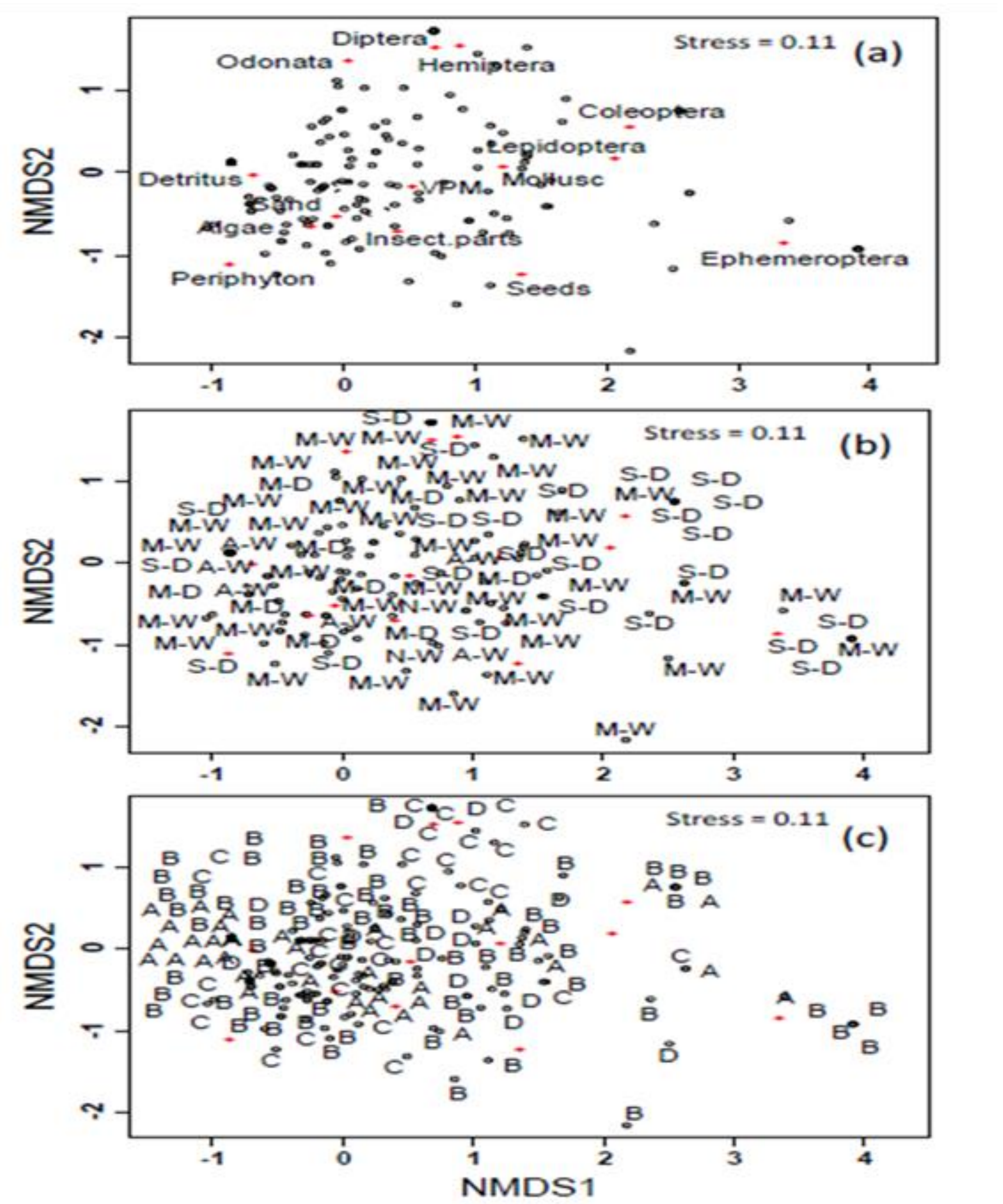

Figure 6. Non-metric Multidimentional Scaling (NMDS) based on the diets and food composition of *Labeo victorianus*. A-C is the same ordination with loadings for (a) food composition, (b) rivers, and (c) size classes in terms of length (cm): Rivers and seasons: A-W = Awach wet, M-D = Mara dry, M-W = Mara wet, N- W = Nyando wet, and S-D = Sondu dry.

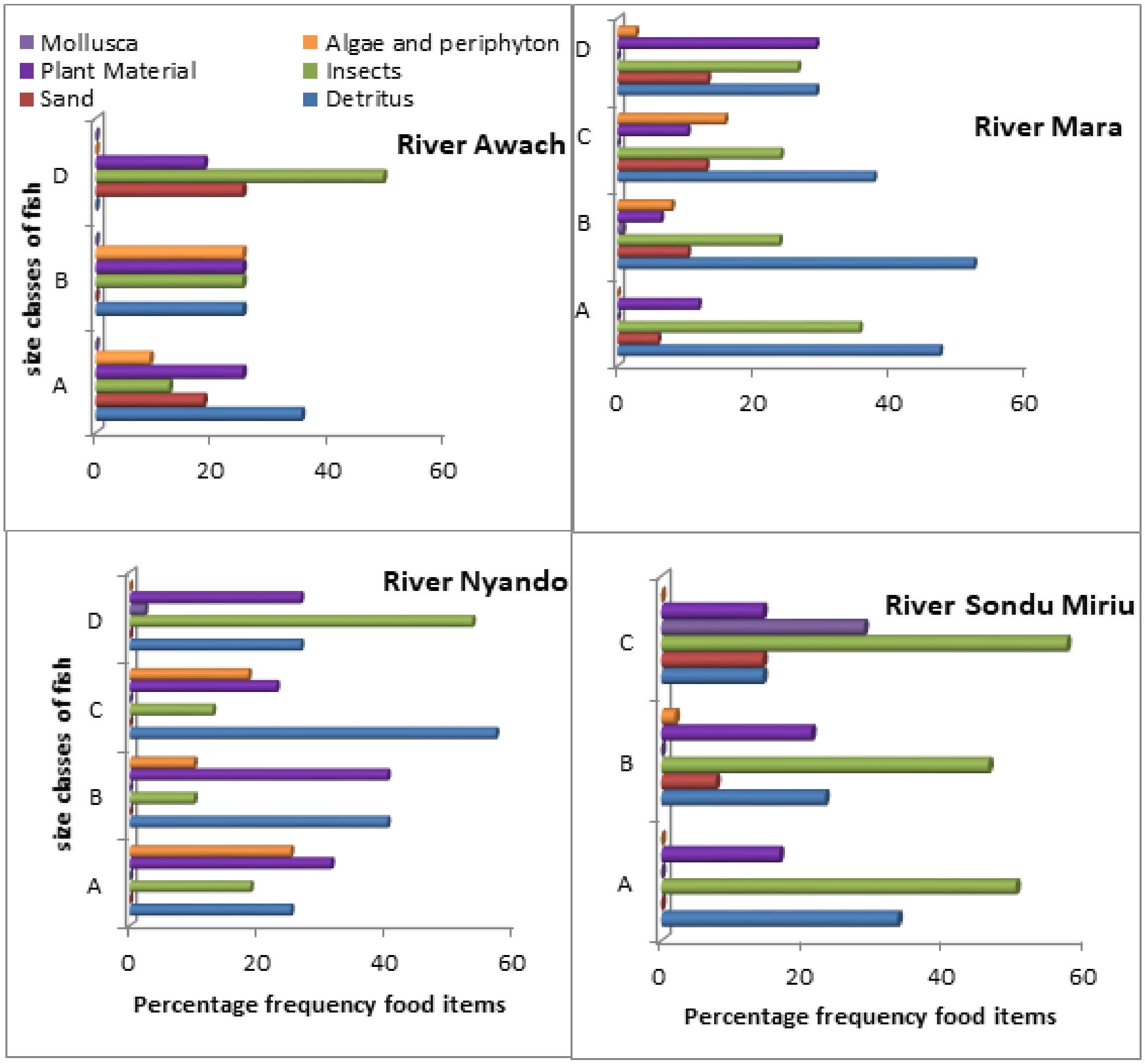

Figure 7. Variation in the food composition of *Labeo victorianus* per size-classes in the sampled rivers. Size classes: A = fish total length 0.5-10.4 cm, B = 10.5-20.4 cm, C = 20.5-30.4 cm, and D = >30.5 cm

Seasonal variation of the food composition of *Labeo victorianus* in the four rivers of the Lake Victoria Basin

There was an influence of seasonality on the food composition (Chi square test, *p<0,001*). Detritus, insects and plant material were more consumed in the wet season while algae and periphyton and sand were most consumed in the dry season (Fig 9).

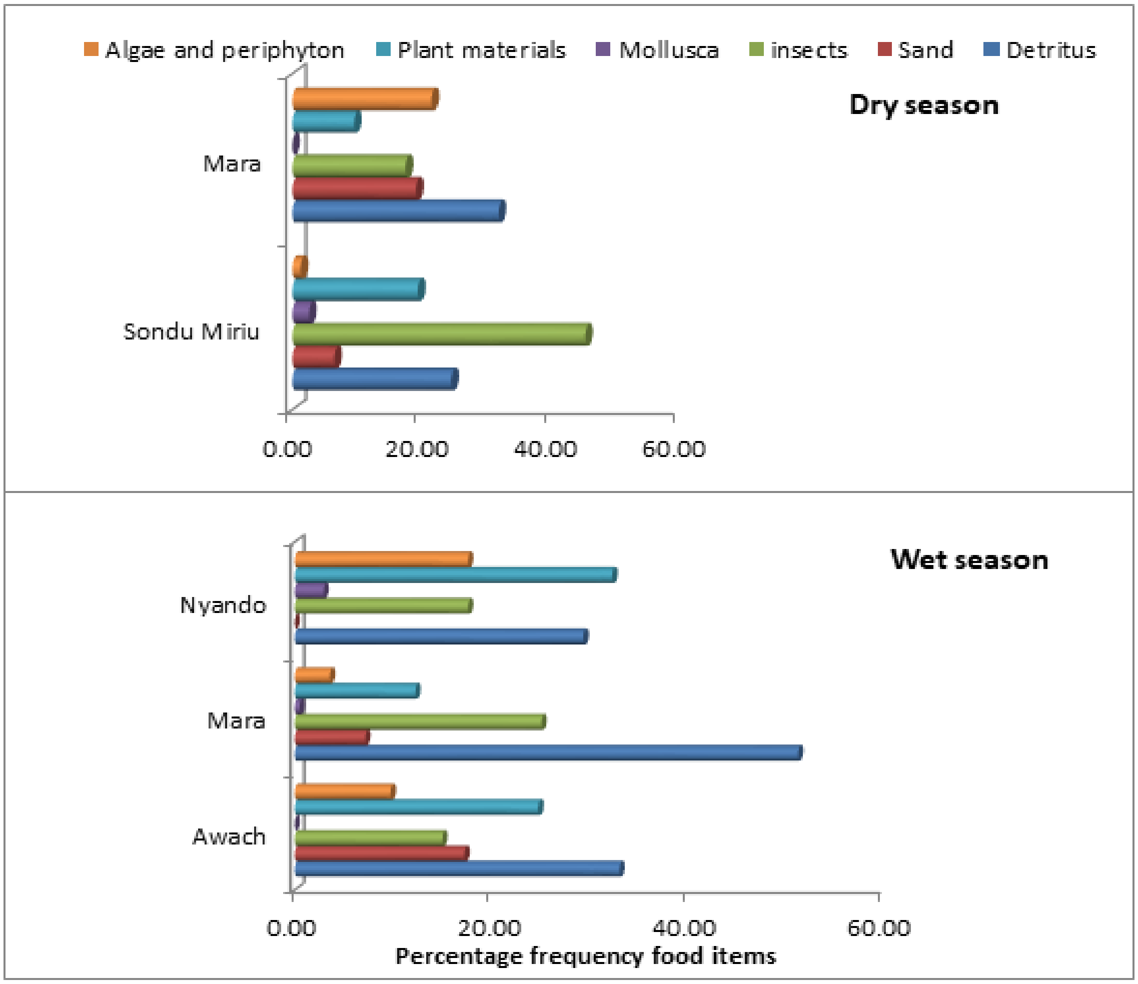

Figure 8. The seasonal variation in the food composition of *Labeo victorianus* in the Lake Victoria Basin.

Table 4. Pair-wise PERMANOVA for food composition in *Labeo victorianus* between rivers, combinations of rivers and seasons and size-classes and seasons.

	PERMANOVA statistics		
Comparisons	***F* - Model**	***R*²**	**Corrected *P* - value**
Rivers			
Awach vs Mara	16.5	0.07	0.002***
Awach vs Nyando	2.1	0.04	0.083
Awach vs Sondu	19.8	0.18	0.002***
Mara vs Nyando	7.2	0.04	0.003***
Mara vs Sondu	12.1	0.05	0.002**
Nyando vs Sondu	7.3	0.12	0.007***
Rivers X seasons			
Dry_Mara vs Dry_Sondu	17.5	0.18	0.002***
Dry_Mara vs Wet_Awach	4.8	0.05	0.006***
Dry_Mara vs Wet_Mara	19.4	0.10	0.002***
Dry_Mara vs Wet_Nyando	6.6	0.11	0.002***
Dry_Sondu vs Wet_Awach	19.8	0.18	0.002***
Dry_Sondu vs Wet_Mara	12.4	0.06	0.002***
Dry_Sondu vs Wet_Nyando	7.3	0.12	0.003***
Wet_Awach vs Wet_Mara	23.3	0.12	0.002***
Wet_Awach vs Wet_Nyando	2.1	0.04	0.094
Wet_Mara vs Wet_Nyando	9.2	0.06	0.002***
Size-class#			
A vs B	6.7	0.04	0.012*
A vs C	4.3	0.03	0.024*
A vs D	4.0	0.04	0.024*
B vs C	1.5	0.01	0.265
B vs D	3.2	0.02	0.050
C vs D	1.3	0.01	0.276

#Size classes for *Labeo victorianus* are: A = 5.5-10.5 cm, B = 10.5-20.5 cm, C = 20.5-30.5 cm, and D = > 30.5 cm. *Asterisks on p values are for significant differences: $*p < 0.05$, $**p < 0.01$ and $***p < 0.001$.

4.3. The spatial and temporal variation in the condition factor of *Labeo victorianus.*

4.3.1. Abundance and relative condition of *Labeo victorianus* in the sampled rivers

The mean condition factor for *L. victorianus* is shown in **Table 5.** *Post-hoc* test indicates no significant variation in mean relative condition (K_n) of *L. victorianus* (ANOVA F= 0.54, *p* = 0.65) in the sampled rivers. The mean condition factor recorded for this study varied between 1.019 and 1.056 for Mara and Sondu Miriu rivers respectively. The mean condition factor value *K* is around 1.00, showing that the condition of the fish good. The length (ANOVA F = 64.20, df = 3, $p < 0.001$) and weight (ANOVA F = 25.56, $p < 0.001$) were significantly different in fish of the river Mara.

Table 5. Statistical description obtained from *L. victorianus* sampled in the different rivers of the Lake Victoria Basin: Length (cm), Weight (g) and Condition factor (K_n).

	Length (cm)		**Weight (g)**		**K_n**
Rivers	Mean±Sd	min-max	Mean±Sd	min-max	Mean±Sd
Nyando	13.4±7.26	8-31	51.25±88.83	6-268	1.051±0.3612
Mara	20.39±6.62	8.5-37.4	110.56±106.74	4.42-615.8	1.019±0.144
Awach	10.27±5.32	4.9-24	20.28±32.14	1.5-146	1.023±0.251
Sondu-Miriu	12.81±4.76	5.5-24	30.83±40.82	1.5-158.2	1.056±0.258

4.3.2. The length-weight relationship of *Labeo victorianus* in the sampled rivers.

In the spatial relationship between weight of *L. victorianus* and rivers, fish from River Mara was significantly different from fish from Rivers Awach, and Sondu-Miriu *(F=25.93; p<0.001)* (Figure 9). The length of the fish in River Mara was significantly different from fish of the other rivers *(F=64.20; p<0.001*). The length of the fish from River Nyando was not significantly different from the others. The *b* value of the length-weight relationship (LWR) of *L. victorianus* fish populations was above 3.0 (the ideal fish shape), showing positive allometric growth in rivers Mara and Sondu Miriu. The value of exponent *b* of the length-weight relationship (LWR) was slightly below 3 in fish from rivers Nyando and Awach, showing tendency towards negative allometric growth.

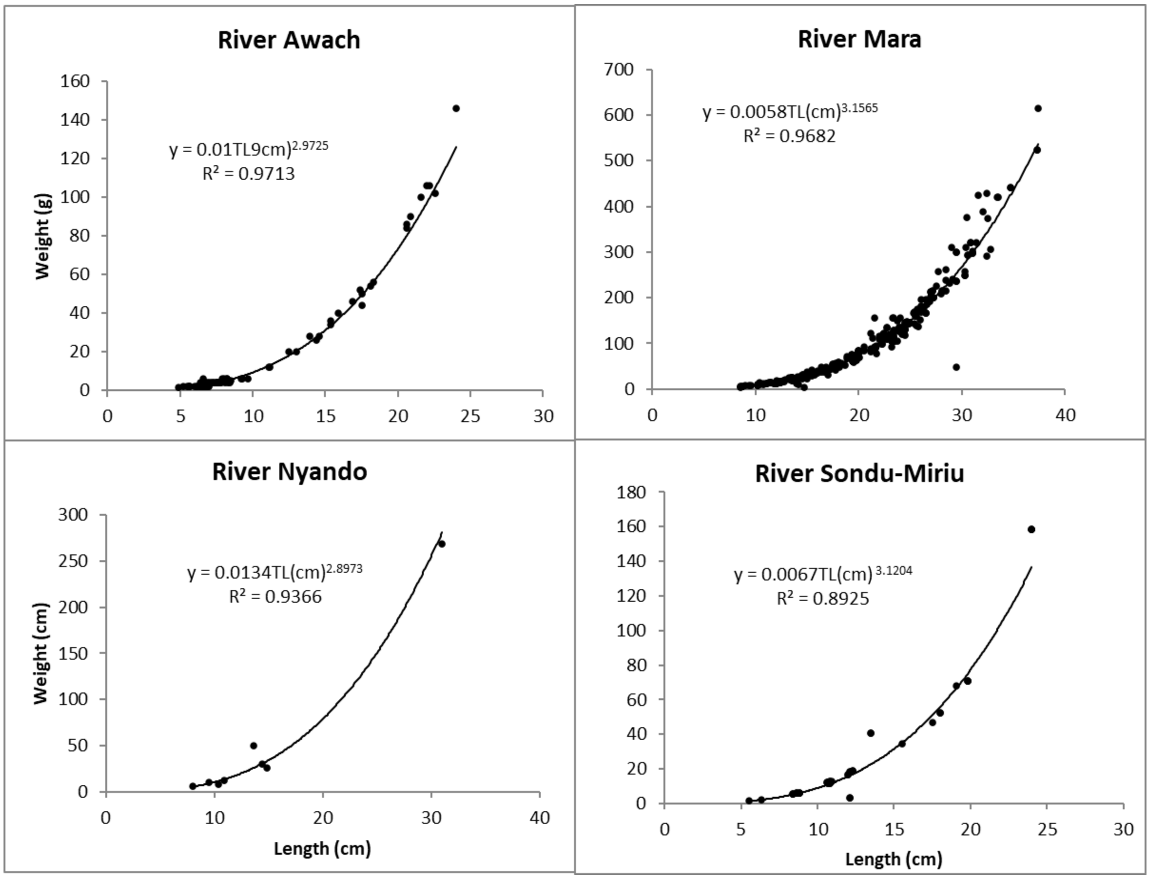

Figure 9. Relationship between the weight (g) and the total length (cm) for *Labeo victorianus* derived from pooling data from all the sampled rivers (Awach, Mara, Nyando and Sondu-Miriu).

4.4. Population structure, maturity stage, sex ratio, and fecundity of *Labeo victorianus*.

4.4.1. The population structure

The size structure of *Labeo victorianus* populations was unimodal (7-15cm) in Awach, Nyando and Sondu Miriu rivers while it was bimodal in Mara River (Figure 10). The first mode consisted of 11-17cm TL juveniles while the second consisted of 19-37cm TL adults and sub-adults.

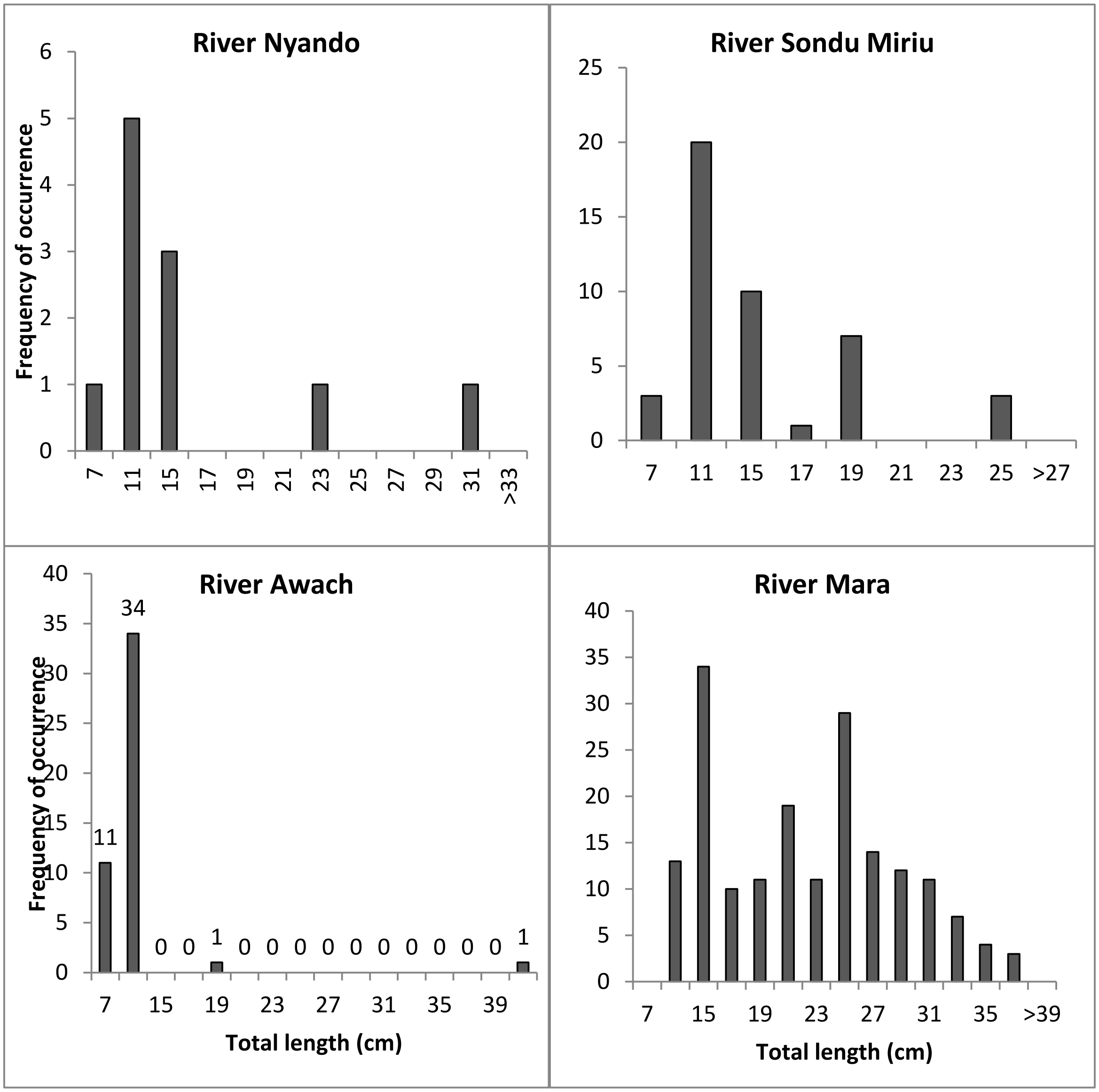

Figure 10. The population size structure of *Labeo victorianus* from sampled in the rivers of the Lake Victoria Basin.

The length and weight of male and female fish are shown in Table 6. The mean length and weight for males and females were significantly different ($p< 0.05$) for both males and females in River Sondu- Miriu. The length and weight of male and females of the fish did not vary significantly in Rivers Awach, Mara and Nyando.

Table 6. Statistical description of length and weight of adults' male and females obtained from *Labeo victorianus* sampled in the different rivers of the Lake Victoria Basin

Males

	Length (cm)		**Weight (g)**	
Rivers	Mean±Sd	min-max	Mean±Sd	min-max
Nyando	17.9±6.08	13.6-22.2	78±35.59	50-106
Mara	22.31±5.97	8.5-37.4	133.51±105.37	4.5-615.8
Awach	18.23±3.09	12.5-22.6	62.16±29.52	20-106
Sondu-Miriu	12.21±3.14	8.4-19.8	21.32±21.24	3.3-70.8

Females

	Length(cm)		**Weight(g)**	
Rivers	Mean±Sd	min-max	Mean±Sd	min-max
Nyando	16.55±9.81	10.4-31	78.5±126.75	8-268
Mara	21.40±7.17	10.2-37.3	131.56±135.24	30.5-523.7
Awach	20.1±2.95	15.9-24	84.33±20.1	40-146
Sondu-Miriu	15.94±5.21	8.4-24	55.35±55.26	3.3-158.2

4.4.2. The gonadal maturity stage for *Labeo victorianus* from four rivers of the Lake Victoria Basin

The gonadal maturity stages are presented in Figure 11. Fish from the Mara River presented a high proportion of sexually mature fish for both sexes while fish from Nyando River had the lowest proportion of sexually mature fish. The highest proportion of immature fish was found in the Awach River. Variation of sexual maturity of fish was high in River Mara compared to River Awach which recorded the lowest variation.

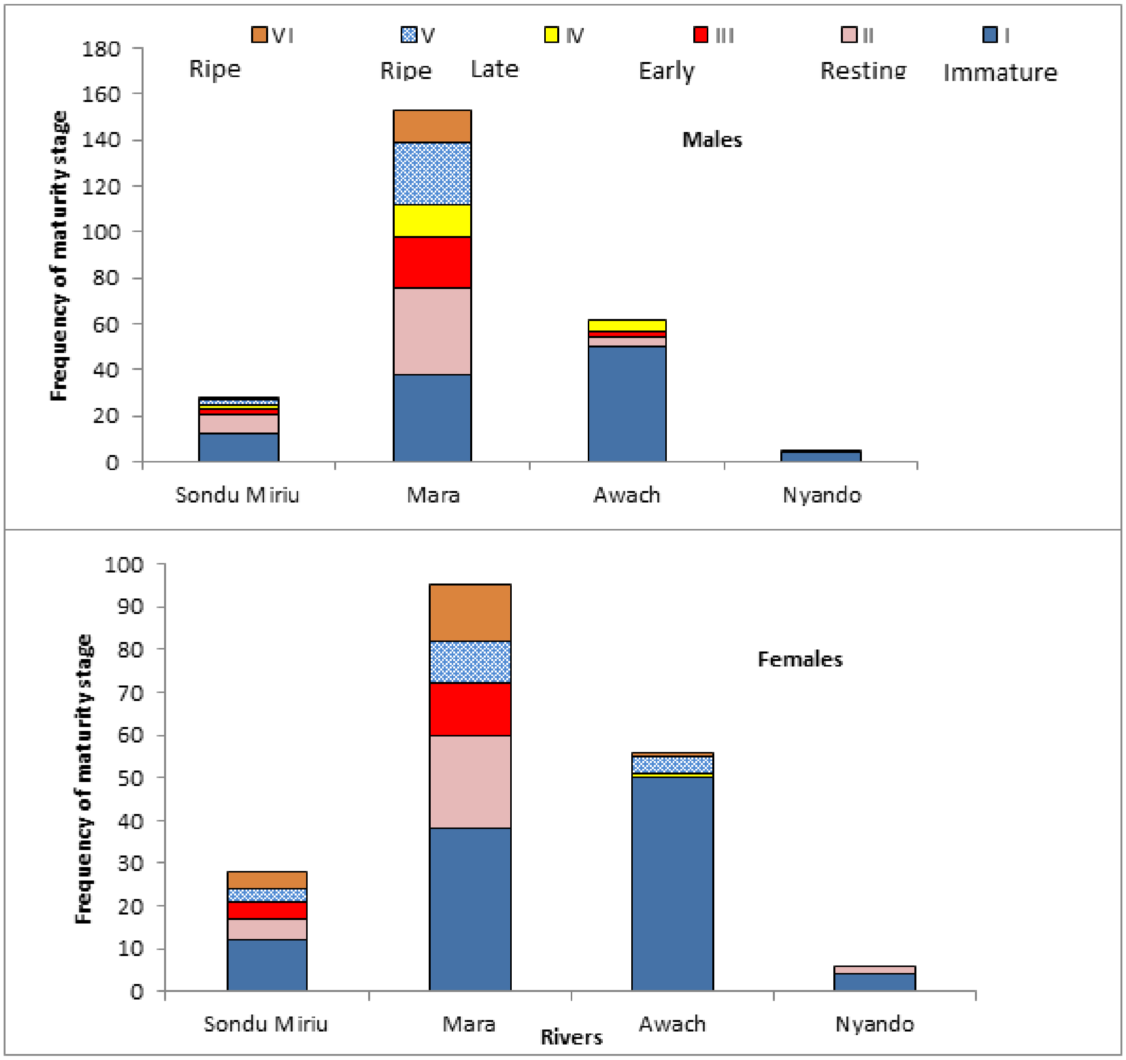

Figure 11. The frequency of gonadal maturity stages of *Labeo victorianus* in rivers Mara, Sondu Miriu, Nyando and Awach of the Lake Victoria Basin

4.4.3. Seasonal variation in the gonadal maturity of *Labeo victorianus* in the Mara River

In the Mara population, the seasonal variation in the sexual maturity of *L. victorianus* is presented in Figure 12. In the wet season, the number of mature fish significantly differed from those of the dry season (Chi-square test; $p<0.05$).

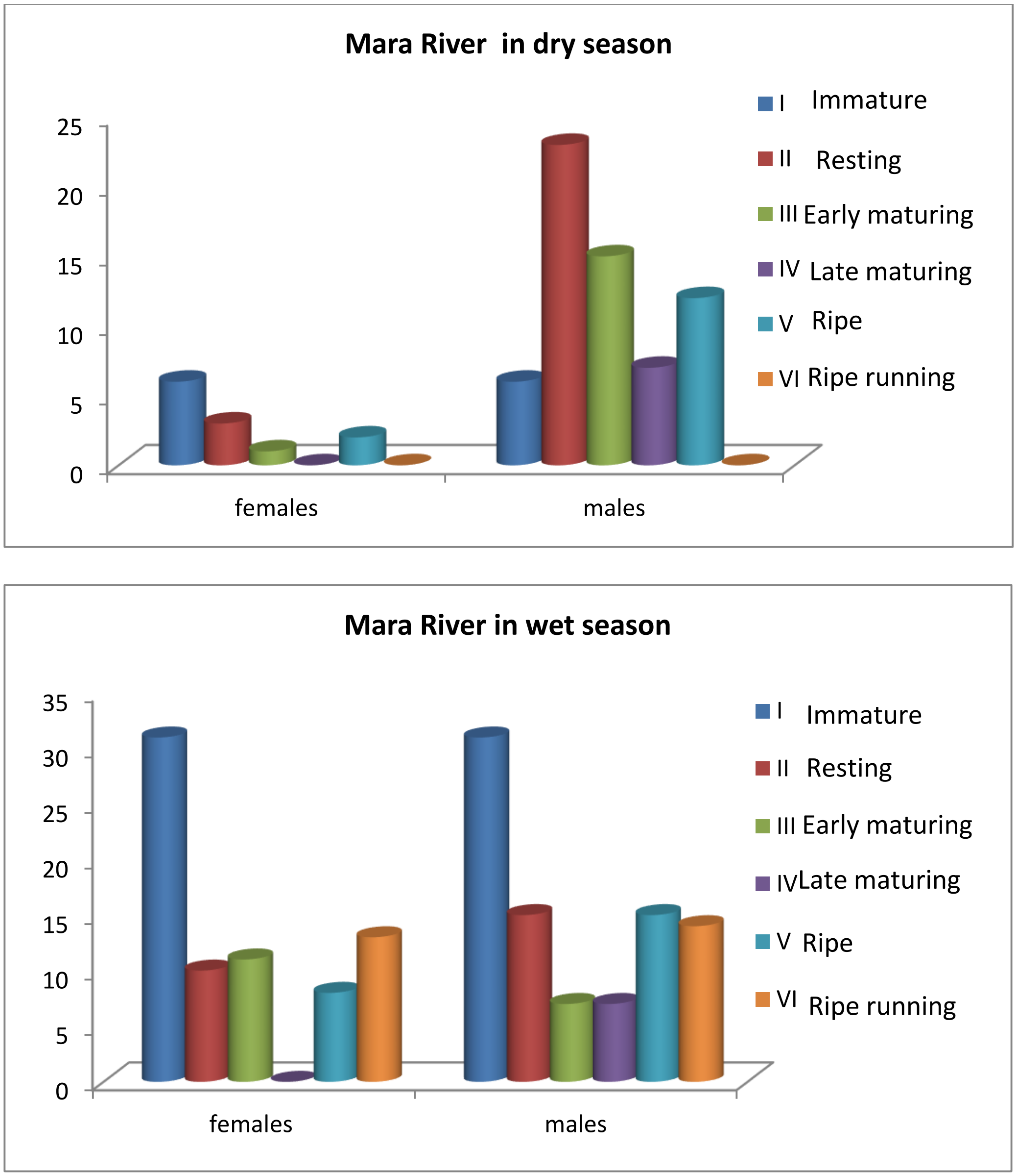

Figure 12. The seasonal variation in the sexual maturity of *Labeo victorianus* in the Mara River.

4.4.4. Sex-ratio of *Labeo victorianus* sampled from Rivers Mara, Sondu Miriu, Nyando and Awach of the Lake Victoria Basin.

The sex ratio of *L. victorianus* sampled from the four rivers is presented in Table 7. There was no significant difference between males and females in all the rivers sampled (Chi-square test; $p > 0.05$ for males and females respectively).

Table 7. Sex-ratio of *Labeo victorianus* sampled from rivers Mara, Sondu Miriu, Nyando and Awach (values in parentheses are percentages)

Rivers	Awach	Mara	Nyando	Sondu- Miriu
Males	11 (64.7)	115 (66.86)	2 (33.33)	16 (50)
Females	6 (35.3)	57 (33.14)	4 (66.67)	16 (50)
Total	17	172	6	32

4.4.5. Determination of size at first maturity of *Labeo victorianus* from Rivers Mara, Sondu Miriu, Nyando and Awach of the Lake Victoria Basin, Kenya

The size-at-maturity was determined as the length at which 50% of the fish samples are sexually mature as shown in Table 8. The lowest size-at-maturity was observed in Sondu-Miriu River (10.8 cm) for males and Awach River (16.15cm) for females; while the highest values were recorded in Nyando River for both males and females 22.2cm and 31cm respectively).

The lowest size-at-maturity for males was observed in Sondu Miriu River (12cm) while the highest value was observed in Nyando River (22.2cm). For females, the lowest size-at-maturity was found in Awach River while the highest value was found in Nyando River (31cm).

Table 8. Logistic function parameter estimating the length at first maturity of *Labeo victorianus* sampled from Rivers Mara, Sondu Miriu, Nyando and Awach of the Lake Victoria Basin.

Rivers	Group	Logistical function	L_{50}
Awach	Male	$PL=1/1+e^{(-0.0632)(L-22.15)}$	22.15cm
	Female	$PL=1/1+e^{(-0.0047)(L-16.15)}$	16.15cm
Mara	Male	$PL=1/1+e^{(-0.00112)(L-18.95)}$	20.45cm
	Female	$PL=1/1+e^{(-0.0377)(L-24.45)}$	26.45cm
Nyando	Male	$PL=1/1+e^{(-0.0027)(L-22.2)}$	22.2cm
	Female	$PL=1/1+e^{(-0.0014)(L-31)}$	31cm
Sondu-Miriu	Male	$PL=1/1+e^{(-0.0599)(L-10.8)}$	12cm
	Female	$PL=1/1+e^{(-0.0527)(L-18)}$	19.8cm

CHAPTER FIVE

DISCUSSION

5.1. Seasonality in the water quality and nutrients

The pH, DO levels were within the permissible limits in all the rivers and during both seasons. The significant high levels of electrical conductivity, turbidity and temperature recorded during the dry season in the Mara River are mostly associated to water discharges from agricultural runoffs and organic matters from mammals living around this river. High nutrient concentration recorded in the Awach, Nyando and Sondu-Miriu rivers in the wet season have increased eutrophication (Ouma *et al.*, 2016). Phosphorus and nitrogen enrichments are responsible for eutrophication and anoxic waters resulting to impede of the fish biodiversity in rivers (Weigelhofer and Bondar-Kunze, 2018). Similar results were found by Ouma *et al.,* (2016) in the LVB suggesting that the wet season is accompanied with high concentrations of pollutants compared to the dry season.

5.2. Diet and food composition in *Labeo victorianus* in four rivers of the Lake Victoria Basin of Kenya

The main food items in the diet of *L. victorianus* in all the rivers sampled in this study were detritus followed by plant material and insects. Detritus are important food items for majority of fishes found in floodplain rivers in the tropics including *Labeo* species (Junk *et al.*, 1989). Studies also report that the diet of *Labeo* species is quite variable, depending on environmental conditions (Ochumba and Manyala, 1992; Owori, 2004, 2009; Kobingi *et al.*, 2018). This behavior is reported for riverine species which are opportunist feeders, which allows for their vast dispersal. In previous studies, plant materials and detritus are reported as important basal sources of energy in the rivers of the LVB (Corbet, 1961; Ochumba and Manyala, 1992; Adite, 2005; Masese and McClain, 2012). The copius consumption of detritus and plant material reported for this fish and other fishes in LVB rivers (Corbet 1961), is intriguing given the low nutritive value of the resource as compared with periphyton and insects (Thorp and Delong, 1994; Lau *et al.*, 2009). A couple of reasons could explain this observation. First, feeding on detritus is likely one of the mechanisms through which these fishes incorporate periphyton and microalgae in their diet. Periphyton and other microbiota form major components of decomposing leaf litter, through the process of conditioning, which makes the leaves more palatable to insects and other aquatic consumers (Wantzen *et al.*, 2008). Studies utilizing stable isotopes to track energy sources for consumers in the Mara River have identified periphyton or algae to be very important energy resources for invertebrates and fishes, including *L. victorianus* (Masese *et al.*, 2015; Subalusky *et al.*, 2017). Secondly, the increasing turbidity and organic matter inputs in LVB rivers scour substrates (Masese & McClain, 2012; Dutton *et al.*, 2018a, b) and likely compromise the basal resources mostly depended upon by benthophagus fishes, and making them be opportunistic feeders of any available food resources (Winemiller and Jepsen, 1998).

Indeed, detritus dominated the diet of *L. victorianus* in the Mara River, which experiences high turbidity because of soil erosion and organic matter loading by hippopotamus (Dutton *et al.*, 2018a, b). Similarly, plant materials and detritus dominated the diet in the Awach and Nyando rivers, which are also known to have high turbidity levels (Guya, 2019). The incorporation of sand in the diet of fish individuals in Awach and Mara rivers is further evidence of deteriorating environmental conditions, but might also have been accidentally consumed by the fish while feeding by scraping the rocks for periphyton (Owori, 2009). On the contrary, the Sondu-Miriu is less turbid and insects were the most important food items for the fish. Less turbid environments in streams and rivers allow for an abundance of aquatic insect communities (Manning and Sullivan, 2021)

Labeo victorianus display a flexible diet, showing that the species can adapt to the food items present in the environment. This could also mean that the fish prefer easy to access and abundant food items that save energy that could have been expended during foraging (Chemoiwa and Hilda, 2018). The dry season is characterized by the consumption of plant material and algae while in the wet season insects were the most consumed. The wet season appear to provide abundant and more diversified food items compared to the dry season. This is due to the fact that seasonal flooding influences primary and secondary production and the flood water carry allochthonous food resources making it accessible to the fish (Adite *et al.*, 2005). Terrestrial and other insects are also abundant in the rainy season as they fall from overhanging vegetation into the water during the wet season (Junk *et al.*, 1989).

5.3. Ontogenetic shifts in food composition of *Labeo victorianus* in the four rivers of Lke Victoria, Kenya.

Ontogenetic shifts in food composition were observed during the study where *L. victorianus* shifted to animal food items (insects) when maturing. This might be due to the energy building and nutritional needs required when migrating to floodplains areas to breed. Plant materials and other food items appear to be for survival purposes when the preferred ones become rare. Similar results by Owori (2004) were reported for *L. victorianus* larvae in Kagera and Sio Rivers which fed on zooplankton rotifers then changed to plant diets as they grew older. According to past studies ontogenetic shifts in diet often occur during fish growth with modifications in the mouth and body morphology (Brandt, 1986; Sánchez-Hernández *et al.*, 2019). This is also caused by sexual maturity, intra-interspecific food competition and availability or presence of predators (Winemiller, 1989; Nakazawa, 2015; Cornelissen *et al.*, 2018). Results presented here are similar with Rahman *et al*., (2009) in Rohu (*Labeo rohita*) in semi intensive ponds whereby *L. rohu* fed on zooplankton and later shifted to plant-based diets.

5.4. Spatial and temporal variation in condition factor of *Labeo victorianus* in the four rivers of the Lake Victoria Basin

The condition factor is associated with the length and weight of fish and helps understand dynamics in fish population growth which vary with location, species and season (Nash *et al.*, 2006). The result of this study indicates that the mean condition factor was around unity (1), which is an indication of good health condition of the fish in all the rivers. Lack of spatial variability in fish condition is unexpected given the different levels to which fish communities in LVB Rivers have been influenced by human activities (Raburu & Masese, 2012; Achieng *et al.*, 2020; Masese *et al.*, 2020a). However, despite lack of variability in fish condition among rivers, differences were noted at the site level. For instance, the lowest value (0.90) was reported at Mulot in the Mara river, while the highest value (1.06) was reported at Wadh Lang'o site in the lower Sondu-Miriu River; all condition factor K_n values in Mara River were below 1. This variability is in response to the changes in environmental conditions in the rivers (Singh and Serajuddin, 2017), but could also be due to various biological reasons like gonadal development, sex, growth and fatness (Le Cren, 1951; Pervin and Mortuza, 2008; Muzzalifah *et al.*, 2015). Moreover, the Mara River is highly hydrologically variable and experiences multiple stressors arising from land use change, such as supra-reduced base flow conditions; the Talek and Sand River tributaries are seasonal but host large populations of *Labeo* in pools during the dry season. The Mara River also receives organic matter and nutrient loads from livestock and wildlife (hippopotamus) in the middle and lower basin, which affect water quality, river functioning and the composition of macroinvertebrates and fishes (Subalusky *et al.*, 2018; Dutton *et al.*, 2018a, b; Masese *et al.*, 2020b).

From a conservation standpoint, the ongoing environmental transformation in LVB rivers is a threat to the structure and the functioning of the rivers (Masese & McClain, 2012), including water quality and food availability for riverine fishes. The food composition reported for *L. victorianus* in this study is indicative of stressed conditions whereby the fish feed opportunistically, including consuming low-quality food resources for survival. This is not good for maintaining healthy populations for the once lucrative riverine fishery (Masese *et al.*, 2020a) and propagation of the species. The declining populations of the species are further threatened by a significant decline in migratory populations and permanent residence in the rivers (Ojwang *et al.*, 2007; Chemoiwa *et al.*, 2013) where they will be more vulnerable to any developments in the catchments. The fish is one of the fishes in LVB in the IUCN Red List of threatened species as a result of human activities, including water pollution, habitat degradation, overfishing and introduction of exotic species (IUCN, 2018; Masese *et al.*, 2020a). Similar threats posed by human activities have been reported for other *Labeo* species (Kembenya *et al.*, 2014; Kobingi *et al.*, 2018), suggesting that human activities have to be minimized for the conservation of the species.

5.5. The Length-Weight Relationship (LWR) of *Labeo victorianus* from four rivers of Lake Victoria Basin, Kenya

The fish were collected through electrofishing giving the considerable variety in sizes and growth stages. The *b*-value is critical to assess the fish well-being. Known as the relative fish condition, it is defined as healthy when the highest length-weight relationship is achieved (Muzzalifah *et al.*, 2015; Ondhoro *et al.*, 2016). The *b*-value of the length-weight relationship was above 3.0 for the fish samples from the Sondu-Miriu and Mara rivers, suggesting positive allometric growth where the fish increase in body weight faster than body length (Kuriokose, 2015). This is the ideal fish shape according to LeCren's concept (LeCren, 1951) which shows that fish increases in both length and depth as it grows (Jones *et al.*, 1999). Positive allometric growth in fish samples from Sondu Miriu and Mara rivers could be attributed to high feeding and the diversity of food available in these environments (algae, aquatic insects and molluscs). The positive allometry observed for this study also reflects the appetite and the gonadal development of fish (most mature fish were found in the Mara and Sondu Miriu Rivers).

In addition to the high dissolved oxygen found in riverine ecosystems, the presence of macroinvertebrates and shredders play an important role for disintegrating particulate matters and macrophytes for invertebrate organisms. Wildlife reserves (especially Hippopotamus) allows water fertilization promoting primary productivity in Mara River providing the necessary food for the fishes (Mayo *et al.*, 2018). Other authors also emphasized the fish body shape, fatness, sex, gonadal maturity, gut content and season as responsible for positive allometric growth in fish (Pervin and Mortuza, 2008; Muzzalifah *et al.*, 2015, Singh and Serajuddin, 2017).

On the other hand, fish samples from those collected from river Nyando and Awach had *b*-value below 3 which showed an isometric growth with strong length weight relationship (R^2=0.97 and R^2=0.93 in Awach and Nyando respectively) where the fish is thin, increases in body length while it does not increase in weight or the fish length is not related to the fish weight (Kuriakose, 2017; Patrick *et al.*, 2021). Isometric growth occurs when large fish vary in body shape compared to their size or the small fish were in good diet during the sampling period compared to the large fish (Kuriakose, 2017). It could also be attributed to the environmental conditions and habitat characteristics in those rivers found to be difficult compared to the first ones; probably associated to the ecosystem health and the impact of anthropogenic activities influencing the organisms by reducing the quality of the water and the food availability and affecting the fish health for instance the high nutrient concentration observed during the wet season. They are autotrophic as they produce the major source of energy necessary for the herbivorous species from decomposed plant material and primary production. The energy is then transferred to higher trophic levels (Masese and McClain, 2012). Similar results were reported for *Channa punctatus* from Gomti, Ganga and Ken rivers in India by Singh and Serajuddin (2017), *Labeo bata, L. rohita, Oreochromis mossambicus* (Hossen *et al.*, 2018, Sheriff and Altaff, 2018) emphasizing the rapid growth of fish in riverine ecosystems.

5.6. Population structure, sexual maturity, sex ratio and length at maturity of Labeo victorianus from four rivers of the Lake Victoria basin, Kenya

The unimodal population size structure displayed by the fish caught in Awach, Nyando, and Sondu-Miriu rivers might be due to the high recruitment of both adult males and females caught when moving upstream to the rivers to spawn during wet season, however in the dry season, the fish are scarce in the catchment rivers of the LVB (Shoko *et al.*, 2007), which also explains the small number of adult fish samples found during this study in Awach and Nyando Rivers. According to Khatali (2017), high disturbance caused by human activities are main factors in river degradation in the Awach River. Mara River on the other hand displayed a bimodal population structure, showing less effect of anthropogenic activities and overexploitation. Bimodality of a fish population consists of fish individuals of different ages confined within two length ranges (Borgstrøm *et al.*, 2015). Similar results were reported by Montchouwi *et al.*, (2010) for *Labeo senegalensis* in the Ouémé River in Benin.

For this study, the size at first maturity is smaller for males than females; with values of 10.8 cm for males in River Sondu-Miriu, to 16.15cm for females in River Awach respectively. Similar results were found by Cadwalladr (1969), Rutaisire and Booth (2005) in the Kagera and Sio and rivers, Uganda. Early maturating was previously recorded in Awach, Nyando and Sondu-Miriu Rivers whereby fish could reach maturity as early as 7.3 cm and 7.9 cm for females and males respectively (Ochumba and Manyala, 1992, Maithya *et al.*, 2012). Babiker (1984) also reported early maturity in female *Labeo niloticus* in the Jebel Aulia Dam (White Nile) in Soudan.

Length at first maturity and age at maturity differ among and within fish species and population (Trippel, 1995). Rutaisire and Booth (2005) suggested that early sexual maturity could be due to a reproductive adaptation to abiotic and biotic conditions, a compensatory population response to the fishing pressure or genetic disparities in different fish populations. It is therefore accompanied with population disproportion by the removal of large fishes, leaving smaller fishes that engage in precocious breeding and rapid growth that allows the fish to reproduce at least once in its life history (Weyl and Booth. 1999; Neuheimer and Taggart 2010). The energy allocation is diverted to prolific reproduction, physiological demand and escapes from predation (Dieckmann and Heino, 2007; Jørgensen and Fiksen, 2010) at the expense of somatic growth. However, survival increases with body size (Jørgensen and Fiksen, 2010). For instance, in the Mara River, we only found adults in some sites, meaning the lack of or limited recruitment. Trippel (1995) emphasized that early maturation of Atlantic cod (*Gadus morhua*) stocks in Canada as a stress indicator in fisheries which might be explained by two hypotheses: decrease in fish stock biomass and genetic selection and/or adaptation of genotypical advantaged species which mature at a small body size.

According to Witte *et al.* (2013), early maturation and smaller size can be attributed to adaptation to the changing environment. For many *Labeo* species, the length at first maturity may vary a lot, ranging from as early as 9cm up to 62cm in both males and females for *L. horie* and *L. cylindricus* in lakes Chamo and Chicamba (Weyl and Booth, 1999; Dadebo, 2003), depending on the species and the location. Information on length at first maturity is crucial for the regulation of the minimum mesh size of nets to be used by the fishermen to trap the least size fish (Dadebo, 2003; Montchouwi *et al.*, 2010).

Investigations on the reproductive biology of “Ningu” by Rutaisire and Booth (2005) also reported early sexual maturity for males and females. Disparities during the sexual maturation between the dry and the wet season observed for this study are following previous studies confirming that the fish reproduce during the wet season (Cadwalladr, 1965, 1969; Ochumba and Manyala, 1992). Though it is not inevitably synchronized with the rain, the sexual maturity entails a demand for energy allocation for physiological metabolisms (food availability, change in temperature affecting metabolic rates, low concentration of electrolytes…) required for the reproduction (Rutaisire and Booth, 2005; Lowerre-Barbieri *et al.*, 2011). On the other side, Babiker (1984) reported that the reproduction was steady and not seasonal for *Labeo niloticus* suggesting that the gonadal maturation is synchronic in the entire population and that sexual maturation and reproduction also vary among *Labeo* species. The presence of mature fish in the Mara River was related to the water quality status that availed necessary food supply and suitable conditions for gonadal maturing. The high electrical conductivity has played a favorable to sexual maturation in this river compared to the high nutrient concentration observed in the others.

The unbalanced sex-ratio is observed when extreme change occurs in the environment, the notably constant high temperature that would decrease the proportion of the majority sex (Conover *et al.*, 1992). The unstable environments produce unexpected physiological changes that can result in early maturation, short lifespan and quick growth (Weyl and Booth, 1999). Therefore, the balanced sex ratio observed during this study is associated with the relatively stable environment provided by the tributary rivers of Lake Victoria for the adult fish. Similar results were found by Rutaisire and Booth, (2005) in the Kagera and

Sio rivers (Uganda) where the sex-ratio did not vary. However, this is in contradiction with results found by Maithya *et al.*, (2012) where the number of males was found to be more than females in Awach Nyando and Sondu-Miriu rivers of the LVB. The sex determination in fish is affected by intrinsic factors (genes) and extrinsic factors (environment and social) and varies with species yet increased anthropogenic influence may induce abnormal skewing of sex ratio in animal communities (Chan and Yeung, 1983; Stelkens and Wedekind, 2010).

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The LVB provides refuge to many endemic and endangered biodiversity and other different economic benefits to the increasing surrounding population. Its riverine catchments are subjected to many stressors and need to be protected. The shift in the diet observed during this study is a key element in the farming industry of the threatened species as it gives more information on the food preference during growth stages to meet the specific requirements of quality feed, to provide good quality fish seed banks and to maintain healthy populations to restock the rivers of the LVB for an increase in protein intake for the growing human population to fight food insecurity for the fast-growing population.

The findings of this study suggest that the feeding habits of *Labeo victorianus* in the LVB is strongly influenced by seasonality and environmental conditions found in the basin, especially turbidity and organic matter loading affecting food availability and impeding fish vision. This information is important as it enlightens the causes of the decrease in *Labeo victorianus* in the rivers of the Lake Victoria Basin and gives more evidences of ecosystem disturbances on the fish condition. The findings also have implications for the management of other fish species threatened by human activities in the LVB and might be used to inform for sustainable management of riverine fisheries used for economic, recreational, and cultural benefits.

6.2. Recommendations

1. There is a need of raising awareness of the public and the local communities on the benefits of riverine ecosystem conservation and multiply efforts for sustainable use of water resources for future generations**.**

2. Continuous investigations on the ecology of *Labeo victorianus* needs to be carried out, histological and genetic research need to be carried out to understand genetic differences in Labeo *victorianus* populations for better management in aquaculture production.

3. Similar studies on potential *Labeo victorianus* competitors in the LVB need to be investigated, as competition is a potential contributor to diet shift of the fish species.

4. Fishery stock assessment of *Labeo victorianus* in the LVB need to be implemented and updated on a regular basis to evaluate the status of the threatened fish species in the rivers of the LVB. It includes the prohibition of fishery exploitation in rivers during the spawning period in the view of producing sufficient offspring's, assessment of the mortality rate to fight the decline of the fish species to insignificant levels in the LVB.

5. The formulation of adequate policy regulations is required for efficient management and conservation of the fish species to optimize fish production by increasing fish biomass in rivers and achieve conservation of the fish species by reducing the impact of anthropogenic activities in the Lake Victoria Basin. For instance, consistency in net mesh sizes should be larger in all riverine ecosystems of the LVB. If well implemented, it will reduce recruitment and increase fish production which will benefit to the country's GDP as well as the fishermen's livelihoods.

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APPENDICIES

Appendix I: The logistic function parameter used to estimate the length-at-maturityand the L_{50} (PL= (1+exp (L – L_{50})/δ)-1) for the Awach, Mara, Nyando and Sondu Miriu rivers are shown below:

RIVER AWACH

Males

Classes (cm)	TL (cm)	sample size	Number ripe	proportion ripe	adjusted prop. Ripe
5.2-7.1	6.15	24	0	0	-0.071326212
7.2-9.1	8.15	16	0	0	-0.082354822
9.2-11.1	10.15	4	0	0	-0.097417763
11.2-13.1	12.15	3	1	0.333333333	-0.119224226
13.2-15.1	14.15	3	3	1	-0.153608754
15.2-17.1	16.15	4	1	0.25	-0.215864568
17.2-19.1	18.15	4	4	1	-0.362973401
19.2-21.1	20.15	1	1	1	-1.139586325
21.2-23.1	22.15	3	2	0.666666667	1

Females

Classes (cm)	TL (cm)	sample size	Number ripe	proportion ripe	adjusted prop. Ripe
5.2-7.1	6.15	24	0	0	-0.111693028
7.2-9.1	8.15	16	0	0	-0.143626814
9.2-11.1	10.15	4	0	0	-0.201131721
11.2-13.1	12.15	2	0	0	-0.335430432
13.2-15.1	14.15	3	0	0	-1.009466723
15.2-17.1	16.15	4	2	0.123839009	1
17.2-19.1	18.15	1	1	0.055096419	0.334378595
19.2-21.1	20.15	1	1	0.049627792	0.20075306
21.2-23.1	22.15	2	2	0.090293454	0.14343362
23.2-25.1	24.15	1	1	0.041407867	0.111576158

RIVER MARA

Males

Classes (cm)	TL (cm)	sample size	Number ripe	proportion ripe	adjusted prop. Ripe
8.5-11.4	9.95	18	3	0.166667	-0.126586086
11.5-14.4	12.95	23	3	0.130435	-0.202709212
17.5-20.4	18.95	22	13	0.590909	1
20.5-23.4	21.95	22	15	0.681818	0.252105874
23.5-26.4	24.95	25	19	0.76	0.144234065
26.5-29.4	27.95	14	12	0.857143	0.101012526
29.5-32.4	30.95	12	11	0.916667	0.077722121
32.5-35.4	33.95	3	2	0.666667	0.063159475
35.5-38	36.95	3	0	0	0.053192834

Females

Classes (cm)	TL (cm)	sample size	Number ripe	proportion ripe	adjusted prop. Ripe
8.5-11.4	9.95	17	0	0	-0.077139506
11.5-13.4	12.45	14	1	0.071428571	-0.09473266
13.5-15.4	14.45	11	1	0.090909091	-0.115874614
15.5-17.4	16.45	5	2	0.4	-0.149164358
17.5-19.4	18.45	8	3	0.375	-0.209292118
19.5-21.4	20.45	4	3	0.75	-0.350630252
21.5-23.4	22.45	7	4	0.571428571	-1.079909413
23.5-25.4	24.45	10	5	0.5	1
25.5-27.4	26.45	4	3	0.75	0.34176308
27.5-29.4	28.45	3	3	1	0.206100272
29.5-31.4	30.45	6	5	0.833333333	0.147535912
31.5-33.4	32.45	3	2	0.666666667	0.114889516
33.5-35.4	34.45	1	1	1	0.094073218
35.4-37.4	36.45	1	1	1	0.079643062

RIVER NYANDO

Males

TL (cm)	Sample size	Number ripe	proportion ripe	adjusted prop. Ripe
6.7	1	0	0	-0.069164872
8	1	0	0	-0.07597796
9.5	1	0	0	-0.085720975
10.9	1	0	0	-0.097375429
14.8	1	0	0	-0.156738659
13.6	1	0	0	-0.131981642
22.2	1	1	0.045045045	1

Females

TL (cm)	sample size	Number ripe	proportion ripe	adjusted prop. Ripe
6.7	1	0	0	-0.042981167
8	1	0	0	-0.045521125
9.5	1	0	0	-0.048852167
10.4	1	0	0	-0.051095539
10.4	1	0	0	-0.051095539
10.9	1	0	0	-0.052433217
14.4	1	0	0	-0.064198136
14.8	1	0	0	-0.065887716
31	1	1	0.032258065	1

RIVER SONDU-MIRIU

Males

TL (cm)	Sample size	Number ripe	proportion ripe	adjusted prop. Ripe
5.5	1	0	0	-0.25051034
6.3	1	0	0	-0.308797879
6.7	1	0	0	-0.349452319
8.4	1	0	0	-0.793360578
8.4	1	0	0	-0.793360578
8.6	3	0	0	-0.932758231
8.8	3	0	0	-1.13158343
10.6	1	0	0	1.232091159
10.7	4	0	0	1.103979248
10.8	4	2	0.5	1
12	1	0	0	0.469432777
12	1	1	1	0.469432777
12.1	1	0	0	0.449556132
12.3	1	1	1	0.414458282
13.5	1	1	1	0.282245207
17.5	1	0	0	0.136790421
19.1	1	1	1	0.113411765
19.8	1	1	1	0.105521648
22.6	1	1	1	0.082549574
26.3	1	1	1	0.064107454

Females

TL (cm)	Sample size	Number ripe	proportion ripe	adjusted prop. Ripe
8.4	1	0	0	-0.123347455
10.6	1	0	0	-0.166109706
10.9	1	1	1	-0.174352155
12.1	3	2	0.666666667	-0.21752745
12.3	1	1	1	-0.226891753
12.6	1	0	0	-0.242554271
13.5	1	0	0	-0.305904829
15.5	1	1	1	-0.729042884
18	2	1	0.5	1
19.8	2	2	1	0.369331288
24	3	3	1	0.149432439

Appendix II: The relative condition factor Kn was obtained from the fish LWR and the regression constants a and b

RIVER AWACH

TL(cm)	Weight	$aL^{(b)}$	K_n	TL(cm)	Weight	$aL^{(b)}$	K_n
22.2	106	100.4695	1.05505	7.3	4	3.68321	1.08600
20.6	86	80.43968	1.06912	7	2	3.25127	0.61514
22	106	97.80283	1.08381	6.8	2	2.98285	0.67049
24	146	126.6712	1.15259	6.5	4	2.60846	1.53346
21.6	100	92.61126	1.07978	7.5	4	3.99134	1.00216
22.6	102	105.9467	0.96275	7.1	4	3.39129	1.17949
20.6	84	80.43968	1.04426	6.5	2	2.60846	0.76673
18.1	54	54.75825	0.98615	7	4	3.25127	1.23028
18.3	56	56.57647	0.98981	6.9	4	3.11515	1.28404
20.9	90	83.97207	1.07178	6.2	2	2.26664	0.88236
17.4	52	48.70041	1.06775	6.9	2	3.11515	0.64202
17.5	50	49.5371	1.00934	6.7	2	2.85435	0.70068
15.9	40	37.25229	1.07376	6.5	2	2.60846	0.76673
15.4	34	33.87703	1.00363	6.4	4	2.49097	1.60579
16.9	46	44.65738	1.03006	6.7	4	2.85435	1.40136
13.9	28	24.9811	1.12084	6.7	2	2.85435	0.70068
14.6	28	28.90939	0.96854	6.4	2	2.49097	0.80289
14.4	26	27.74805	0.93700	6.1	2	2.15969	0.92605
13	20	20.47371	0.97686	5.6	2	1.6749	1.19410
15.4	36	33.87703	1.06266	6.4	2	2.49097	0.80289
11.2	12	13.14621	0.91281	5.7	2	1.76537	1.13290
11.1	12	12.80037	0.93747	7.6	4	4.15162	0.96347
9.3	6	7.565116	0.79311	5.2	2	1.34375	1.48836
8.4	4	5.590108	0.71555	17.5	44	49.5371	0.88822
9.2	6	7.325872	0.81901	12.5	20	18.2207	1.09765
7.2	4	3.535256	1.13146	7.7	4	4.31612	0.92675
9.7	6	8.573911	0.69979	8.5	5	5.79025	0.86352
6.6	6	2.729571	2.19814	7.9	6	4.65796	1.28811
6.8	4	2.982859	1.34099	6.8	2	2.98285	0.67049
8	6	4.835429	1.24084	6.5	2	2.60846	0.76673
8.2	6	5.203693	1.15302	5.6	2	1.6749	1.19410
8.1	4	5.017319	0.79723	5.6	2	1.6749	1.19410
6.6	2	2.729571	0.73271	5.5	2	1.58755	1.25980
7.7	4	4.316122	0.92675	4.9	1.5	1.12618	1.33193
7.5	4	3.991348	1.00216	6.7	2.9	2.85435	1.01599

RIVER NYANDO

	TL(cm)	Weight	aL$^{(b)}$	K_n
	31	268	280.5608	0.95523
	14.8	26	32.93852	0.789349
	10.9	12	13.57815	0.883773
	14.4	30	30.42485	0.986036
	10.4	8	11.85101	0.675048
	13.6	50	25.78143	1.93938
	9.5	10	9.11724	1.096823
	8	6	5.541501	1.082739
Min	**8**	**6**		
Max	**31**	**268**		
Mean	**8**	**51.25**		
StD	**7.257853**	**88.82688**		

RIVER SONDU-MIRIU

TL(cm)	Weight	aL$^{(b)}$	K_n	TL(cm)	Weight	aL$^{(b)}$	K_n
8.4	5.7	5.1309	1.1109	8.8	5.9	5.9325	0.9945
8.6	5.9	5.5218	1.0685	10.6	12.3	10.6033	1.1600
8.8	5.9	5.9325	0.9945	10.7	12.2	10.9185	1.1174
10.6	12.3	10.6033	1.1600	10.7	11.5	10.9185	1.0533
10.7	12.2	10.9185	1.1174	10.8	11.4	11.2401	1.0142
10.7	11.5	10.9185	1.0533	10.8	12.9	11.2401	1.1477
10.8	12.9	11.2401	1.1477	10.9	12.8	11.5681	1.1065
10.8	11.4	11.2401	1.0142	12	16.4	15.6154	1.0502
12	16.4	15.6154	1.0502	12.1	3.3	16.0250	0.2059
12.1	18.1	16.0250	1.1295	12.1	18.1	16.0250	1.1295
12.1	3.3	16.0250	0.2059	12.3	18.8	16.8661	1.1147
12.3	18.8	16.8661	1.1147	13.5	40.7	22.5511	1.8048
13.5	40.7	22.5511	1.8048	15.5	34.7	34.7045	0.9999
17.5	46.9	50.6817	0.9254	18	52.5	55.3385	0.9487
18	52.5	55.3385	0.9487	19.1	68.2	66.5904	1.0242
19.8	70.8	74.5056	0.9503	19.8	70.8	74.5056	0.9503
24	158.2	135.7957	1.1650	19.8	70.8	74.5056	0.9503
5.5	1.5	1.3687	1.0959	24	158.2	135.7957	1.1650
6.3	1.9	2.0909	0.9087	24	158.2	135.7957	1.1650
8.4	5.7	5.1309	1.1109	**Min**	1.5	5.5	

8.4	5.7	5.1309	1.1109	**Max**	158.2	24
8.6	5.9	5.5218	1.0685	**Mean**	22.33333	11.47083
8.6	5.9	5.5218	1.0685	**StD**	34.03872	4.392333
8.8	5.9	5.9325	0.9945			

RIVER MARA

TL(cm)	**Weight**	**$aL^{(b)}$**	**Kn**	**TL(cm)**	**Weight**	**$aL^{(b)}$**	**K_n**
28.8	232.5	234.4231	0.9918	25.8	137.4	165.6554	0.8294
23.2	106	118.4652	0.8948	30.3	257.8	275.1704	0.9369
23.2	106	118.4652	0.8948	32.4	290.4	339.9878	0.8541
23.5	104.4	123.3683	0.8462	32.8	306.7	353.4140	0.8678
23.5	104.4	123.3683	0.8462	8.5	6.2	4.9790	1.2452
24.5	130.9	140.7119	0.9303	8.7	5.8	5.3582	1.0824
24.5	130.9	140.7119	0.9303	8.7	5.8	5.3582	1.0824
24.5	130.9	140.7119	0.9303	9.6	7.2	7.3108	0.9848
26	151.8	169.7428	0.8943	10.2	8.8	8.8527	0.9941
21.2	82.1	89.1266	0.9212	10.2	8.8	8.8527	0.9941
19.4	60.2	67.3557	0.8938	12.3	15.2	15.9850	0.9509
19.4	60.2	67.3557	0.8938	12.3	15.2	15.9850	0.9509
19.5	59.3	68.4577	0.8662	17.3	43.5	46.9160	0.9272
19.8	62.3	71.8376	0.8672	30.3	249.6	275.1704	0.9071
13.6	20.6	21.9505	0.9385	30.3	249.6	275.1704	0.9071
11.1	11.5	11.5609	0.9947	30.6	293.4	283.8623	1.0336
11.8	12.7	14.0224	0.9057	30.6	293.4	283.8623	1.0336

12	12.6	14.7864	0.8521	32.1	388.6	330.1499	1.1770
12.4	14.5	16.3989	0.8842	34.7	441.1	422.1609	1.0449
13.6	17.9	21.9505	0.8155	34.7	441.1	422.1609	1.0449
13.5	19.3	21.4450	0.9000	37.3	523.7	530.3065	0.9875
15.7	31.7	34.5371	0.9179	37.3	523.7	530.3065	0.9875
16.4	37.9	39.6353	0.9562	8.5	4.5	4.9790	0.9038
16.7	36.6	41.9694	0.8721	8.5	5.7	4.9790	1.1448
17	30	44.3956	0.6757	10.2	9.2	8.8527	1.0392
17.8	42.3	51.3309	0.8241	10.2	9.2	8.8527	1.0392
18.1	47	54.1116	0.8686	12	15.7	14.7864	1.0618
19.6	64.6	69.5720	0.9285	12	15.7	14.7864	1.0618
19.7	67.5	70.6986	0.9548	12.1	16.2	15.1789	1.0673
19.7	67.5	70.6986	0.9548	15.3	32.4	31.8351	1.0177
20.1	68.1	75.3297	0.9040	18	51.1	53.1736	0.9610
21.7	78	95.9319	0.8131	18.9	66.5	62.0268	1.0721
23.2	93.4	118.4652	0.7884	19.2	67.2	65.1881	1.0309
23.8	105.8	128.4083	0.8239	19.2	67.2	65.1881	1.0309
24.2	120.4	135.3447	0.8896	23.4	114.1	121.7189	0.9374
24.4	123.3	138.9070	0.8876	23.4	156.1	121.7189	1.2825
24.4	120.3	138.9070	0.8660	23.4	114.1	121.7189	0.9374
24.5	117.2	140.7119	0.8329	24	156.6	131.8453	1.1878
25.6	139.1	161.6358	0.8606	26.9	191.2	188.9910	1.0117
37.4	615.8	534.8072	1.1514	33.4	419.2	374.2258	1.1202

TL(cm)	Weight	aL$^{(b)}$	K	TL(cm)	Weight	aL$^{(b)}$	K
30.9	320.20	292.74	1.0938	13.8	20.13	22.986	0.876
29.5	300.15	252.88	1.1869	14.4	23.97	26.291	0.912
24.6	143.89	142.53	1.0095	17.9	54.12	52.247	1.036
24.1	133.82	133.59	1.0017	17	41.83	44.396	0.942
25.4	167.52	157.68	1.0624	18.7	51.91	59.979	0.865
23.9	127.25	130.12	0.9780	21.2	88.29	89.127	0.991
27.2	215.05	195.72	1.0987	22.7	108.88	110.592	0.985
24.9	143.25	148.09	0.9673	21.6	90.24	94.543	0.954
24.7	148.05	144.37	1.0255	22.3	99.16	104.557	0.948
24.5	144.63	140.71	1.0278	24.5	139.12	140.712	0.989
25.5	159.14	159.65	0.9968	23.2	115.18	118.465	0.972
23.4	128.36	121.72	1.0546	14.5	31.92	26.871	1.188
27.3	200.57	198.00	1.0130	13.3	22.67	20.458	1.108
26.1	169.66	171.81	0.9875	13.5	21.43	21.445	0.999
26.5	166.14	180.26	0.9217	28.1	214.1	216.905	0.987
26.5	196.25	180.26	1.0887	25	145.52	149.977	0.970
21.6	90.24	94.54	0.9545	27	211.93	191.218	1.108
22.3	99.16	104.56	0.9484	29.5	236.48	252.884	0.935
24.5	139.12	140.71	0.9887	15	28.85	29.906	0.965
23.3	115.18	120.08	0.9592	23	119.26	115.272	1.035
31	297.53	295.74	1.0061	25.4	143.06	157.683	0.907
22.7	134.31	110.59	1.2145	25.5	159.94	159.651	1.002

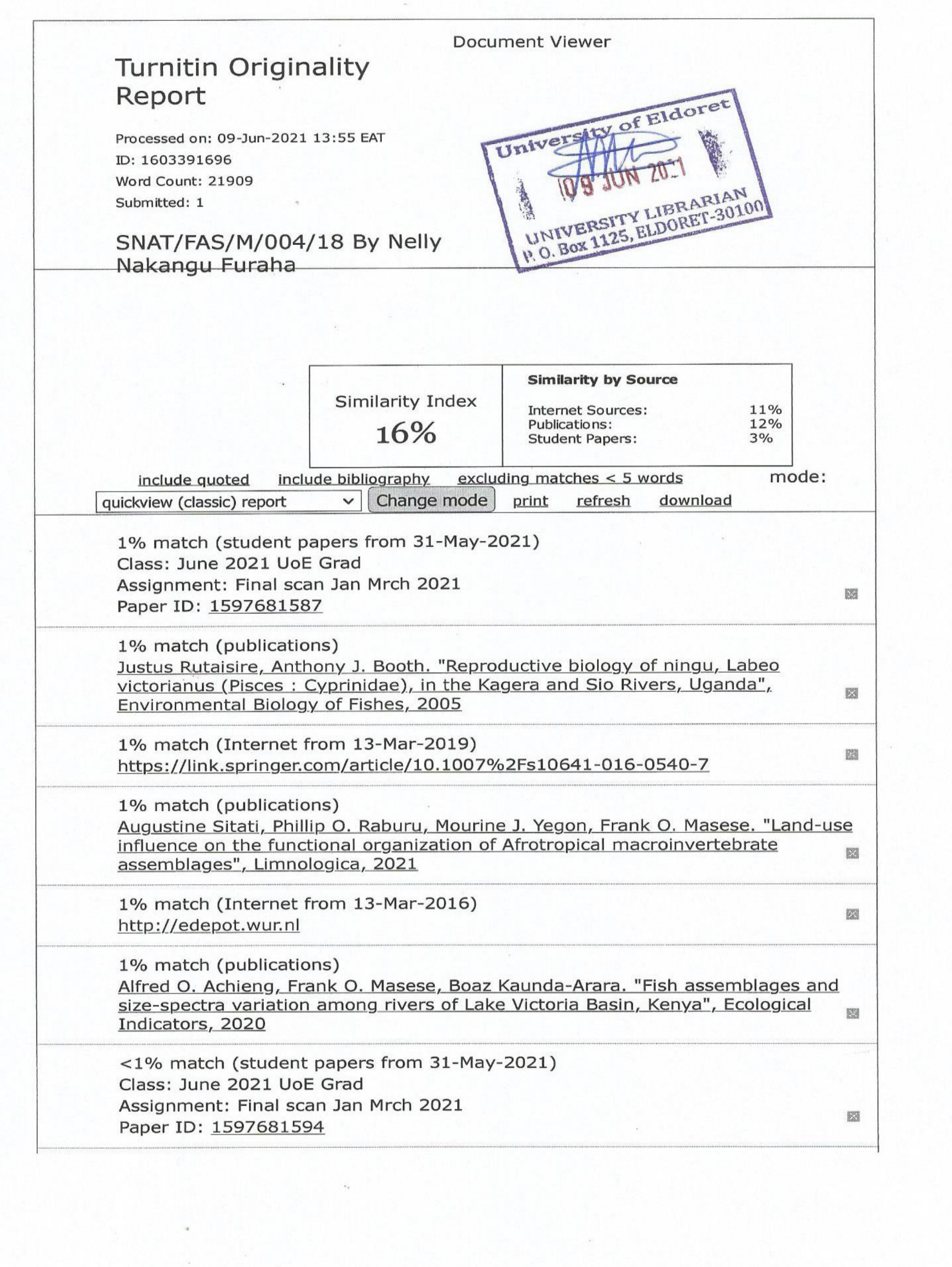
22.5	122.25	107.55	1.1367	26.1	168.66	171.812	0.982
22.4	120.76	106.04	1.1388	26.1	196.25	171.812	1.142
22.7	108.88	110.59	0.9845	24.1	133.52	133.587	0.999
11.5	14.70	12.93	1.1371	22.9	117.1	113.697	1.030
11	12.25	11.24	1.0903	23.5	129.25	123.368	1.048
11.3	13.60	12.23	1.1119	24.6	143.89	142.533	1.010
13.5	23.84	21.45	1.1117	24.9	143.25	148.092	0.967
14.3	24.15	25.72	0.9390	25.4	167.52	157.683	1.062
13.5	24.45	21.45	1.1401	24.7	148.05	144.370	1.025
15	33.78	29.91	1.1295	24.5	144.63	140.712	1.028
18	59.45	53.17	1.1180	23.4	128.36	121.719	1.055
19.7	68.08	70.70	0.9630	27.3	200.67	198.005	1.013
19.5	67.33	68.46	0.9835	26.5	166.14	180.262	0.922
24	131.88	131.85	1.0003	28.5	238.63	226.801	1.052
23.9	134.56	130.12	1.0341	27.2	215.03	195.724	1.099
27	201.56	191.22	1.0541	29.5	300.15	252.884	1.187
14.9	28.11	29.28	0.9600	30.9	320.96	292.740	1.096
13.6	21.15	21.95	0.9635	16	34.83	36.663	0.950

TL(cm)	**Weight**	**aL$^{(b)}$**	**K**	**TL(cm)**	**Weight**	**aL$^{(b)}$**	**K**
16.8	42.36	42.7678	0.9905	16.8	48.60	42.7678	1.1364
14.5	23.17	26.8711	0.8623	16.4	48.41	39.6353	1.2214

12.8	17.08	18.1274	0.9422	15.5	42.15	33.1673	1.2708
15.3	30.76	31.8351	0.9662	12.7	19.13	17.6842	1.0818
13.3	19.74	20.4581	0.9649	13.5	21.92	21.4450	1.0221
15	36.54	29.9061	1.2218	12	17.94	14.7864	1.2133
22	109.61	100.1810	1.0941	11.9	15.18	14.4010	1.0541
15.5	33.34	33.1673	1.0052	9.4	7.85	6.8408	1.1475
15.9	36.41	35.9450	1.0129	29.1	240.75	242.2179	0.9939
15	34.72	29.9061	1.1610	26.1	181.12	171.8121	1.0542
16.7	41.42	41.9694	0.9869	26.6	185.46	182.4177	1.0167
17.5	52.33	48.6494	1.0757	20	83.24	74.1531	1.1225
23.3	156.69	120.0845	1.3048	19.3	74.70	66.2658	1.1273
18.3	56.83	56.0215	1.0144	27.5	225.60	202.6197	1.1134
23.8	149.87	128.4083	1.1671	21.5	92.65	93.1687	0.9944
21.2	121.87	89.1266	1.3674	15	22.11	29.9061	0.7393
19.3	69.10	66.2658	1.0428	14	11.30	24.0537	0.4698

17.8	55.60	51.3309	1.0832	31	297.50	295.7408	1.0059
17.5	54.44	48.6494	1.1190	22.7	134.31	110.5920	1.2145
14.2	25.60	25.1551	1.0177	22.5	119.65	107.5455	1.1126
14.7	4.42	28.0586	0.1575	22.4	120.76	106.0439	1.1388
13.2	25.03	19.9765	1.2530	22.5	122.25	107.5455	1.1367
21.7	94.23	95.9319	0.9823	19.1	69.97	64.1224	1.0912
10.3	9.14	9.1295	1.0011	17.5	54.65	48.6494	1.1233
12.9	20.68	18.5782	1.1131	**Min**	7.85	9.4	
10.4	13.42	9.4123	1.4258	**Max**	240.75	29.1	
13.5	24.73	21.4450	1.1532	**Mean**	75.88077	17.63846	
14.6	30.50	27.4605	1.1107	**StD**	76.5134	7.653172	
21.5	155.45	93.1687	1.6685				

Appendix III: Similarity report



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