STUDIES ON LIFE HISTORY STRATEGIES OF *Labeobarbus altianalis* (BOULENGER 1900) AND *Labeo victorianus* (BOULENGER 1901) IN RIVER KUJA -MIGORI, KENYA

KEMBENYA ELIJAH MIGIRO

MSc (Kisii University), BSc Hons (Moi University)

A THESIS SUBMITTED TO THE BOARD OF POST-GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN FISHERIES OF THE SCHOOL OF AGRICULTURE AND NATURAL RESOURCE MANAGEMENT, DEPARTMENT OF ENVIRONMENT, NATURAL RESOURCES AND AQUATIC SCIENCES

KISII UNIVERSITY

2022

DECLARATION AND RECOMMENDATIONS

Declaration by the Candidate

This thesis is my original work and has neither, wholly nor in part, been presented for examination for award of PhD in any other University.

Kembenya Elijah Migiro Signature: __________ Date: ________________

DAN18/50073/16

Recommendation by Supervisors

This thesis is the candidate's original work and has been prepared with our guidance and assistance and submitted with our approval as the Supervisors.

1. Prof. Albert Getabu Signature __________________Date ____________________

   School of Agriculture and Natural Resource Development

   Department Aquatic and Fishery Sciences

   P.O Box 408-40200, Kisii University

2. Prof. James Njiru Signature ____________________ Date _________________

   Kenya Marine and Fisheries Research Institute

   P.O Box 81651-080100, Mombasa

3. Dr. Reuben Omondi Signature _____________________Date __________________

   School of Agriculture and Natural Resource Development

   Department Aquatic and Fishery Sciences

   P.O Box 408-40200, Kisii University

PLAGIARISM DECLARATION

Declaration by the Student

i. I declare that I have read and understood Kisii University Postgraduate Examination Rules and Regulations, and other documents concerning academic dishonesty.

ii. I do understand that ignorance of these rules and regulations is not an excuse for a violation of the said rules.

iii. If I have any questions or doubts, I realize that it is my responsibility to keep seeking an answer until I understand.

iv. I understand that I must do my own work.

v. I also understand that if I commit any act of academic dishonesty like plagiarism, my thesis can be assigned a fail grade ("F")

vi. I further understand that I may be suspended or expelled from the University for Academic Dishonesty.

Kembenya Elijah Migiro ……………………

DAN18/50073/16

Recommendation by Supervisors

We declare that this thesis has been submitted to plagiarism detection service and contains less than 20% of plagiarized work. We hereby give consent for Library Binding

1. Prof. Albert Getabu Sign_______________ Date______________
2. Prof. James Njiru Sign_______________ Date______________
3. Dr. Reuben Omondi Sign________________ Date_______________

DECLARATION OF NUMBER OF WORDS

Declaration by the Candidate

I confirm that the word length of the thesis, including footnotes is 50,625, bibliography 5,466 and appendices 103 words. I also declare that the electronic version is identical to the final, hard bound copy of the thesis and corresponds with those on which the examiners based their recommendation for the award of the degree.

Kembenya Elijah Migiro Signature: Date: _______________

DAN18/50073/16

Declaration by Supervisors

I confirm that the thesis submitted by the above-named candidate complies with the relevant word length specified in the School of Postgraduate and Commission of University Education regulations for the PhD Degrees.

1. Prof. Albert Getabu Sign________________ Date_______________

2. Prof. James Njiru Sign________________ Date_______________

3. Dr. Reuben Omondi Sign_________________ Date________________

COPY RIGHT

DEDICATION

This thesis is dedicated to my loving wife Elizabeth, dear parents; Wilson and Keziah, siblings; Joshua, Charles, Evans, Wilter, Rael, Sarah, and Late Enock, children; Ezra, Keziah, Elvin and Merab for their love, moral support, and prayers during my study period. May God bless you all.

ACKNOWLEDGEMENTS

I give glory to the Almighty God for the opportunity to pursue this PhD degree and for the good health throughout the entire period of study at Kisii University. I appreciate the outstanding commitment and guidance of my supervisors Prof. Albert Getabu, Prof James Njiru and Dr. Reuben Omondi in proposal development and field work. I thank most sincerely the technical team of: Zablon Awuondo, Caleb Ochiewo, David Andere, Peter Miruka, Justus Abuga, Geofrey Kirui, John Onsase, Alice Oguta, Pheline Owuor and Alice Osinde without whom this research could not have been possible. I am thankful to my wife Elizabeth Osebe, mum Keziah Mbera and dad Wilson Kembenya for their moral support and encouragement. I cannot forget the tireless support and encouragement from my friends, Judith Achoki, Robert Ondiba for their moral support during low moments. I acknowledge the Germany Academic Exchange Program (DAAD) in-Country/in-Region Scholarship Programme Kenya, 2016 and National Research Fund (NRF) for funding my studies. I acknowledge Kisii University and Kenya Marine and Fisheries Research Institute (KMFRI) for infrastructural support offered to me during the process of my proposal development and field work. I am highly indebted to the Kisii University’s School of Postgraduate Studies for the guidance and support throughout the study period. Finally, my thanks go to Linet Kombo and Erick Oyunge of research, extension, innovation, and resource mobilization office at Kisii University for timely processing of research funds.

ABSTRACT

Fish life history strategies are all the changes through which a fish passes in its development from birth to natural death. Life history comprise feeding, growth, reproduction, and migration. Life history strategies determine how fish populations respond to dynamics in their environment such as fishing and environmental perturbations. The present study was done in River Kuja – Migori from January 2018 to June 2019. The overall objective was to describe life history strategies of *Labeo victorianus* and *L. altianalis* in River Kuja – Migori. The specific objectives were to determine the spatial and temporal distribution of *L. victorianus* and *L. altianalis,* correlate the abundance of *L. victorianus* and *L. altianalis* to physical and chemical parameters, determine spatial and temporal variation of condition factor, gonadosomatic index, fecundity, egg size, and determine temporal variation of the diets of *L. victorianus* and *L. altianalis* in River Kuja- Migori. Fish specimens were collected using an electrofisher from five sampling stations along River Kuja – Migori. The total length and weight of fish specimens were measured in centimeters and grams respectively. The fish were dissected to reveal their gonads, which were weighed, and the data obtained was used to calculate gonadosomatic index. A small proportion of the ovary was excised out, weighed and the eggs in the ovary teased out, counted then used to estimate fecundity. Selected physical and chemical parameters were determined using standard methods according to American Public Health Association, (2000). Population dynamic parameters were estimated using Fish Stock Assessment Tools software. There were significant differences in the spatial and temporal distribution of *L. victorianus* and *L. altianalis* ($p < 0.05$). Condition factor, gonadosomatic index, and fecundity significantly varied spatially and temporary ($p < 0.05$). Results on sexual maturity revealed that both *L. victorianus* and *L. altianalis* males attain sexual maturity earlier than females. The length at 50% maturity of *L. victorianus* was estimated at 18 cm and 20 cm total length for males and females respectively while in *L. altianalis* it was estimated at 16.3 cm and 18 cm total length for males and females respectively. Fecundity ranged from 47,842 - 101,902 eggs (mean = 83,663 ± 2605) in *L. victorianus* and 1320 - 2382 eggs (mean = 1552 ± 23.3) in *L. altianalis*. The mean egg diameter for *L. victorianus* was 0.65 ± 0.002 mm and 1.2 ± 0.007 mm for *L. altianalis*. There were no significant differences in sex ratio from the hypothetical 1:1 (χ^2, $p > 0.05$) for both species. The results showed that *L. victorianus* has a longevity of 6 years while *L. altianalis* can live to a maximum of 9 years. The instantaneous growth rate (K) was estimated to be 0.25 yr^{-1} and 1.0 yr^{-1} for *L. victorianus* and *L. altianalis* respectively. The length-based growth performance indices were 2.86 yr^{-1} and 3.03 yr^{-1} for *L. victorianus* and *L. altianalis* respectively. Feeding habits of both species showed a shift in preference of food items from juvenile to adult. The results indicated that both species are omnivores mainly feeding on invertebrates during their juvenile life and detritus and plant material, during their adult life. Results showed that there could be competition between the two fish species on similar food resources in the river, both feeding exactly on the same type of food items. This study provides useful information for the formulation of management advice for *L. victorianus* and *L. altianalis* fisheries in River Kuja Migori.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMNS

List of abbreviations

μ Scm^{-1}	Micro siemens per second
A	Amps
asl	Above sea level
Chl a	Chlorophyll a
cm	Centimetres
F	Fishing mortality
K	Instantaneous growth constant
L_r	Instantaneous rate of mortality
km^2	Square kilometre
L_∞	Maximum length
M	Natural mortality
mg	Milligrams
ml	Millilitres
mm	Milli metre
Ms-222	Methane sulfonate
NTU	Nephelometric turbidity unit
t_{max}	Maximum age
V	Volts
W_∞	Maximum weight
yrs	Years
Z	Total mortality

List of acronyms

ANOVA	Analysis of Variance
APHA	American Public Health Association
ASP	Available Sum of Peaks
DAAD	Germany Academic Exchange Program
DO	Dissolved Oxygen
ELEFAN	Electronic Length Frequency Analysis
ESP	Explained Sum of Peaks
FAO	Food and Agricultural Organization
FiSAT	Fish Stock Assessment Tools
FL	Fork Length
GPS	Geographical Positioning System
GSI	Gonadosomatic Index
GW	Gonad Weight
IDPs	Internally Displaced Persons
IUCN	International Union for Conservation of Nature
KMFRI	Kenya Marine and Fisheries Research Institute
MT	Metric Tonnes
NRF	National Research Fund
PUFAs	Poly unsaturated fatty acids
SE	Standard Error
SL	Standard Length
SRP	Soluble Reactive Phosphorous
TL	Total Length

TN	Total Nitrogen
TP	Total Phosphorous
UNDPI	United Nations Department of Public Information
WP	Winter Point

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

In the aquatic environments fishes are the most diverse and numerous groups of animals. Due to their long history of evolution, fish diversity exceeds the diversity witnessed in terrestrial animals (Volff, 2004). Life history of an organism refers to the changes through which an organism passes in its development from birth to its natural death. It's the series of living phenomena exhibited by an organism throughout its life. Therefore, life history strategies are the adaptive traits that an organism uses to successfully survive in its habitat throughout its life (Winemiller & Rose 1992). Fish life history strategies are co-evolved complex traits of an aquatic ecosystem (Olden & Kennard, 2010). For example, the strategy of fish in the production of a maximum number of offsprings to enable them cope with variation in environmental conditions result to changes in the patterns of recruitment which greatly contributes to future variable annual harvestable stocks (Winemiller & Rose 1992). Fish life history strategies are regarded as being responsible for the way populations of fish respond to changes in aquatic habitats in which they live (King & McFarlane 2003).

Life history strategy comprise three most important areas of an organism's existence, feeding, growth, reproduction, and migration (Stearns, 1992). There may be trade-offs among these that may be at work simultaneously across several dimensions. However, reproduction is the only facet of life-history theory that contributes to an organism's fitness. Reproduction and growth are inter-linked; growth can increase future reproduction at the cost of current reproduction (King & McFarlane 2003). The interaction of growth and reproduction is regarded as one of the most crucial trade-offs in fishes (Stearns, 1992). This is because most of the reproductive traits such as fecundity and growth are a function of the body size of a fish (Wootton, 1984). The trade-off pattern that exists between reproduction and growth may differ depending on the reproduction strategy of a given species of fish. Fish in an aquatic environment must consider the costs for survival and the availability of energy for purposes of reproduction. Therefore, the fish must decide on how to allocate the available energy for the present and future reproduction as an adaptation to the changing conditions of their aquatic environment (Winemiller & Rose 1992). The increase in growth in terms of length and weight during the period of spawning would be related to a decrease in the production of offsprings, but the resulting bigger fish size could confer a benefit of high number of egg production in the subsequent spawning seasons (Nunez & Duponchelle, 2009). The surplus energy in a fish is essential to the metabolic requirements that is for maintenance, locomotion, and avoidance of predators. Hence, feeding is allocated to storage of energy, somatic growth, and reproduction when the fish attains sexual maturity (Nunez & Duponchelle, 2009).

There are very tight links between reproduction and survival; an individual fish must survive until it attains sexual maturity, and reproduction itself is associated with the risk of mortality (Wootton, 1984). The size at sexual maturity and natural mortality are the major life history strategies that define changes in fish population and determine the response of fish populations to the conditions of their aquatic environment (Domínguez-Petit et al., 2017; Pérez-Palafox et al., 2022). There are several trade-offs associated with growth and survival, foraging behaviour and the threat of predation risk. Changing the allocation of time and energy towards reproduction throughout a lifetime has interlinked consequences for fitness. The premise of natural selection and life history theory is to maximize expected future reproduction which is achieved through these trades-offs and selected life history strategies. The estimation of the basic fish life history characteristics, which include spawning season, the age and size at first sexual maturity and the number of eggs per spawn, is important when predicting generalizations on how different fish species respond to modification of the environment in which they live. Also, understanding their adaptation responses to fishing, guiding the management direction of fishery resources, development of the most appropriate culture requirements, fueling studies on general ecology at community or ecosystem level and developing fish reproduction strategies (Nunez & Duponchelle, 2009). Sexual maturation is when a fish attains the age of being able to reproduce sexualy. This occurs once in the life of a fish when it moves from juvenile to adult stage (Domínguez-Petit *et al*., 2017).

The knowledge on reproduction in fish is crucial for proper management of fisheries. This is so because regulators of most fisheries resources rely on the size at which fish become sexually mature, the time they commence breeding activities and the duration they take during spawning for proper management (Trindade-Santos & Freire, 2015). Furthermore, some measures for fish management are based completely on reproductive characteristics of fish stocks (Morgan, 2008). Late sexual maturation of fish may lead to bigger fish with increased fecundity at the spawning season (Nunes et al., 2011). Overexploitation of natural fish stocks is most likely to occur when there is lack of information on reproduction (Domínguez-Petit et al., 2017).

Estimation of condition factor in fish is important as it indicates the overall wellbeing of a fish in its habitat and a good condition exists in heavier fish than in lighter fish at a given length (Dadebo et al., 2011; Ogamba et al., 2014). When the fish condition is poor, growth rate slows down, the fish's potential to produce eggs or sperms is reduced and this can negatively affect survival and reduce its longevity. A fish is fit in its environment when the condition factor is equal or close to one (Abobi, 2015; Nazek et al., 2018).

Information on fecundity is important when exploring the changes in reproduction and energetics of spawning in fish stocks and when estimating yearly reproductive output (Mohammed & Patahk, 2011). Fecundity is employed to determine spawning biomass through production of eggs (Ganias et al., 2014). Furthermore, knowledge on fecundity of fish is important in estimating the potential of spawning activity and its ultimate success (Murua et al., 2003; Ojutiku et al., 2012).

Gonadosomatic index is a crucial parameter used to describe allocation of energy in fish (Mohammad and Pathak, 2011). It gives an insight regarding spawning in fish as it is used to determine the level at which the ovaries are mature (Mishra & Saksena 2012; Manal et al., 2017). It is also used in identification of the spawning events (Gupta et al., 2013). Therefore, gonadosomatic index is useful in formulation of suitable breeding policies in fisheries management (Mishra & Saksena 2012; Manal et al., 2017).

The interactions of physical and chemical characteristics of water play a very crucial role in fish abundance, movements, distribution, and diversity (Deepak & Singh, 2014). Fish populations are dependent highly on variations of physical and chemical parameters of the aquatic ecosystems which support their biological activities (Mbalassa, et al., 2014).

River Kuja-Migori is of immense significance in terms of ecological services, fisheries resources, and economic benefits to riparian communities (Achieng et al., 2021). It is used as source of water and fish and contributes to livelihood sustenance of the local communities (Ogutu-Ohwayo, 1990; Achieng et al., 2021). It also provides feeding and spawning grounds for migratory fish species from Lake Victoria (Ochumba & Manyala, 1992).

Efforts have been made to manage fisheries resources, but the largest portion of fisheries resources are overexploited (Wenjia et al., 2015). UNDPI (2010), reported that about 28% of fish stocks around the globe were either overexploited, depleted or recovering from depletion, thus yielding less than their maximum potential due to excess fishing. A further 52% of fish stocks were fully exploited approaching their maximum sustainable limits (Abd El-Hack et al., 2022).

There exists no information on life history strategies for riverine fishes of the Lake Victoria basin. For instance, there is very little information on fish assemblages in River Kuja - Migori. The life history strategy information of the River Kuja - Migori is crucial in efforts geared towards formulating regulations on fisheries management of riverine fishery. Therefore, the main objective of the present study was to describe the life history strategies of two fish species: the Ningu, *Labeo victorianus* (Boulenger 1901) and the Ripon barbel, *Labeobarbus altianalis* (Boulenger 1900) in River Kuja – Migori, Lake Victoria basin, southwestern Kenya.

1.2 Statement of the problem

River Kuja-Migori play an important role for provision of fish food and other services to the riparian communities (Achieng et al., 2021). Commercial fishery in major rivers in Kenya was once lucrative (Balirwa et al., 2003) where *L. victorianus* and *L. altianalis* were the only fish that formed a commercial riverine fishery and accounted for about 60% of the riverine fishes (Masese et al., 2020). However, these two fish species are vulnerable to fishing due to their habit of aggregating at the river mouths (Ogutu-Ohwayo, 1990) as they exploit the interconnectivity between the lake and rivers for migration to breed upstream (Rutaisire et al., 2015; Gebremedhin, 2012). This has led to a decline in these riverine fish populations which can be attributed to pollution, overfishing, degradation of fish habitats, competition for food resources, use of gears considered illegal which target egg laden females and predation by introduced species (Cadwalladr, 1965; Balirwa & Bugenyi, 1990; Ogutu-Ohwayo, 1990; Achieng et al., 2021). The decline of these two fish species in the rivers is a threat to food and nutrition security of local communities who depended on the species for livelihoods.

Earlier studies have shown that there is a decline in the number of migratory riverine fishes, where alien fish species dominate with fewer indigenous fishes (Ochumba & Manyala, 1992). However, most of the past studies (Omwoma et al., 2014; Manyala et al., 2005; Witte et al., 2008; Njiru et al., 2008) focused on lacustrine fishes while assuming riverine fish species. Hence there is little existing information concerning the life history strategy of riverine fish species which can be utilized to formulate conservation and management measures. Therefore, the present study aimed at describing the life history strategies of the two fish species (*L. victorianus* and *L. altianalis*) in River Kuja - Migori.

1.3 Objectives

1.3.1 General Objective

To describe life history strategies of *L. victorianus* and *L. altianalis* in River Kuja - Migori.

1.3.2 Specific objectives

1. To determine the relationship between physico-chemical parameters and abundance of *L. victorianus* and *L. altianalis* in River Kuja- Migori.
2. To determine the spatial and temporal distribution and abundance of *L. victorianus* and *L. altianalis* in River Kuja- Migori.
3. To determine spatial and temporal variation in condition factor of *L. victorianus* and *L. altianalis* in River Kuja- Migori.
4. To determine the spatial and temporal variation of gonadosomatic index, fecundity, and egg size of *L. victorianus* and *L. altianalis* in River Kuja- Migori.
5. To determine temporal variation in diets of *L. victorianus* and *L. altianalis* in River Kuja- Migori.

1.4 Hypotheses

1. There is no relationship between physico-chemical parameters and abundance of *L. victorianus* and *L. altianalis* in River Kuja- Migori
2. There are no significant differences in spatial and temporal distribution and abundance of *L. victorianus* and *L. altianalis* in River Kuja- Migori
3. There are no spatial and temporal variations in condition factor of *L. victorianus* and *L. altianalis* in River Kuja- Migori.
4. There are no spatial and temporal variations of gonadosomatic index, fecundity, and egg size of *L. victorianus* and *L. altianalis* in River Kuja- Migori.
5. There are no temporal variations in diets of *L. victorianus* and *L. altianalis* in River Kuja- Migori.

1.5 Justification

This study aims at describing the life history strategies of *L. victorianus* and *L. altianalis* in River Kuja – Migori. Information on life history strategies is important in the conservation of riverine fish populations. More descriptions of life history characteristics for these riverine fish species are needed to develop adequate conservation and management measures to prevent further decline of fish populations in River Kuja -Migori. The information obtained from the present study on fish life history strategies of River Kuja - Migori can be used to formulate fisheries regulations for the management of the fishery of the two riverine fish species.

1.6 Scope of the study

This study covers life history strategies of two fish species of the family Cyprinidae namely *L. victorianus* and *L. altianalis*. The physical and chemical characteristics in River Kuja – Migori were determined and correlated with fish abundance. The physical and chemical parameters determined were alkalinity, hardness, dissolved oxygen, temperature, turbidity, pH, conductivity, total phosphorous, total nitrogen, nitrates, nitrites, soluble reactive phosphorous, silicates and chlorophyll *a*. Distribution and abundance of the two fish species was also determined. The population parameters of *L. victorianus* and *L. altianalis* were estimated which include length - weight relationship, condition factor, parameters of the Von Bertalanffy growth function using two methods namely; the Electronic Length Frequency Analysis (ELEFAN 1) method and the Powell-Wetherall methods, instantaneous growth constant (K), the asymptotic length (L_∞), length and weight based growth performance indices, maximum length (L_{max}), longevity (t_{max}), natural mortality, fishing mortality, recruitment patterns and virtual population analysis using both mean lengths method and catch curve analysis. Reproductive biology parameters were assessed which include sex ratio, egg size, fecundity, gonadosomatic indices, sexual maturity stages, length at 50% maturity (L_{M50}), the smallest mature fish and breeding season. Other aspects determined were the food composition and feeding habits of the fish including ontogenic shifts in the diets. Finally, the life history strategies of the two fish species were identified, and their characteristics explained together with suggestion for the management and conservation of their fisheries.

1.7 Assumptions

The major assumption in this study was that the River Kuja - Migori environment was in a steady state or dynamic equilibrium. Therefore, it was assumed that the condition of the river environment remained the same from year to year. It was further assumed that sampling of the population parameters and measurement of physical and chemical characteristics were conducted with accuracy at each sampling station from month to month throughout the sampling period.

1. 8 Conceptual Framework

The conceptual framework (Figure 1) is broadly classified into independent, dependent, and intervening variables. The independent variables which mainly consist of environmental factors such as, rainfall, water depth, electrical conductivity, temperature, chlorophyll *a*, dissolved oxygen concentrations, alkalinity, hardness, pH, nitrates, nitrites, soluble reactive phosphorous, total phosphorous and total nitrogen directly affects the dependent variables namely; growth rate, growth performance, longevity, (*r* - selection) recruitment size, frequency of recruitment (*r* and *k* - selection) fecundity, egg size, size and age at first maturity, length at 50% maturity and fish behavior such as migration. The relationship between environmental factors may be affected by extrinsic factors that the researcher may not be able to control (intervening variables). In this study anthropogenic activities such as pollution, mining and damming were the major intervening variables.

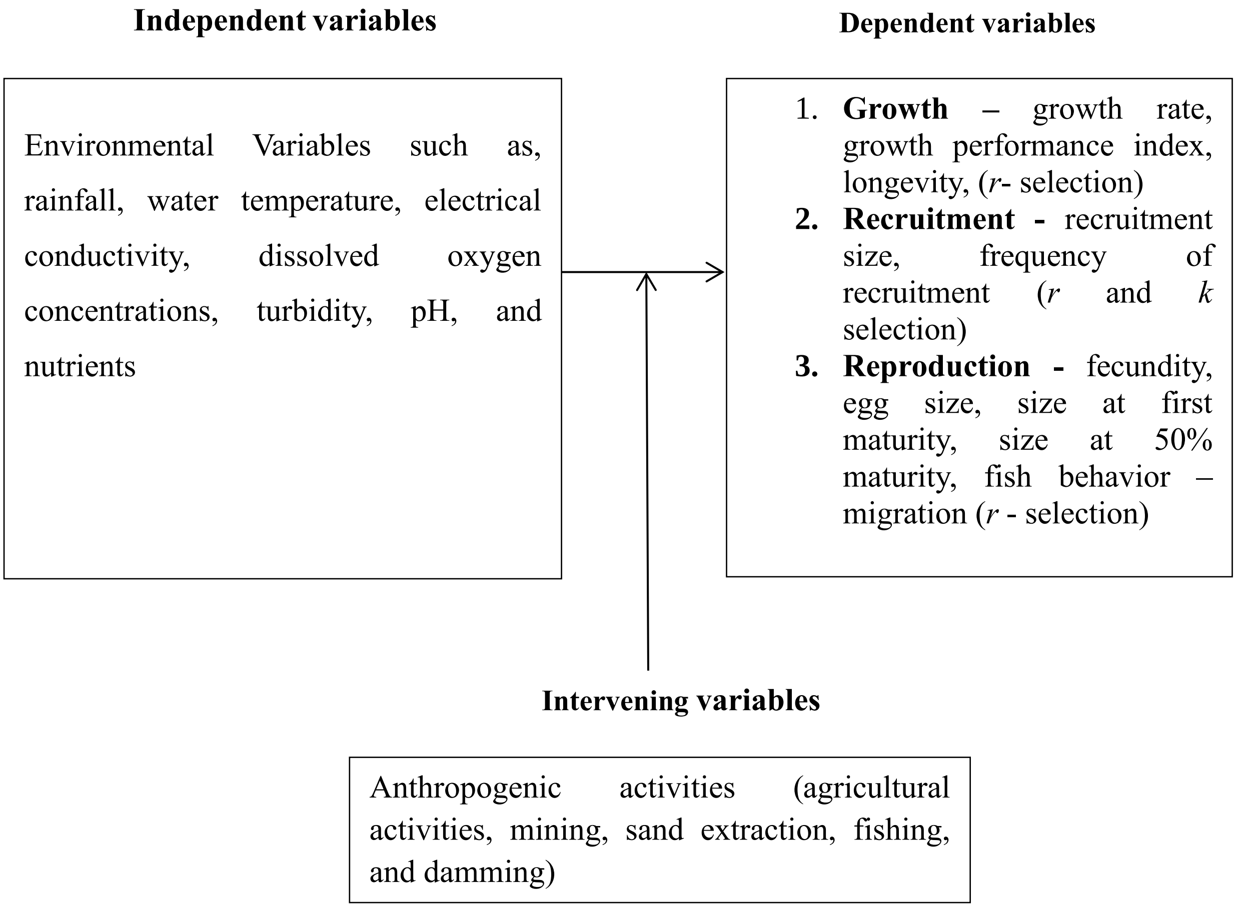

Figure 1. Conceptual framework

1.9 Operational Definition of Terms

Fecundity	the number of vitellogenic oocytes present in the ovaries before a spawning season
Growth	Increase in length and weight or increase in numbers of fish
Life history	It entails reproduction, growth, feeding and migration in fish
Longevity	Life span of fish from hatching to its death
Reproductive biology	Sexual maturity, sex ratio, fecundity and gonadosomatic index

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A river can be defined as a complex natural system of flowing water draining specific landscapes into the sea, lake or joining with another river (Peters et al., 1997). Rivers are important in carrying and distributing water and nutrients to their catchments around the globe. They are critical components of the hydrological cycle and act as drainage channels for surface water runoff (Lawson, 2011). Rivers globally drain nearly 75% of the earth's land surface. They have been an integral part of development, where they are used as a source of drinking water, irrigation of land used for agricultural crops, supply of industrial and municipal water, disposal of industrial and municipal wastes, navigation, fishing, boating and other recreational activities, generation of hydroelectric power and aesthetic value (Mwangi et al., 2012; Poff et al., 2015). The ever-growing demand for water resources coupled with the rate at which much of the fresh waters around the globe are being adversely affected by human activities, demonstrates a developing crisis if environmental water resources are not well managed (Peters et al., 1997).

The riverine aquatic ecosystems are largely influenced by human activities on the catchment (Livingston et al., 1997; Rose, 2000). Rivers draining to Lake Victoria are no exception and River Kuja - Migori currently face serious anthropogenic degradation such as poor agricultural activities, clearance of riparian vegetation, nutrient enrichment, and climate change (Achieng et al., 2021). Water quality of a river is defined in terms of its physical, chemical, and biological contents. Physical and chemical water parameters provide nutritional balance and ultimately govern the biotic relationships of organisms in an aquatic ecosystem (Mwangi et al., 2012). The distribution and diversity of aquatic organisms in rivers is greatly influenced by the flow of water downstream and the changes which occur along the longitudinal gradient (Larsen et al., 2019). This is explained by river continuum concept which describes how both physical and biological changes occur longitudinally along river ecosystems right from the source to the mouth. The headwaters are regarded as heterotrophic by depending on energy produced in the surrounding watershed. As the channel widens downstream, the amount of sunlight and average temperatures increase which in turn increase primary production due to increase in light penetration, which shifts streams to depend on allochthonous materials from the watershed. The mid river develops increased reliance on primary productivity by phytoplankton but continue to receive inputs of fine and dissolved organic particles from upstream. Here, populations of invertebrates are dominated by fine particle collectors which include zooplankton. Towards the mouth of the river increased loads of fine silt and clay become prominent, which increase turbidity of the river, decrease light penetration, and subsequent increased significance of heterotrophic processes. In general, the river system from the headwaters to the mouth can be regarded as a gradient of conditions from heterotrophic regime at the source to seasonal regime of autotrophy at the mid reaches and then a return of heterotrophic processes downstream (Vannote et al., 1980). Its therefore hypothesized that structural and functional characteristics of communities of fish in a river distributed along the river gradient are selected to conform to the most probable position or mean state of the physical river system (Larsen et al., 2019).

2.2.1 Description of *Labeo victorianus*

The biological classification of *L. victorianus* is as follows; Kingdom – Animalia; Phylum – Chordata; Class – Actinopterygii; Order- Cypriniformes; Family – Cyprinidae; Sub family- Labeoninae; Genus - *Labeo*; Species – *Labeo victorianus* (Figure 2).

Figure 2. A specimen of *Labeo victorianus* (Boulenger 1901) collected from River Kuja – Migori during the study

Labeo victorianus is one of the ray-finned fishes in the family Cyprinidae. It has a more spindle-shaped body that is suited to its riverine environment in which there is a continuous water flow. The mouth of the fish is placed at a ventral position and is well adapted to its mode of feeding on benthic deposits and riverine aquatic vegetation. The fish possess a rostral cap well pronounced, that cover the upper lip. The lips are expanded to thick sausage shaped pads with keratinized edges. The jaws possess horny cutting ridges, and the mouth parts are relatively apomorphic. At the rear edges of the lower maxilla the fish has a well- developed vomeropalatine organ (Bayona, 2006). It is suggested that the organ is primarily concerned with bolus formation by the active co-mixing of precipitating mucous secretions with ingested food particles. The forked caudal fin is asymmetrical with the upper lobe being longer than the lower one. Along the middle of the flank and the caudal peduncle runs a lateral line. *L. victorianus* has a mouth with soft and retractable lips possessing soft teeth-like barbs with soft toothed pads.

There is no evidence of possession of pharyngeal teeth in this species, but it has a hard pad on the upper palate of the buccal cavity. The oesophagus appears as a short muscular tube about 1 cm in length. The epithelium possesses goblet cells which aid in mucous secretion to lubricate food during swallowing. It leads to a large intestinal bulb with a length of about a quarter of the intestine, which then tapers yet to a relatively smaller tract of the intestines, then ends at the anal pore. The intestines of the adults are long and ranges between seven to eleven times the fork length (FL) of the fish. More than 90% of the intestinal tract is coiled into concentric circles so that it can fit into the belly of the fish (Owori-Wadunde, 2004).

The genus *Labeo* constitutes about 80 fish species widely distributed mostly in the African continent. It constitutes about 16.4% of the African cyprinids (Weyl and Booth, 1999). In this family, there is only one genus in Lake Victoria with only one species *L. victorianus* (Rutaisire & Booth, 2005). The species used to be commercially important in Lake Victoria before 1960s (Njiru et al., 2005). African cyprinids of the genus *Labeo* are known to be susceptible to over-exploitation. For instance, the collapse of the fishery of *Labeo mesops,* in Lake Malawi (Anteneh et al., 2012) and the fishery of *Labeo altivelis* in Lake Mweru (Gordon, 2003) was caused by overfishing.

The population decline in *L. victorianus* and that of other potamodromous species in Lake Victoria basin is well documented in the Kenya, Uganda, and Tanzania sectors of Lake Victoria. For example, catch per net at the mouth of River Kagera declined from 13.6 in 1954 to 0.5 in 1963 (Rutaisire & Booth, 2005). According to Kibaara, (1981) the contribution of *L. victorianus* to the fish catches in Lake Victoria in 1969 was 595 tonnes and in 1968 was 467 tonnes. Then the catches decreased from 204 fish per hactare to less than 1 fish per hactare in the late 1980s and 1990s respectively (Balirwa et al., 2003).

Exploitation of *L. victorianus* and other riverine fish species started lightly in the early 1900's mostly at the mouths of major rivers flowing into Lake Victoria (FAO, 1988). This involved the use of primitive fishing gears such as weirs, reed fences and traps (Cadwalladr, 1965; Ogutu-Ohwayo, 1990). As the catch declined the fishermen started adopting more efficient gears such as flax gill nets in the year 1905 to improve the catches and as catches dwindled further the fishermen adopted the more efficient monofilament nylon gillnets (Cadwalladr, 1965; Ogutu-Ohwayo, 1990). The use of these fishing gears reduced the populations of *L. victorianus* and other potamodromous fish species to the verge of extinction in the Lake Victoria basin (FAO, 1988). Overfishing using illegal smaller mesh gillnets and other gears such as beach seines, mosquito nets and traps have been demonstrated to capture sexually mature fish before they spawn (Rutaisire & Booth, 2005).

The other factors which largely contributed to the reduction of populations of *L. victorianus* and other riverine species are predation from the intentionally introduced *Lates niloticus* (Nile perch) in Lake Victoria in the mid and late 1950s (Oyoo-Okoth et al., 2011). Competition for same food items with other fish species which include *Oreochromis niloticus* (Nile tilapia) and *L. altianalis* (Ogutu-Ohwayo, 1990; Greboval & Mannini, 1992). These fish species share the same food resources of benthic deposits and invertebrates with *L. victorianus.*

2.2.2 Description of *Labeobarbus altianalis* of the Lake Victoria basin

The biological classification of *L. altianalis* is as follows; Kingdom – Animalia; Phylum – Chordata; Class – Actinopterygii; Order- Cypriniformes; Family – Cyprinidae; Sub family-Cyprininae; Genus- *Labeobarbus*; Species – *Labeobarbus altianalis* (Figure 3).

Figure 3. A specimen of *L. altianalis* (Boulenger 1900) collected from River Kuja – Migori during the study

Labeobarbus altianalis is one of the potentially high value fish which is highly threatened with overfishing (Rutaisire, 2004; Ondhoro et al., 2016). It grows up to more than 90 cm total length and attains approximately 10 kg individual wet weight (Rutaisire, 2004). It is an inter lacustrine-riverine species found in the streams and rivers within the Lake Victoria Basin. The species is distributed widely in the Lake Victoria basin and in many rivers and streams in East Africa. In Uganda it is found in River Kagera and in Lake Edward (Aruho et al., 2018) while in the Democratic Republic of Congo, it’s found in Lake Kivu (Snoeks et al., 2012). In Kenya, *L. altianalis* is found in rivers Nyando, Nzoia, Yala and Sondu - Miriu, Kuja-Migori and Mara (Chemoiwa et al., 2017). It is considered a delicacy among fishing communities around Lake Victoria, Kenya, and Uganda and in the eastern region of the Democratic Republic of Congo (Anteneh et al., 2012). In nature of their life history, they migrate up rivers and streams to breed during the rainy season. In so doing they congregate at river mouths during migration where they become an easy target of overexploitation, since they become highly susceptible to fishing during such periods (Aruho et al., 2018). This has led to a considerable decline in numbers of this species in the catches around Lake Victoria (Outa et al., 2018). According to Balirwa et al., (2003) the catches for *L. altianalis* in 1980s reduced from 8,173 tons to 152 tons in 1990s.

2.3.1 The ecology of *L. victorianus* of the Lake Victoria Basin

Several fish species in the genus *Labeo* are regarded commercially important in many African countries and have greatly contributed to various fisheries (Weyl and Booth, 1999). The species is endemic to Lake Victoria basin (Gichuki et al., 2001). The fish is a potamodromous species which migrates from the main lake up to the rivers to spawn especially inside pools formed after floods. After spawning and fertilization the eggs hatch into larvae/fry and start feeding at the side pools entering the riverine habitat as the waters recede. They live and grow in the riverine habitat and then move closer and closer to the lake and eventually enter the lake where they stay until they mature and are ready for spawning in the riverine habitat (Rutaisire & Booth, 2005).

This species was once distributed widely in the Lake Victoria basin and supported a major commercial fishery until the late 1950s (Cadwalladr, 1965; Ochumba & Manyala, 1992; Owori-Wadunde, 2004; Njiru et al., 2005; Oyoo-Okoth et al., 2011) but its population has long declined (Rutaisire, 2004) due to combined effects of overfishing, modification of riverine regimes due to anthropogenic activities and predation by Nile perch. Further, the predictable migratory habits coupled with the fact that *L. victorianus* is regarded a delicacy among the local communities inhabiting the Lake Victoria basin have contributed to its considerable decline through intensive use of illegal fish traps to harvest gravid fish migrating up the rivers to breed. Balirwa and Bugenyi (1990) states that the decline of the species is because of degradation of the ecosystem, predation by introduced species, competition with other fish species, as well as overfishing.

2.3.2 The ecology of *L. altianalis* of the Lake Victoria basin

The adults of *L. altianalis* migrate upstream for purposes of spawning and prefer spawning in clear running water (Skelton et al., 1991). The juvenile fish are normally found moving in 'schools' in riverine waters (Rutaisire & Booth, 2005). This is a clear indication that the fish deposits eggs in fresh clean running water with enough supply of oxygen and that the juvenile fish require high concentrations of dissolved oxygen for their energy requirements in the riverine environment (Aruho et al., 2018).

2.4 Distribution and abundance of riverine fish in Lake Victoria basin

The abundance of riverine fish in the Lake Victoria basin has reduced in the recent past in response to increased complexity and stressors in many river catchments. This has led to loss of sensitive fish species, migration of fish to headwaters and sub-catchments which are less polluted (Achieng et al., 2021). However, earlier studies by Mugo and Tweddle (1999) on preliminary surveys of the fishes of the Nzoia, Nyando and Sondu - Miriu rivers, in the Lake Victoria catchment showed that fish catches upstream were negligible but increased downstream. They identified 20 species comprising of the following families: Cyprinidae 12 species in the genus *Labeo* and *Barbus* - currently known as *Labeobarbus*, Cichlidae 3 species, Schilbeidae 1 species, Clariidae 3 species, Mastacembelidae 1 species, Mormyridae 1 species and Mochokidae 1 species. The importance of potamodromous fishes of the Lake Victoria basin has been recognized by many authors in past studies (Cadwalladr, 1965; Balirwa & Bugenyi, 1990; Ochumba & Manyala, 1992) but the fisheries have been declining since the 1940s (Muli & Ojwang, 1996). *Labeo victorianus* in the past constituted a significant riverine fishery particularly at or in the neighbourhood of rivers but due to overfishing using monofilament nylon gillnets, its catches drastically reduced to the extent that the fish species is now listed as endangered in the International Union for Conservation of Nature (IUCN) red list. Studies on the quantity and value of riverine fish species in the Lake Victoria basin are limited and yet riverine fishery contribute significantly to the subsistence of the riparian communities. Biological information on the riverine fish species both in terms of their economic and nutritional importance is necessary for assessment and management of fisheries. Majority of studies have focused on Lake Victoria fish species while fish distribution patterns and community structure in the rivers has been left largely un-addressed. The headwaters of most rivers are species deficient and are mainly dominated by small-bodied cyprinids and clariids which includes a few fish species considered endemic to the Lake Victoria basin (Masese et al., 2020). More often the species dominance and succession in rivers is low and a survey of available literature indicates that there is a decline in migration of potamodromous fishes in the rivers of the Lake Victoria basin. It has been stated before that *L. victorianus* and *L. altianalis* have a stenotopic population (Ojwang et al., 2007). Furthermore, a most recent investigation by Masese et al., (2020) shows that there are several exotic fish species in the Lake Victoria basin rivers which include *Oreochromis niloticus*, *Oreochromis leucostictus*, *Coptodon zillii* and *Gambusia affinis*. These fishes have invaded and successfully established themselves in rivers posing a serious threat to native riverine populations. For example, tilapiine species especially *O. niloticus* and *O. leucostictus*, compete for same energy resources in the benthic riverine habitat (benthic materials) as those of *L. victorianus* and *L. altianalis* while *G. affinis* is insectivorous just like several other riverine fish species. These species could also be having similar or near similar habitat preferences as the indigenous riverine species.

Most riverine fish populations in the Lake Victoria basin are faced with multiple environmental stressors emanating from ever expanding human population and associated anthropogenic activities (Achieng' et al., 2020). Interference with fish migration such as alteration of river flow, pollution from agricultural, urban, and domestic effluents, invasive species including fish, aquatic macrophytes, eutrophication, siltation, and overfishing. These stressors negatively impact on the distribution, abundance, and biodiversity of fish in the river (Akongyuure & Alhassan, 2021). Studies have indicated that migration activity of fish is triggered by various extrinsic factors such as, rainfall, lake water or river water level, water currents and discharge level, the lunar cycle, photoperiod, temperature, dissolved oxygen concentrations, turbidity, fish density, hunger, and unexpected appearance of certain insects (Nabi et al., 2014; Zhang et al., 2020; Pfauserova et al., 2022). For example, emergence of the lake fries in Lake Victoria which attract both birds and fish to migrate to a locality for purposes of feeding. The hormones: thyroxin, prolactin, growth hormone, somatolactin, insulin like growth factor, luteinizing hormone, gonadotropin releasing hormone, follicle stimulating hormone, testosterone and ketotestosterone has either a direct or indirect role in triggering fish migration (Peter & Yu, 1997; Abrehouch et al., 2010).

Since the mid-1960s most areas of the Lake Victoria basin have experienced rapid expansion in agricultural, industrial and urbanization activities (Raburu et al., 2009). There has been an increase in food processing capacity of agro based industries such as sugar mills, tea and coffee processing factories as well as some occasional mining activities which include gold mining along the River Kuja - Migori. These factors together with poor agricultural practices are responsible for alteration of integrity of riverine ecosystems thus affecting their capacity for fish production and biodiversity (Aura et al., 2020). Largely, due to their negative impacts on fish breeding and feeding grounds as well as migratory routes. This is supported by observations that most wetlands upstream which acts as riverine fish habitats and refugia from predators and fishing have been largely converted to agricultural farms. Thereby affecting growth, reproduction, and recruitment of riverine fish species. Examples of areas influenced by human activities can be witnessed along the River Kuja - Migori, River Yala, River Nyando at Ahero rice irrigation scheme and River Nzoia delta (Orwa et al., 2012). The cultivation of rice, millet and maize in these areas relies on the use of agricultural fertilizers and pesticides as well as replacement of fish habitats with farmland hence reducing fish populations. Most of these areas are not suitable for agriculture as they suffer from frequent annual floods which results in displacement of the communities living there into internally displaced persons (IDPs) camps. Hence occupation and dependence of these areas for food production and habitation are not sustainable and therefore should be rehabilitated into their original state to help conserve the riverine fish communities and habitats. Studies on riverine fish habitat preferences are poorly documented, information on these will help understand how the fish are distributed. In addition to their limited scope, most of these studies are old and fail to address the potential impacts of the changes in environmental conditions on fish communities and the functioning of the riverine ecosystem because of increasing anthropogenic influences on the catchments (Achieng' et al., 2020).

In all the rivers in the Kenyan sector of Lake Victoria, the number of riverine fish species as a fishery is not known (Mugo & Tweddle, 1999). This is because there is scanty information on the biology and ecology of the species. Such knowledge is necessary to discern the extent to which the riverine fish populations can support riparian human communities in terms of nutrition and income generation. Data on such fish species is important for effective conservation and management of other fish species, biomonitoring of changes in the environment and the assessment of the viability and the state of riverine fishery as a resource for commercial exploitation. Taxonomy of small cyprinid fish species in the riverine habitats of the Lake Victoria basin is not well known. The number of indigenous and introduced fish species into Lake Victoria basin by family are shown in Table1.

Table 1. The number of indigenous and introduced fish species in the Lake Victoria basin by family [adapted from Witte et al., 2008]

Family/ Tribe	Number of indigenous species	Number of introduced species
Alestidae	2	
Anabantidae	1	
Bagridae	1	
Cichlidae/ haplochromines	500	
Cichlidae/ tilapiines	2	4
Clariidae	6	
Cyprinidae	17	
Latidae	1	1
Mastacembelidae	1	
Mochokidae	2	
Mormyridae	7	
Nothobranchiidae	2	
Poeciliidae	5	
Protopteridae	1	
Schilbeidae	1	

Cyprinid fishes dominate fish communities in riverine habitat contributing approximately 86.5% (Masese et al., 2020, Mugo & Tweddle, 1999). However, there has been a decline in distribution and occurrence of *L. victorianus, L. altianalis, Oreochromis variabilis, Oreochromis esculentus, Mormyrus kannume* and *B. docmak,* which contributed economically to the fisheries of the lower reaches of most rivers in the Lake Victoria basin (Cadwalladr, 1965;

Balirwa & Bugenyi, 1990; Ochumba & Manyala, 1992).

There are few studies on fish migration between the lake and the rivers in the Lake Victoria basin neither is there any evidence of the habitats within the river into which they migrate. Few earlier studies only used conventional methods of studying migration, using nylon floy and related tags which do not have the capability of identifying the location and habitat conditions to where the fishes migrate to. Therefore, there is need to apply modern methods which include radio telemetry, and molecular techniques to obtain information that can be used for management and conservation purposes. Despite information in literature that the major potamodromous fishes in the Lake Victoria basin include *L. altianalis* and *L. victorianus Synodontis afrofischeri, Synodontis victoriae, Clarias gariepinus,* and *Schilbe intermedius,* (Masese et al., 2020), there is still little published information about the migration routes, habitats together with their chemical and physical characteristics to which these fish species migrate. There are few records detailing catches or yields of riverine fish species in the Lake Victoria Basin. Further, there are no programmes put in place for monitoring riverine fish catches and yields in the region. The decline of lacustrine catches of *L. victorianus* and *L. altianalis* is attributed to three factors: predation by introduced Nile perch, overfishing and pollution due to anthropogenic activities (Ogutu-Ohwayo, 1990; Greboval & Mannini, 1992).

2.5 Growth

2.5.1 Growth of *L. victorianus* in the Lake Victoria basin

Individual growth in terms of length and weight of fishes is one of the crucial parameters in their life history. Besides the dependence of growth on behavior, fish growth depends on environmental factors such as food and temperature. It’s the growth of individual fish that contributes towards the total landings in capture fisheries that is harvested from year to year. The length at first maturity of female *L. victorianus* from Kagera River and Sio River in Uganda was estimated at 21.9 cm and 11.8 cm FL respectively while for the males from River Kagera was estimated at 22.1 cm FL and from Sio River it was estimated at 12.8 cm FL (Rutaisire & Booth, 2005). Studies by Ochumba and Manyala (1992) on the fishes of Sondu - Miriu River and Lake Victoria, Kenya, found that the length at first maturity of *L. victorianus* was 11.1 cm and 15.1 cm standard length (SL) for males and females respectively. The biggest size of male *L. victorianus* ever reported was 41 cm SL by Bayona, (2006). There is a varied nature of the length at first maturity attained by this species in different environments, thus demonstrating the influence of the environment on its growth.

2.5.2 Growth of *Labeobarbus altianalis* in the Lake Victoria basin

The size at maturity has been determined for several fishes and is considered an important factor for reproduction. In fisheries, size at maturity is used widely to regulate and control exploitation of fish for sustainable conservation. The biggest size of *L. altianalis* to be recorded is a male of 90 cm TL (10 kg individual weight) and length at sexual maturity of 54 cm TL (Froese & Pauly, 2022).

2.6 Length - weight relationship in fish

Length - weight relationship is crucial in estimating the growth rate of fish, structures of length and age, mean weight at a certain length class, the health status of a fish, and other components of dynamics in fish populations (Miranda et al., 2009; Moradinasab et al., 2012). It enables fisheries scientists to convert growth in length equations to growth in weight in fish stock assessment models to estimate biomass from length frequency distributions. It is also important when comparing fish life histories and morphological aspects of populations living in different regions (Froese et al., 2013; Sarkar et al., 2006). This relationship allows the calculation of fish condition indices and enables the comparison of growth trajectories of fish between different sexes and different seasons and areas. The parameter *b* which is the slope of length - weight relationship in fish is used to calculate a factor used to convert acoustic measurement into fish biomass (Hossain et al., 2011). Weight - length relationships and condition factors of fish populations are crucial tools that support the management of fisheries resources and therefore help in formulation and implementation of fisheries management policies (Shabir et al., 2012; Froese et al., 2013). The body size a fish attains is an important parameter in the determination of the life history strategy that it assumes. Two important measurements that relates to the body size of a fish are length and weight. These parameters are used in estimation of condition factor and the development of the weight - length relationship (Sarkar et al., 2006). Fish with a small body weight, a fast growth rate and high fecundity are always said to have a tendency to the *r* - selected life history strategy. Therefore, length - weight relationship is related to the life history strategy of a fish. Factors limiting or enhancing the body size of a fish eventually determines whether a fish has a short or long lifespan. Therefore, changes in the weight of the fish significantly affect the length - weight relationship as well as the condition factor (Abdul et al., 2016). The length - weight relationship of a fish can be used to estimate biomass from its length frequency distribution so that it's always not necessary to measure the weight of an individual fish. They can also be compared with parameters of past years, or parameter estimation among fish groups to identify their condition or population robustness (Abobi, 2015). The length - weight relationship is used in the yield equation and sometimes it may be used as a character for the differentiation of small taxonomic units (Abobi, 2015; Shabir et al., 2012).

2.7 Condition factor in fish

Condition factor of fish is a necessary tool in fish biology, physiology, ecology, fish stocks assessment, and conservation. Fish condition factor is important in indicating the general wellbeing of fish in their aquatic environment. It is assumed that a fish is in a good condition if its heavier (Dadebo et al., 2011; Ogamba et al., 2014). When the condition of a fish is poor it slows down the rate at which fish grows, lowers the potential to produce milt and eggs and this may affect survivorship negatively or a reduction in its lifespan. A fish is said to be in a good condition when the condition factor is close or equal to one (Abobi, 2015). The fitness of a fish is directly related to its life history strategy in as much as it refers to the fish's capacity to inhabit and successfully exploit resources in its habitat (Abobi, 2015; Nazek et al., 2018).

2.8 Reproductive parameters

2.8.1 Fecundity

The definition of fecundity adapted in this study is that of Bagenal and Braum, (1978), whereby its defined as a measure of the potential of a fish species to reproduce through the number of vitellogenic oocytes present in the ovaries before a spawning season. The measurements of fecundity in fisheries biology are important in exploring dynamics in reproduction and spawning energetics of a fish stock to estimate its annual reproductive output and how this is linked to recruitment (Mohammed & Patahk, 2011). Furthermore, fecundity estimation is employed in the assessment of spawning biomass through the production of eggs (Ganias et al., 2014). In fish, variation in fecundity is brought about by several factors which include the fish species in question, the size of the fish, the age, the season and availability of food resources (Murua et al., 2003; Ojutiku et al., 2012).

2.8.2 Gonadosomatic index

The Gonadosomatic index (GSI) of a fish refers to the gonad weight relative to total body weight, usually expressed as a percentage. Gonadosomatic index is important in describing the allocation of energy in fish (Mohammad & Pathak, 2011). If the fish population is limited by nutrition, then large amounts of energy resources will be directed towards development of gonads (Abedi et al., 2011). In this case, the values of GSI will be relatively high. High mean values of GSI are usually indicative of a good status for the fish population (Mohammad & Pathak, 2011). A ratio of the weight of a fish's eggs or sperms to its body weight is used to determine the spawning time of a species of fish. It is particularly useful in identification of the season when spawning events are expected (Gupta et al., 2013). This is so because the ovaries of gravid females increase gradually in size just prior to spawning. GSI, an index of the size of the gonad relative to the size of fish is a good indicator of the development of the fish gonads. Furthermore, the percentage of the weight of a fish which is used for egg production is determined by gonadosomatic index (Shoko et al., 2015). GSI increases as the development of fish gonads approaches maturation; then it starts to reduce towards spawning time (Maskill et al., 2017). GSI gives an insight regarding spawning and important in determining the degree of maturity of the ovaries. It is also used to formulate suitable fish breeding policies in management of fisheries (Mishra & Saksena 2012; Manal et al., 2017).

2.9.1 Food and feeding of *L. victorianus* of the Lake Victoria basin

Labeo victorianus is a bottom feeder that scrapes epilithic materials from surfaces of submerged objects and filter detritus to obtain its nutriments. The findings of Owori-Wadunde, (2004), indicates that zooplankton, especially rotifers, were the best starter food for the larvae of the species. The larvae start feeding on animal food items and then shifts to plant food items as they grow. Fish of the genus *Labeo* have been found to feed on detritus, epilithic algae, diatoms, and crustaceans.

2.9.2 Food and feeding of *Labeobarbus altianalis* of the Lake Victoria basin

Studies by Balirwa (1979) on the food of six cyprinid fishes in Lake Victoria basin showed that all the species possess tubular stomachs and its omnivorous, feeding on a variety of food items ranging from debris, diatoms, detritus, insect larvae to mollusks. In another study by Okito (2017) on *L. altianalis* in the tributaries of Luhoho River in the Democratic Republic of Congo showed that the species feeds on phytoplankton mainly diatoms (Bacillariophyceae), cyanophytes, chlorophytes and euglenophytes in all sites considered and at all ages. Gebremedhin et al., (2019) while studying feeding habits in *Labeobarbus* sp. which is endemic to Lake Tana in Ethiopia found that the major food items preyed by the fish were phytoplankton, zooplankton, and detritus.

Life history of an organism refers to the changes through which an organism passes in its development from birth to its natural death. It's a series of living phenomena exhibited by an organism throughout its life. Thurow (2016) gives a detailed description of life history stages of a fish. The main life history stages of a fish include embryo, larvae, juvenile, sub-adult, and adult. The life of a fish starts when eggs get fertilized then are buried in the substrates within the areas of spawning, laid on the surface of substrates, shed onto the column of water, or get attached to aquatic plant material especially macrophytes. They mature after the incubation period lasting for a few days in cyprinid fishes to several months in salmonid fishes when they hatch into the embryo stage (Mims et al., 2010). They undergo a short embryo phase, the time during which they rely entirely on energy sources supplied by an egg yolk sac. In some fish species, hatched larvae start to feed before the egg yolk sac absorption and thereafter the fry disperses into open water (Thurow, 2016). After the embryo phase fish enter the larval stage where they begin feeding on external food sources such as micro algae. The larval stage varies in duration and ends after completion of the organogenesis stage whereby the larvae convert into the juvenile part of life. At this stage all the essential organs of the fish are fully formed and functional. Starting from the juvenile stage, fish undergo unspecified number of seasonally favorable and unfavorable periods in which there is alternate rapid and reduced growth rate respectively until they attain sexual maturity (Schlosser, 1991). Juvenile fish grow into sub adult and adult (mature fish) at different rates depending on the species. After maturation adults undergo spawning migration to locate spawning sites so that the life cycle is re-initiated by egg laying. Iteroparous type of fishes repeat spawning migration from year to year. Therefore, life history strategies are the adaptive traits that an organism uses to successfully survive in its habitat throughout its life (Williams, 2011). A strategy is a genetically determined life history trait or behavior which has evolved due to maximization of individual or fish population fitness where fitness is a lifetime success in reproduction. For example, the production of many eggs to ensure continued survival of an organism living under harsh environmental conditions such as habitats that frequently experience desiccation or attaining of early sexual maturity at a young age to ensure that an organism can reproduce over long period in its lifetime to increase chances of survival of its progeny (Brown - Peterson et al., 2011).

2.10 Fish life history theories

Fish life history theories try to explain traits evolution as an adaptation to responses in changes to the environment and resource allocation during different life stages (Stearns, 1992). They also examine the way strategies are inter-related and constrained by ecological variables. Life history theories have been invoked to predict the relative influence between density-independent and density-dependent ecological influences on various life stages and age classes. Fish life history strategies have been examined in relation to diverse challenges facing the management of fisheries, which include environmental assessment, the risk of extinction and resilience of the fish species to fishing and other sources of mortality induced by human (Xiang et al., 2021).

Life history theory endeavors to explain general characteristics of the life cycle of an organism. It elaborates on intra specific and inter specific variation in fish survival, growth, and reproduction strategies of fish and it is concerned with growth rate, age, or size at first sexual maturity, the life span of a fish (longevity), and the number of times it undertakes spawning (Kominoski et al. 2018). The theory is based on the premise that fishes face certain trade-offs emanating from allocation of energy resources, physiological, developmental, or genetic constraints and that the trade-offs have an influence on interactions that occur in nature. It directly deals with natural selection and is therefore central to evolutionary ecology. It further assumes that a phenotype encompassing demographic traits, birth, age, and size at first sexual maturity, number and size of off-spring, investment on reproduction and growth, longevity, and death, relate to constraining relationships and trade-offs. The theory was initially premised on the believe that population density regulates demographic traits (Hitt et al., 2012)

The theory advances the idea that where population densities are low and expanding, selection should favour individuals that rapidly get resources, and invest them into off-springs to increase the size of their populations and densities over habitat carrying capacity. A situation in which selection favors individual persistence in the presence of scarcity of food resources and their more efficient utilization. Models suggest that evolution of life history strategies are dependent on heterogeneous mortality among organism age classes. Mortality is due to density dependent and external factors that interact with variable factors in the environment such as the presence or absence of predators, availability of food resources and fluctuating water quality conditions. Stearns, (1992) suggested that a habitat can be related to life histories in two ways: how mortality regimes are determined by the habitat and how mortality regimes define optimal life history of an organism. There are three ecological factors that determine evolution of life histories namely climatic stability, food scarcity and simple fish communities with minimal predation. Recent developments include the application of life history theory to the fisheries resource management, research on the responses of a species to changes in environmental conditions and a greater understanding of the mechanisms that determine old age and life span of fish (Hitt et al., 2012; Zhou et al., 2016).

Life history theory predicts that aquatic environments favour certain suites of fish traits, giving rise to evolved life history strategies or tactics which make a fish species suitable to cope with a range of environmental stresses (Stearns, 1992). There are three fish life history strategies identified by Winemiller and Rose (1992); the opportunistic strategists which exhibit early sexual maturation and have a low survival rate for juveniles and are associated with frequent and high disturbance habitats (Zhou et al., 2016). Almost all fish species in the riverine habitat of the Lake Victoria basin are small bodied and demonstrate most of the characteristics. Equilibrium strategists have a body size from small to medium with moderate size at maturity in relation to other freshwater fishes. They have a low number of eggs per spawning activity, and high survival of juveniles, which is greatly associated with high parental care and relatively small clutch sizes. They are predicted to thrive well in more stable aquatic habitats with less changes in the environment. Fish that exhibit periodic strategies are characterized by larger body sizes, mature late, spawn many eggs, have low juvenile survival rate and they are associated with high periodic and environments that are seasonal (Winemiller & Rose, 1992). The three life history strategies of the continuum are said to be adaptive with respect to the variation and predictability of changes in the environment. The relationship between selective environmental forces and trait composition of assemblages of freshwater fish provides a basis for developing predictive models to conserve indigenous species (Olden & Kennard, 2010). These help to develop protocols for risk assessment of indigenous species based on generalized changes in fish populations and their responses to variation in environmental conditions. Studies by Mims et al., (2010) on North American freshwater fishes showed a strong conformity to Winemiller and Rose (1992) life history continuum model who defined equilibrium, opportunistic and periodic life history strategies by trade-offs between the length at sexual maturation and the number of eggs and juvenile survival. Periodic freshwater strategists have a long-life span, late age at maturity, and spawn many eggs while opportunistic freshwater strategists are relatively small fish species with short life span, early size at maturity, and low fecundity and equilibrium strategists exhibit high parental care and have large egg size. Cyprinidae and clariidae display the highest diversity in trait composition. This could be the factor that make them to easily adapt to the varied environmental habitat characteristics in the riverine environment (Olden & Kennard, 2010).

Studies on species life history traits can be used to understand the complex phenomena, which includes the reason fish live in the environments where they are, how many fish taxa can co-exist in an environment and their ability to respond to changes in the environment (Winemiller, 2005; Olden & Kennard, 2010). Further observations by Mims et al., (2010) indicated that several fish families exhibited a strong relationship with a particular life history strategy. Among these fish were killi fishes (Cyprinodontidae) and top minnows (Fundulidae) that were dominated by fishes that display opportunistic life history strategy that is early size at maturity, small bodies, short life expectancy, for example, salmon and trout of the family Salmonidae and suckers of the family Catostomidae which were associated with the periodic strategy where individuals were exhibiting late maturation, were large bodied and had a long lifespan with high fecundity. The catfishes of the family Ictaluridae and sunfishes of the family Centrarchidae were mainly equilibrium strategists exhibiting high parental care, big egg size, moderate body size, and moderate size at sexual maturation. Although several fish families had a single dominant life history strategy, other fishes varied in their overall composition including Cyprinidae, a family in which the two fish species in this study belong. Cyprinidae is the largest family of all the freshwater fishes, and it encompass species which show opportunistic life history strategies for example, chubs, daces, and shiners. Periodic life history strategists include the pike minnows while intermediate between periodic and equilibrium were the carps. Other diverse families are perchidae which include darters (opportunistic) and periodic - perches (equilibrium) and ictaluridae including madtoms (opportunistic) and catfishes and bullheads (equilibrium).

Family level correlations with life history strategies exist and they vary among freshwater fishes. Previous studies have shown support for Winemiller and Rose (1992) three strategy life history continuum model of where periodic, opportunistic, and equilibrium life history strategies are explained by trade offs between the number of eggs produced and survival of juvenile fish. The life history model of Winemiller and Rose (1992) is an important consideration in variation of traits of fish and therefore trade-offs among the traits is continuous and hence strategies that are in between the three end points are expected (King & McFarlane 2003; Olden & Kennard, 2010).

Most global fishery resources are over fished and therefore, studies on fish life history strategies are crucial in revealing various life history and give a clear picture on how fish populations respond to overfishing (Wenjia et al., 2015). Life history traits of fish evolve by the fish adapting to the changes of environmental conditions (Lytle & Poff, 2004). Studies on life history strategies of riverine fishes are crucial in explaining fish assemblage structures in different riverine ecosystems (Goldstein & Meador, 2005). Riverine fish species are characterized by a short life span, early age at maturation, an extended period of spawning, multiple spawning bouts and high egg production. The evolution of these strategies has allowed riverine fish to overcome their unpredictable lives in the dynamic aquatic ecosystems (Olden & Kennard, 2010). Prolonged periods of reproduction increase the probability that spawning will occur when the aquatic environmental conditions are favourable. Thus, allowing fish to overcome fluctuations that may lead to failure in annual reproduction.

The dependence of fish life history strategies on environmental conditions of assemblages of freshwater fish forms the basis for development of models aimed at conserving indigenous species based on the way they respond to changes in their aquatic habitats (Welcomme et al. 2006). Fish life history strategies encompass conditions related to the survival of the off springs, the number of eggs and the spawning frequency, which represent adaptive traits that enable a given fish species to resist variation in abiotic conditions in space and time (Gonçalves et al., 2013). If several life history strategies such as growth, reproduction, maturation, feeding, and mortality are compared for many fish species, clear patterns become apparent. Tropical freshwater fishes are known to be smaller; quickly attain their asymptotic length and asymptotic weight and experience high natural mortality as compared to fishes from temperate regions (Stergiou, 2000).

2.10.1 The *r* and *k* selection theory

Fish life history strategy enable fish populations to respond favorably to the changes in their environment and may differ in a consistent pattern explained and predicted by the *r* and *k* – selection theoretical constructs (Olden & Kennard, 2010). During unpredictable and non-selective mortality, a fish allocates a high portion of its energy resources to reproduction. The optimal allocation of energy resources for a fish which is subjected to a high proportion of predictable and selective mortality will increase towards individual fitness, through the ability to compete effectively in its habitat (King & McFarlane, 2003). The *r* and *k* - selection life history strategies can be used to show selection pressure associated with reproduction strategy, and therefore much of the life history of a fish. The characteristics of organisms that are *r* -

selected include: high growth rate, high number of off-spring, minimal parental care, high mortality rate, shorter life span while the characteristic of species that are *k* - selected include: low number of off-spring, longer life span, low mortality and have high parental investment. A good example of *r* – selected fish is pacific salmon (*Oncorhynchus* spp.) which reproduce only once in its lifetime and is therefore termed as semelparous. Some organisms have a longer lifespan and reproduce more than once in their lifetime and are termed iteroparous. Most freshwater fishes are known to exhibit iteroparity. Some of this type of organisms has a *r* - selected life history strategy because they are short lived (Olden & Kennard, 2010).

Major aspects of life history strategies are known as trade-offs. During their lifetime, organisms are faced with making of choices or prioritizing certain traits according to the type of life history strategy. For example, investing more energy resources in maximizing body size in the *k* type of life history strategy and life span as opposed to investing in reproductive processes in the *r* - selection life history strategy (King & McFarlane, 2003). Organisms are not capable of investing energy resources in multiple traits or choices at once and as such they mostly invest in one choice at a time. For example, an organism can invest in energy resources towards growth initially and later turn the investment into reproductive processes such that the end of the period of growth marks the beginning of investment in reproductive processes (Stearns, 1992). Once knowledge on trade-offs is fully understood they can be used in models to estimate their effects on different life history strategies to respond to questions on selection pressures of different life events. Energy contained by organisms is often finite and therefore cannot fully support trade-offs as a result, trade-off naturally limit or constrain the organism's adaptations and potential for fitness (Volff, 2004). Another example of life history model is the optimal life history strategy. In this kind of model populations can adapt to a situation to achieve an optimal life history strategy. For example, some types of populations adapt or invest energy resources to achieve an "optimal" life history strategy that guarantees them highest level of fitness. Models of the allocation of resources have been developed and employed to study life histories such as parental care.

The *k* - selected fish species are known to be highly sensitive to over exploitation and if overfished, their stocks take a long time to recover or may never recover at all. This demonstrates the dependence of natural selection on life history strategies. For example, at one time, tilapiine fish species constituted the highest catches in the Kenyan side of Lake Victoria but due to overfishing occasioned by the advent of nylon gill nets and predation by Nile perch its fishery collapsed and has never recovered. Also, the fishery of the siluroid catfish *Bargrus dokmac* used to constitute significant catches however due to overfishing and predation by Nile perch it also collapsed and has never recovered. Both the tilapiine fishes and *Bagrus docmak* have life history strategies that tend to *k* selection on the *r* - *k* continuum.

There is a high interdependence between ecological and genetic properties of a fish species. Natural selection exerts its influence on the morphology and reproduction characteristics, the size of populations and genetic constitution to enable a species to adjust itself to the environment in which it lives. Therefore, species that live in different habitats have different characteristics of life history patterns. Consequently, relationships among fish aquatic habitats, strategies in relation to ecology and parameters of fish populations are known as *r* and *k* selection or optimal life history strategies. It is assumed that natural selection influences these characteristics to maximize the survival of the off springs. In the Lake Victoria basin, there are few studies that link natural selection to habitat characteristics, ecological strategies, and population parameters. Hence there is lack of information that can be used to manage multispecies nature of the fishery in which species exhibit both *r* and *k* life history strategies.

The lack of any significant ecological and population dynamic analysis of riverine fish population compounds the problem further. In the Lake Victoria basin, a big number of species such as haplochromines and indigenous fish species which also inhabit the riverine environment are not targeted for commercial fisheries (Masese et al., 2020) and hence, they are on a larger part under the influence of non-selective mortality. Its therefore, expected that they allocate their food energy resources to reproductive processes. Therefore, they have *r* - selection life history strategies. For those fish species which are under influence of selective mortality such as through fishing pressure optimal allocation of resources are towards sustenance of individual fitness through competitive ability. An example of such fish species in the Lake Victoria basin is the Nile perch (*Lates niloticus)* which is considered a *k* strategist. There are many factors operating on any species in an environment thereby presupposing that there are no pure *r* or *k* life history strategists. Therefore, the life history strategies can be viewed to be on a *r* - *k* continuum. Comparative studies on life history parameters are valuable and have implications on management of fisheries. The parameters vary consistently in a predictable manner within the *r* and *k* selection continuum.

The *r* strategists are often exposed to a large component of catastrophic or nonselective mortality and are naturally selected for increased production through the processes of reproduction (Winemiller, 2005). This means early sexual maturation, rapid rates of growth, production of great numbers of off-springs at a given parental body size and maximum off-spring production at early age. Other features of the *r* strategists include small body size, high mortality rates and low longevity. Further, the population dynamic characteristics of *r* strategist are a low age at first maturity, high value of K of the Von Bertalanffy growth function, a small asymptotic (L_∞) of the von Bertalanffy growth function, high rates of instantaneous natural mortality (M) and low maximum age (t_{max}). Increased allocation of energy resources to reproductive activities in an environment with predictable mortality takes place when reproductive potential increases with age and there is additional mortality risk associated with reproduction (Mims et al., 2020). Therefore, attributes of *k* strategies include delayed maturity, reduced growth rates, low mortality rates, large body size, and longer life span. Further, *k* - selected fish species exhibit, a high age at first maturity, a low K from the Von Bertalanffy growth equation, a large L_∞ of the Von Bertalanffy growth equation, low natural mortality, and a high maximum age. Knowledge on *r* - *k* selection of a fish species can be used to predict how population parameters namely the instantaneous rate of natural mortality, the mean asymptotic weight (W_∞) which corresponds to asymptotic (L_∞), K of the Von Bertalanffy growth coefficient, and maximum age of a fish (t_{max}). The predicted parameters are the ones employed in the Beverton and holt model which estimates the fish harvest that can be obtained from growth of a cohort. The assumption of this model is that growth of fish is described by the growth function curve by Von Bertalanffy and that the processes of mortality are exponential. Studies by Adams (1980) on fish life history traits in fish and on how they influence fisheries management indicated that, specific differences exist in fisheries based on *r* or *k* selection in species. Here, fisheries based on *k* - selected species, the maximum yield per recruit was found to occur at a lower level of fishing mortality and at a later size at first entry into the fishery based on *r* - selected species (Adams, 1980). And that *k* - selected species would be much more sensitive to over exploitation in terms of mortality due to fishing and age at first entry into the fishery. As in the Beverton and Holt model the parameters of the Schaefer surplus production model namely the maximum size of fish stock or the carrying capacity in weight (B_∞) and k, the instantaneous rate of increase of the fish stock at densities approaching zero can be predicted from species in the *r* and *k* - selection continuum. The analysis indicated that *r* - selected species had the highest productivity and yield per recruit as predicted by the Schaefer surplus production model. For *k* - selection the model predicted that the maximum yield occurs at a lower fishing mortality and that the production of *k* - selected species was much more rapidly reduced to lowest biomass than the *r* - selected ones. Past studies have indicated that there are positive relationships between body size and life span and between growth rates and mortality rates and between body size and the time when a cohort maximizes its biomass. Also, a negative relationship has been obtained between fecundity and the degree of density dependent regulation (Adams, 1980). Further, Adams (1980) noted that there are no strictly *r* and *k* - selected fish species but rather there can be relatively more or less *r* or *k* - selected fish species. The author provides a scenario of reactions of how *r* or *k* - selected fish species react to fishing pressure. Fisheries with more *r* - selected species can be more productive, fished at younger ages and at higher levels of fishing mortality. With minimum stock size, such species show quicker recoveries from overfishing and are likely to be influenced greatly by physical and chemical environmental conditions. Alternatively, fisheries with more *k* - selected species will have a high maximum yield per recruit, but with fewer fish. And maximum equilibrium yield at a much later stage in life at lower levels of fishing mortality and more susceptible to overfishing and depletion of fish stocks. The *k* - selected species are likely to have complex life histories such as parental care systems, nesting or live births, mating systems, or territoriality with more usually competitive interspecific relationships. The *r* - selected species exhibit boom and bust characteristics while *k* - selected species have stable population sizes and catch levels. Therefore, prediction of future catches can easily be made if there is data from larval or pre-recruitment surveys.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The River Kuja - Migori is located on the south-western region of the Lake Victoria drainage area of western Kenya. The basin has an equatorial climate, and it gets rain nearly throughout the year, although there are two major rainy peak seasons. The long rains occur from March to August while short rains occur from September to November hence a yearly rainfall of about 1800 mm falls in a bimodal pattern (Kizza et al., 2009).

Kuja-Migori River Basin traverses a total of five counties namely, Nyamira, Kisii, Narok Homa Bay and Migori. The source of River Kuja is in Nyamira county, which rise to approximately 3,000 m above sea level (asl) at Kiabonyoru peak.

The source of River Migori is in Chepalungu forest, at an altitude of approximately 2,000 m asl. It drains the western part of the Sirian escarpment in Trans Mara which shields the Maasai Mara to the eastern part. These two rivers together cover a catchment area of over 6,900 km^2 in Nyamira, Kisii, Migori and a section in the western part of Narok county. The Kuja catchment constitutes approximately 42% of the total basin area of the River Kuja - Migori system.

In Transmara Narok county there has been a shift from keeping of livestock to commercial agriculture that has led to heavy deforestation and charcoal burning. In the midstream of Kuja-Migori River Basin, the land is arable with heavy investment in sugarcane and tobacco farming. Downstream the land is arable, but the region experiences semi-arid conditions with savanna grasslands as the vegetation cover.

The soils in this area are dominated by brown, red loam soils with a deep profile. The two rives converge at MaCalder Mines, which is situated at about 30 km kilometres from Lake Victoria. The people who live within the Kuja-Migori basin are estimated to be approximately 2.5

million. It is estimated that about 4.9 million people will be living in the catchment by the year 2030 (Sayer et al., 2018). Most of the population living in the basin depend largely on subsistence farming of crops and livestock keeping (Olaka et al., 2019;).

The river supports an artisanal fishery, and it is a source of water for irrigation of crops, domestic uses and for livestock (Balirwa et al., 2003). However, the river is threatened by catchment activities that include conversion of wetlands into farms, urban developments, poor management of domestic and industrial wastes and the leaching of agrochemical residues. These activities lead to soil erosion and river pollution which compromise river water quality affecting distribution and abundance of fish communities (Aura et al., 2020).

This study was conducted in River Kuja – Migori from five selected sampling stations along the river. Sampling stations were identified based on their ecological significance to cover the headwaters, the middle reaches, and lower reaches. Another factor that was considered was accessibility to sampling because most parts of the river are inaccessible especially during rainy seasons. A handheld global positioning system (GPS), model Garmin gps map 78 s was used to mark the coordinates of the five sampling stations along River Kuja – Migori as shown on (Figure 4).

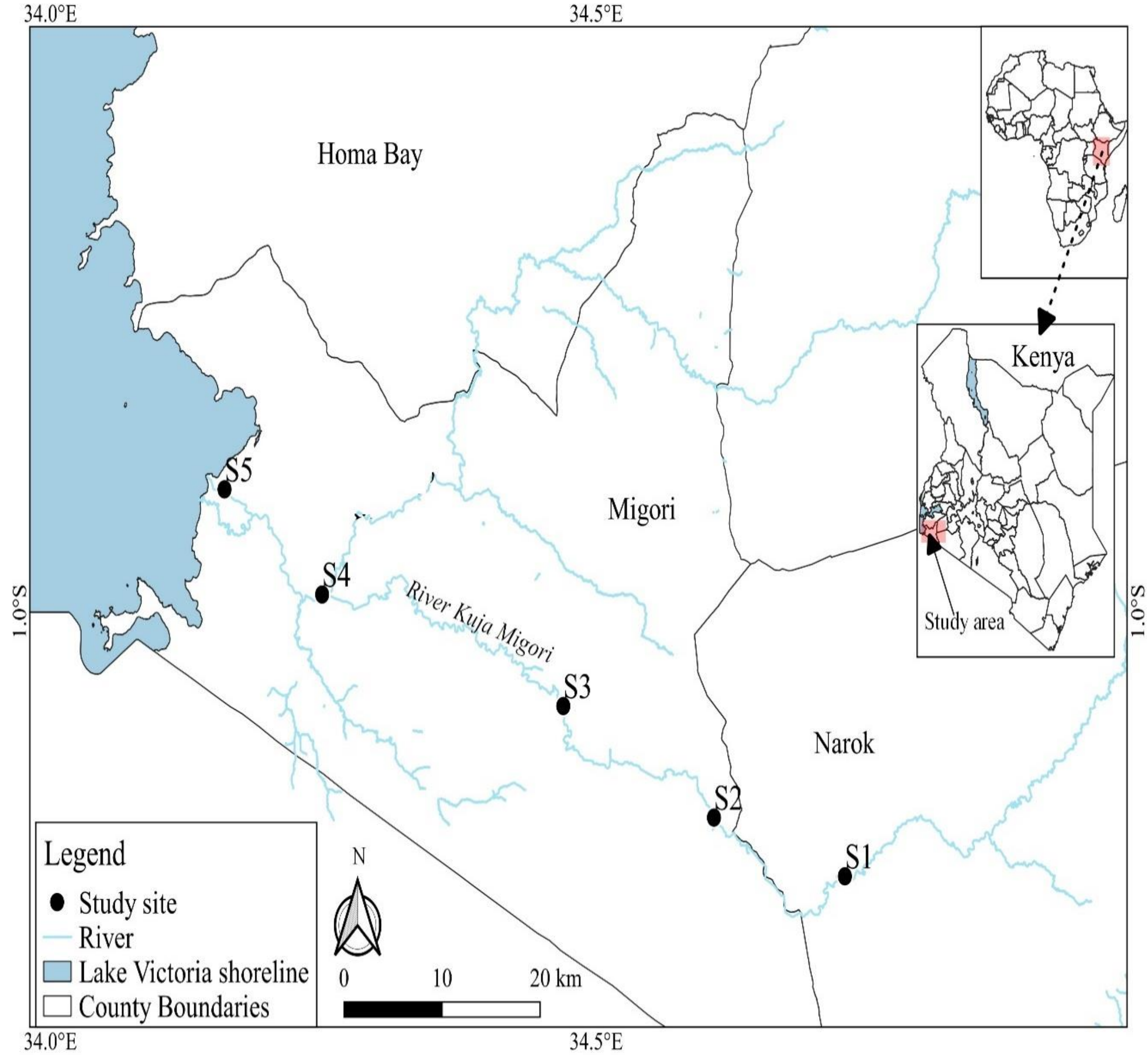

Figure 4. A map showing sampling stations (S1 to S5) along River Kuja – Migori South western Kenya, Lake Victoria basin

Sampling station S1 was located at the most upstream location at 34.72785 E, 1.186067 S. Here, the river was narrower, small, and rocky with forests and grazing areas particularly for the pastoralist Maasai community. The bottom was rocky and river water movement sluggish, forming several subsequent pools. The sampling site also had some scanty emergent vegetation constituting of papyrus species, otherwise the sampling station was directly exposed to sunlight. Sampling site S2 was located at 34.7106420 E, 1.20443630 S just after Lolgorian town enroute to Migori. The site had a rocky bottom and was not covered with any emergent or submerged vegetation. The ground slope was gentle therefore the water movement was slow. The site had a mean depth of 0.46 m. At the middle reach, the sampling site (S3) was situated at 34.4698870 E, 1.0663310 S in the part of the river that has a water depth of 0.53 m. The bottom of the river at this site consisted of soft sediments. There was no emergent or submerged vegetation hence the site was directly exposed to sunlight. The site was located within Migori town and was impacted by urban effluent originating from domestic agricultural and storm water sources. In the lower reaches stations S4 and S5 were located on the Kuja river after its confluence with the Migori tributary before it discharges into Lake Victoria. Station S4 was located at 34.2489590 E, 0.9878524 0 S in an area with a water depth of 0.42 m. Here the river became wider and had no sub-emergent or emergent vegetation. The riverbed was of mixed substrate nature largely constituting of sand silt and some rock out crops. This site was adjacent to Macalder gold mines and therefore impacted by pollutants from this source. There were farming activities on land adjacent to the sampling site where there were crops such as sugarcane, maize, millet, beans, peas, traditional vegetables, cassava, and arrow roots. Hence the site was therefore impacted by agricultural wastes. Sand harvesting was also witnessed along this site especially when the water level was low. Sampling site S5 was in an area of water depth of 0.57 m (34.1595180 E, 0.9139200 S). The bottom of this site constituted fine sand adjacent to the Kuja delta. The area around the sampling station was utilised for agricultural activities. There was clearing activities of vegetation on the wetland to pave way for planting of crops. The area under agriculture was expanding reducing the size of the wetland. Thus, the site was likely impacted by agricultural pollution.

3.2 Research design

This study employed a systematic research design whereby the sampling stations start at upstream sampling station S1 all the way downstream to station S5 adjacent to delta on River mouth of Kuja-Migori. The design considered the upper reaches, middle reaches, and lower reaches of the river. The parameters sampled were physical and chemical parameters namely, alkalinity, chlorophyll *a,* conductivity, depth, dissolved oxygen, hardness, pH, silicates, soluble reactive phosphorus, temperature, total nitrogen, total phosphates, and turbidity in triplicates for a period of 18 months. The sampling design also involved laboratory analyses for nutrients concentrations and measurements of egg size. Further, there were measurements of fish lengths and weights with dissections to identify sexual maturity stages.

3.3 Sampling

3.3.1 Collection of fish specimens from River Kuja- Migori

Fish specimens were collected monthly from each sampling site S1 to S5 in River Kuja – Migori using an electrofisher for a period of 18 months. Electrofishing method of collecting fish samples was chosen because several studies on evaluation of fishing gears spanning broad geographical areas and river types so far have settled on electrofishing as the most effective and versatile gear for capturing fish in riverine environment (Neebling & Quist, 2011; Gibson-Reinemer et al., 2016). The fish were caught using a 400 V and 10 A electrofishing equipment (Appendix 2) with a 50 m long electric cable, model Electra catch Wolvampton W.O 580 Winchester procurement limited. The electrofisher was powered by a Honda GX 240 8 horsepower generator running on petrol. At every sampling station, the power of the electrofisher was adjusted according to the conductivity of the water within the range of 40 - 350 $\mu S\ cm^{-1}$. Fish were caught in wadable areas whereby the stunned fish were collected by a dip net of 10 mm mesh-size. At each sampling station, a river reach of 100 m was sampled for 60 ± 5 minutes starting from downstream to upstream once every month for a period of 18 months. The total length (TL) and standard length (SL) were measured on a fish measuring board to the nearest 0.1 cm. The TL was measured from the tip of the mouth to the very end of the caudal fin while the SL was measured from the tip of the mouth to the base of the caudal fin. The fish samples were weighed using an electronic balance model Shimadzu AUW 320 to the nearest 0.1 g.

3.3.2 Collection of water samples from River Kuja - Migori

Water samples were collected monthly from sampling stations S1 to S5 at a depth of 10 cm from the water surface along River Kuja - Migori using 500 ml polyethylene sample bottles prewashed with distilled water. The samples were then labelled, kept in cooler boxes with ice cubes and transported to the laboratory for analysis.

3.4 Estimation of population dynamic parameters

In this section, the estimation of population dynamic parameters was based on length frequency measurements of fish. This is so because the use of age-based models for estimating population parameters in the tropics do not give appropriate results. The accurate determinations of fish ages can be made using respective hard body structures such as formation of rings and scales on otoliths and bony spines. The method can only be used in temperate regions where annual rings and marks are made on scales, otoliths, and other hard structures in the body of a fish. The measurements of total lengths were used to develop length frequency distributions for fish specimen. The fish samples were grouped into total length class sizes of 2 cm and 3 cm for *L. victorianus* and *L. altianalis* respectively. The population parameters were then estimated using Fish Stock Assessment Tools (FiSAT) software Version 1.2 (FAO, 2005).

3.4.1 Determination of length-weight relationships

Paired measurements of total length and total body weights of male and female fish were used to estimate the length - weight relationships for *L. victorianus* and *L. altianalis*. Regression analysis was conducted on the paired measurements to obtain a relationship $W = a L^b$ and a coefficient of regression (R^2) where *a* is the y intercept and *b* is the slope of the regression.

3.4.2 Determination of condition factor

Calculation of condition factor was done using measurements of total length (cm) and total body weight (g) using the formula by Abobi, (2015) as follows.

$$KR = W / (a \times L^b),$$

where W is the body weight, L is the total length and *a* and *b* are the parameters of the length - weight relationship. The mean condition factor was then calculated for both species. Temporal plot of the condition factor was then made separately for the two sexes and a combined one for both *L. victorianus* and *L. altianalis*.

3.4.3 Estimation of growth parameters

The growth parameter estimates of *L. victorianus* and *L. altianalis* are based on the generalized Von Bertalanffy growth formula written in the form of:

$$Lt = L_\infty (1-e^{-k (t - to)}).$$

Where L_∞ is asymptotic length or the mean sizes the fish will attain if they were to grow indefinitely, where k is the instantaneous growth constant, and where t_o is the age, the fish will have at zero length if they were to grow according to the growth function of Von Bertalanffy, while L_t is the predicted size at age t.

The model assumes constant environmental conditions. Two methods were used to estimate growth parameters using length frequency data of *L. victorianus* and *L. altianalis:* the methods in the FiSAT package include the ELEFAN 1 and the Powell - Wetherall method. It is well known that fish inhabit environments with seasonally oscillating variables such as temperature, food availability among others. This means that fish growth also fluctuates with temperature and availability of food. Therefore, the Von Bertalanffy growth function version used in FiSAT

1 was:

$$L_t = L_\infty [1- e^{-k (t - to) - (CK/2\pi [\sin \pi (t - ts) - \sin \pi (to - ts)]}]$$

Where L_∞ is asymptotic length or the mean sizes the fish will reach if they were to grow indefinitely, where k is the growth constant, and t_o is the age the fish will have at length if they had always grown according to the equation, while L_t is the predicted size at age t.

Where the parameters C and t_s refer to the intensity of the (sinusoid) growth oscillations of the growth curve and the onset of first oscillation relative to t = 0, respectively. It is a property of parameter C that takes a value of 1 when the growth rate (dL / dt) has exactly one zero value per year. It takes intermediate value when the seasonal oscillations are sufficient to reduce, but not halt the growth of fish in length.

3.4.4 Estimation of growth parameters using ELEFAN 1 method

The ELEFAN 1 method was employed to estimate the asymptotic length (L_∞) and the growth constant (K) using sequential length frequency data for *L. victorianus* and *L. altianalis* measured in River Kuja – Migori over a period of 18 months starting from January 2018 to June 2019. In ELEFAN 1 the above equation is used with two original parameters: the winter point (WP), which represents the period in a year when growth is at its lowest replaces t_s, whereby WP = t_s + 0.5. The parameter t_o in ELEFAN 1 is replaced by the parameter t_z which expresses the time at the origin of the growth curve as a fraction of a year. Alternatively, a starting sample and a starting point are selected and inputted or the variable option of both is selected for analysis. Starting sample and starting point were used to avoid the assumption that small fish do not grow according to Von Bertalanffy growth function. The starting point was defined by a sample number and length, with both coordinates representing a size at which there were zero frequencies. The option of fixed starting point was selected to plot a growth curve.

The ELEFAN 1 method assumes that: (1) samples used are representative of the target population (2) differences in the measured length are attributable to the differences in age of the fishes (3) growth is constant from year to year and (4) that the oscillating version of the Von Bertalanffy growth function can account for growth of fish and aquatic invertebrates.

The method restructures raw frequency data into peaks and troughs. The method then selects the growth curve that passes through most of the peaks. After inputting seed values of L_∞, K, C and WP until the goodness of fit index Rn ($=10^{ESP/ASP/10}$) reaches an optimum (where $0 < R < 1$) in the surface response analysis. ESP is the explained sum of peaks and ASP is available sum of peaks. The seed values of L_∞ and K inputted in the ELEFAN 1 method were first obtained from the Powell -Wetherall method or use of the maximum length (L_{max}) in the length frequency distribution. Then K was estimated through a surface response analysis of Rn versus K with K ranging from 0.1 to 10 year $^{-1}$.

3.4.5 Estimation of growth parameters using Powell - Wetherall method

This was based on the work by wetherall (1986) who suggested a method of obtaining the asymptotic length and the fraction of total mortality with instantaneous growth k using length frequency data from fish catches. The assumptions underlying this method are that the fish catches come from a steady-state population with a constant exponential mortality and growing according to Von Bertalanffy growth function. The model is based on the well-known equation of Beverton and Holt (1956):

$$Z = K\,[(L_\infty - L) / (L - L)]$$

In the Powell - Wetherall method it can be demonstrated that the cut - off lengths within a size of n selected fish, a corresponding series of partially overlapping sub samples can be constructed whereby the i-th sub sample consists of those n_i fish whose lengths are greater than L'_i – the cut off length of the i-th class. Plotting the mean lengths of the sub samples against the cut-off lengths results in a positive linear regression predicted by the equation:

$$Lmean = L_\infty \{1/ [1+ (Z / K)]\} + L' \{1 / [1+ (z / k)]\}$$

From the linear regression coefficient:

$$a = L_\infty / [1+ (Z / K)]$$

and

$$b = (Z / K) / [1 + Z / K]$$

then L_∞ and Z/K can be estimated. The parameters *a* and *b* are estimated from linear regression of L_i on L'_i the method weights each sub sample mean length by corresponding sub sample size. Then L_∞ and Z/K were computed as follows:

$$L_\infty = a / (1 - b)$$

and

$$Z / K = b / (1 - b)$$

The Z/K ratio is a useful component of many standard fish yield models such as yield per recruit and biomass per recruit.

3.4.6 Estimation of growth performance indices

Growth performance indices based on L_∞ and W_∞ with the growth constant k were estimated as follows:

Weight based growth performance

$$Ø = (\log K + 2/3 \log W_\infty)$$

Length based growth performance

$$Ø' = (\log K + 2 \log L_\infty)$$

The L_∞ and W_∞ are in units of cm and grams respectively and the logarithms are in base 10.

3.4.7 Recruitment pattern of *L. victorianus* and *L. altianalis*

Recruitment in tropical fish is represented by peak periods of numbers of fish in the fishery normally represented by several or two pulses in a year. In FiSAT the estimation of the pattern is based on two assumptions:

i) All fish in a data set are assumed to grow as described by a single set of parameters of growth.

ii) One month in a year of 12 months always has zero recruits.

iii) In FiSAT software frequencies are projected on the time axis after growth through a length class after the frequencies have dived by change in time.

Alternatively, the restructured frequencies in ELEFAN 1 are used leading to recruitment patterns with much narrower peaks than when untransformed length frequency data is used. This is followed by summation of the frequencies of each month irrespective of year of the adjusted frequencies projected onto each month. Further, the lowest monthly sum is subtracted from each of the monthly sums to obtain zero number of recruits representing the month with the lowest recruitment. Finally, there is an output of monthly relative recruitment as a percentage of annual recruitment.

3.4.8 Length structured virtual population analysis for *L. victorianus* and *L. altianalis*

The FiSAT software uses growth parameters L_∞ and K together with mean annual catches at length and the terminal mortality (Z) to compute retrospectively, numbers of survivors, natural mortality, fishing mortality and steady-state biomass.

3.4.9 Estimation of total mortality rate

3.4.9.1 Estimation of total mortality from mean lengths

Total mortality rate (Z) was estimated from mean lengths using the Beverton and Holt (1956) method. This is based on a deterministic model for mean lengths of fish in a catch above a length at first capture (L_c) assuming that the population of fish from which the sample for analysis was drawn was in dynamic equilibrium. The total mortality was calculated using the formula:

$$Z = K (L_\infty - Lmean) / (Lmean – L')$$

Where L_∞ is the asymptotic length, K is the curvature parameter of the Von Bertalanffy growth function, L mean, is the average length of a fish in the sample representing a steady state population and L', is the cut-off length or the lower limit of the smallest length class included in the calculation.

3.4.9.2 Estimation of total mortality rate from length converted catch curve analysis

This method is suitable for estimating total mortality rate of fish in the tropics where age cannot be determined from otoliths or scale readings. The method rests on the same assumptions as the age structured models. To obtain total mortality a plot of natural logarithm of numbers of fish caught at different length groups (equivalent to age groups) against corresponding age or age groups here represented by length groups.

The assumptions in the estimation were that Z was constant in all age groups; recruitment intensity was the same in all age groups and that the vulnerability of all age groups to the gear used in the fishery was the same. It was assumed further that the sample was representative of the age groups present in the catches.

The method of estimating Z in the FiSAT software using length converted catch curve involves pooling of catch data to obtain a single large sample representing the target fish population, then a catch curve is constructed using the large sample and a set of growth parameters L_∞, K, estimation of the total mortality rate from the descending right arm of the catch curve.

The catch data of *L. altianalis* and *L. victorianus* for 18 months was pooled together to take care of errors due to seasonal pulses of recruitment. To prevent large samples from unduly affecting the total annual sample, the samples were given same weighting by conversion into percentages. The detailed procedure of taking care of the piling effect due to the growth of slow fish is presented in Gayanilo and Pauly, (1997). The natural logarithm of ln(C/dt) against relative age. Then Z is expressed as the slope of the descending arm of the regression with the negative sign changing to positive.

3.4.10 Estimation of natural mortality

The natural mortality in FiSAT is estimated by the following methods: Pauly, Rickter and Efanov's method. However, in this study the method by Pauly presented in Gayanilo and Pauly (1997) was used to estimate natural mortality.

$$\log (M) = -0.0066 - 0.279 \log (L_\infty) + 0.6543 \log (K) + 0.4634 \log (T)$$

where: L_∞ is the asymptotic length measured in total length; K is the VBGF growth constant, and T is the mean annual habitat temperature.

3.4.11 Estimation of fishing mortality

Mortality rates have the property of being added and subtracted hence the total mortality Z is the sum of the fishing mortality (F) and natural mortality M: $Z = F + M$ and $F = Z – M$

3.4.12 Estimation of exploitation rate

The FiSAT software estimates exploitation rate as a ratio of fishing mortality and total mortality rates: $E = F/Z$ where E = exploitation rate.

3.5 Measurement of physical and chemical parameters

Selected physical and chemical parameters pH, temperature (ºC, conductivity ($\mu S\ cm^{-1}$), turbidity (NTU), dissolved oxygen (mgl^{-1}) was measured 10 cm from the water surface using

YSI multiparameter meter model surveyor II hydrolab. Alkalinity, total hardness, total phosphorous, total nitrogen, chlorophyll *a*, Silica, nitrogen nitrite (NO_2^-) and nitrogen nitrate (NO_3^-) were determined according to APHA (2000).

3.6.1 Determination of sexual maturity stages

Fish samples of *L. victorianus* and *L. altianalis* were anaesthetized with 80 mg l^{-1} of the lethal dose tricaine methanesulfonate (MS - 222) followed by preservation in 10% formalin solution for collecting data on reproduction and feeding habits. At the laboratory, the fish were further weighed using an electronic balance model Shimadzu TX 4202 L to the nearest 0.01 g. After the measurements the fish were dissected, and their gonads observed for maturity stages. The gonads were extracted, weighed to the nearest 0.01g using a sensitive electronic balance (model Shimadzu AUW 320 - Germany). The gonad maturity stages were determined based on sex, and then classified into six maturity stages according to visual traits such as gonad profile, size and colour according to Brown - Peterson et al., (2011). Macroscopic analysis of maturity stages in fish has been the most widely used method due to lower costs involved and easier and faster results (Shinkafi et al., 2011). The development of the gonads was classified into six maturity stages that is immature, developing/recovering, maturing, ripe, running/spawning and spent as shown in Table 2.

Table 2. Macroscopic description of maturity stages of the gonad phases in the reproductive cycle of female and male *L. victorianus* and *L. altianalis* (based on Brown - Peterson et al., 2011)

Stage	Development	Description for females	Description for males
I	Immature	Ovaries were small and translucent, sometimes lightly pink. Oocytes were not distinguished by naked eyes.	Testes were small and translucent, sometimes lightly pink. Transverse sections showed little gonad volume

II	Developing/ recovery	Ovaries were increasing in size and appearing bigger and more consistent. The ovary usually appeared yellow and individual oocytes were not distinguishable macroscopically.	The size of the testes was increasing and appearing bigger and more consistent. The testes remained whitish.
III	Maturing	Ovaries were much bigger and voluminous; vascularization was very apparent. The ovary appeared consistent with granules externally as yellow vitellogenic oocytes were distinguishable individually.	Testes were much bigger and voluminous; vascularization was very apparent. In the testes, accumulation of milt in the spermatic ducts was macroscopically visible.
IV	Ripe	Gametes were ripe and reached their maximum size, but the eggs could not come out of the abdomen when light pressure was applied.	Gametes were ripe and gonads reached their maximum size, but the milt could no come out of the abdomen when light pressure was applied.
V	Running/ spawning	The transparent hydrated eggs of the ovaries were visible through the ovarian wall and eggs were released out of the abdomen after application of light	There was large amount of milt in the testes which easily released after a light pressure was applied.

		pressure.	
VI	Spent	Gametes extruded and cavity of gonad was swollen; gonad appeared as an empty sac, with no eggs remaining in *L. victorianus* but with few eggs remaining in *L. altianalis.*	Gametes extruded and cavity of gonad was swollen, and gonads appeared as an empty sac, with very little milt or no milt remaining for both species.

3.6.2 Calculation of gonado-somatic index

The gonado-somatic index (GSI) of every fish specimen was calculated following Williams (2011) as:

$$GSI (\%) = GW / W*100$$

where GW is gonad weight (g), and W is the fish weight (g). The GSI were pooled by sex and site of sampling followed by the calculations of their mean GSIs.

3.6.3 Estimation of length at 50% (L_{m50}) maturity of both male and female of *L. victorianus* and *L. altianalis*

For estimating the length at which 50% of the fish population were mature (L_{m50}) frequency distributions of lengths and their corresponding sexual maturity stages 1 to 6 were made. The percentage number of fish at each sexual maturity stage was calculated followed by the cumulative percentages. Using the cumulative percentages and mean lengths at each sexual maturity stage, maturity ogives were developed and the lengths at which 50% of the fish population were mature were determined for both males and females of *L. victorianus* and *L. altianalis*.

3.6.4 Estimation of fecundity of female *L. victorianus* and *L. altianalis*

From the fish caught, mature female fish of each species were used for fecundity counts and measurements of the diameter of the eggs at each sampling time. For egg counts, the total weight of the ovaries of each fish were measured and a portion of the ovary excised out and weighed to the nearest 0.01 g. This portion was then placed in a petri dish containing gilson's fluid. This solution hardens, separates the eggs, and chemically dissolves the ovarian tissue. Gilson's solution was prepared according to Snyder (1983) by making a solution from the following combination: 60% ethanol (100 ml), distilled water (880 ml), 80% nitric acid (15 ml), glacial acetic acid (18 ml), and mercuric chloride (20 g). The eggs were freed from the ovary tissue using forceps. The ovary tissue without the eggs was removed and followed by counting of the eggs using a dissection microscope (Leica model stereozoom S9E Leica microsystems Switzerland) at x40. After obtaining the number (n) of eggs in the excised portion, the total number of eggs in the two ovaries were estimated using the formula:

$$F = nG/g$$

where F is the fecundity, n is the number of eggs in the subsample, G is the total weight of the ovaries and g is the weight of the subsample.

3.6.5 Measurement of fish egg size

To measure the egg size or diameter, the left ovary was extracted and dissected, then the eggs were emptied into a petri dish by teasing using a pair of forceps. A hundred eggs were randomly selected for each fish sample and their diameters measured using digital micrometer gauge in millimeters under an inverted microscope (Leica model stereozoom S9E Leica microsystems Switzerland) at x40 magnification.

3.6.6 Fecundity fish size relationships of female *L. victorianus* and *L. altianalis*

To determine the relationship between fecundity and fish size, the number of eggs from each female was regressed with total length in cm to produce a model of the form: $F = a L^b$ where F is fecundity; *a* is the y intercept of the regression; L is the total length in cm and *b* is the slope of the regression.

3.6.7 Food and feeding habits of *L. victorianus* and *L. altianalis*

Representative fish samples from each sampling site at each sampling period were selected randomly for analysis of gut contents. The gut contents of the fish were dissected using a pair of surgical scissors then emptied into an enamel dish. The stomach was then opened after dissection and the food items were grouped into broad categories namely, detritus, insects (ephemeroptera, coleoptera diptera, chironomids, hemiptera), algae, and plant material. These were further grouped to broader taxon categories. Percentage occurrence of each taxon was calculated as number of times a taxon occured over the total number of fish analyzed times 100. The weight of each food taxon was weighed to the nearest 0.01g using an electronic balance and the percentage composition was calculated as the total weight of each taxon over total weight of all taxons multiplied by 100.

3.7 Data analysis

All collected data on fish and physico-chemical parameters was first entered into Microsoft excel spreadsheet and cleaned prior to analysis. To test the collected data for normality Shapiro-Wilk method in statigraphics statistical software was used and when conditions were met the data was subjected to statistical analysis. To test if sex ratio was different from the hypothesized 1:1 for each of the two species chi square was used. To compare spatial and seasonal variation in mean lengths, gonadosomatic index and condition factors ANOVA was used followed by

Tukey post hoc test in cases where there were significant differences. Non-parametric analysis was performed using Spearman's correlation in R-statistical software to show the correlation between physico-chemical parameters and abundance of *L. victorianus* and *L. altianalis.* To verify if the parameter *b* obtained from the length - weight relationship for the two species had significant differences from the predictions assigned for isometric growth of in fish ($b = 3$), the student t -test comparison was employed. Statistically significant variation of *b* from 3 shows either a positive or a negative allometric growth ($p < 0.05$), when *b* is not statistically different from 3 ($p > 0.05$) an isometric growth is assigned. The coefficient of determination (R^2) was used to determine the strength of a linear regression's prediction where a value close to 1 indicates a better model. All the graphs were done in Microsoft excel spreadsheet. Population dynamics parameters of the two fishes were computed from FiSAT software using length frequency data.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter present results on the correlation between physico-chemical parameters and abundance of *L. victorianus* and *L. altianalis* in River Kuja - Migori, distribution, growth parameters, length- weight relationship, condition factor, mortality, and recruitment patterns. It presents results on reproductive parameters of the fishes which include fecundity - body size relationships, gonadosomatic index, egg diameter, sex ratio and length at 50% maturity. Also, presented are results on food and feeding habits of two African carps, *L. victorianus* and *L. altianalis* in River Kuja-Migori.

The potamodromous nature of the life history of the two fish species is strongly related to the seasonality of the climate in the southwestern Kenya geographical region which also affects the limnology of the aquatic habitats in which the fishes thrive. The habitats formed during two peak precipitation seasons strongly relate to the reproductive success of the two fish species. The intensity of precipitation therefore seems to control the recruitment of the two species in River Kuja–Migori.

4.2.1 The correlation of physical parameters and abundance of *L. victorianus* in River Kuja- Migori

The correlation between physical and chemical parameters and abundance of *L. victorianus* from River Kuja - Migori is presented in Table 3.

Table 3. The correlation between physical and chemical parameters and abundance of *L. victorianus* in River Kuja – Migori

	Alk	Chl a	Cond	Dep	DO	Hard	pH	Temp	Turb	Abun
Alk	1									
Chl a	-0.33	1.00								
Cond	0.28	0.58*	1.00							
Dep	0.05	-0.07	0.11	1.00						
DO	-0.02	0.78	0.72	0.03	1.00					
Hard	0.01	0.31	0.02	0.00	0.48*	1.00				
pH	-0.50*	0.04	-0.37	-0.22	-0.26	-0.36	1.00			
Temp	-0.24	0.65	0.62	0.24	0.70	0.05	-0.08	1.00		
Turb	0.41	-0.88	-0.45	-0.06	-0.76	-0.49*	0.05	-0.65	1.00	
Abun	0.30	-0.14	0.18	-0.20	-0.14	0.07	-0.55*	-0.30	0.24	1.00

**Alk- alkalinity (mg $CaCO_3$ L^{-1}) Chl a (mg^{-1}), Cond- conductivity (μs cms^{-1}), Dep-depth (m), DO- dissolved oxygen (mg^{-1}), Hard- hardness (mgl^{-1}), Temp-temperature (^{O}C) Turb- turbidity (NTU), Abun- abundance (fish numbers)
*Correlation considered significant at the 0.05 level

The physical and chemical parameters which had positive correlation with abundance of *L. victorianus* were alkalinity conductivity, hardness, and turbidity. Only pH had negative significant correlation with abundance (r = -0.55). Chlorophyll *a,* depth, dissolved oxygen and temperature had a negative insignificant correlation with abundance of *L. victorianus* in the River Kuja – Migori.

4.2.2 The correlation of physical parameters and abundance of *L. altianalis* in River Kuja - Migori

The correlation between the physical parameters and abundance of *L. altianalis* in River Kuja - Migori is shown on Table 4.

Table 4. The correlation between the physical parameters and abundance of *L. altianalis* in River Kuja - Migori

	Alk	Chl a	Cond	Dep	DO	Hard	pH	Temp	Turb	Abun
Alk	1.0									
Chl a	-0.33	1.0								
Cond	0.3	0.58*	1.0							
Dep	0.0	-0.73	-0.51*	1.0						
DO	0.0	0.78	0.7	-0.6	1.0					
Hard	0.0	0.31	0.0	0.0	0.5*	1.0				
pH	-0.4	-0.16	-0.7	0.1	-0.4	0.1	1.0			
Temp	-0.2	0.65	0.6	-0.6	0.7	0.0	-0.3	1.0		
Turb	0.4	-0.88	-0.5	0.6*	-0.8	-0.5*	0.0	-0.6	1.0	
Abun	0.3	0.36	0.4	-0.2	0.6	0.5*	-0.2	0.3	-0.4	1.0

**Alk- alkalinity mg $CaCO_3$ L^{-1}, Cond- conductivity (µs cms^{-1}), Dep- depth (m), DO- dissolved oxygen (mg^{-1}) Hard- hardness (mgl^{-1}), Temp-temperature (^{O}C) Turb- turbidity (NTU), Abun- abundance (fish numbers)
*Correlation considered significant at the 0.05 level

The physical parameters that were positively correlated with abundance of *L. altianalis* in River Kuja Migori were alkalinity, conductivity, dissolved oxygen, hardness, temperature while those which were negatively correlated were depth, pH, and turbidity. Only hardness had a positive significant correlation (r = 0.5) with abundance of *L. altianalis* in River Kuja-Migori.

4.3.1 Correlation between the nutrient concentrations and abundance of *L. victorianus* in River Kuja - Migori

Correlation between the nutrient concentrations and abundance of *L. victorianus* in River Kuja - Migori is presented in Table 5.

Table 5. The correlation between nutrients and abundance of *L. victorianus* in River Kuja - Migori

	NO_3^-	NO_2^-	TN	TP	Silicates	SRP	Abundance
NO_3	1						
NO_2	-0.26	1.00					
TN	0.25	-0.45	1.00				
TP	0.57*	-0.12	0.09	1.00			
Silicates	-0.20	-0.46	0.05	-0.31	1.00		
SRP	-0.08	-0.76	0.29	-0.23	0.63	1.00	
Abundance	0.59	-0.44	0.25	0.36	0.15	0.27	1.00

NO_3 - nitrates, NO_2 – nitrites, TN- total nitrogen, TP-total phosphorous, SRP- soluble reactive phosphorous were measured in mg l^{-1}
*Correlation considered significant at the 0.05 level

The nutrients which positively correlated with abundance of *L. victorianus* were nitrates, total nitrogen, total phosphorous, silicates and soluble reactive phosphorous while nitrites were negatively correlated. None of the nutrients had a significant correlation with *L. victorianus* in River Kuja-Migori.

4.3.2 The correlation of nutrients and abundance of *L. altianalis* in River Kuja - Migori

The correlation between nutrients and abundance of *L. altianalis* in River Kuja - Migori is shown on Table 6.

Table 6. The correlation between nutrients and abundance of *L. altianalis* in River Kuja - Migori

	NO_3^-	NO_2^-	TN	TP	Silicates	SRP	Abundance
NO_3	1						
NO_2	-0.26	1.00					
TN	0.25	-0.45	1.00				
TP	0.57*	-0.12	0.09	1.00			
Silicates	-0.20	-0.46	0.05	-0.31	1.00		
SRP	-0.08	-0.76	0.29	-0.23	0.63	1.00	
Abundance	-0.04	-0.31	0.39	0.19	0.25	0.32	1.00

NO_3 - nitrates, NO_2 – nitrites, TN- total nitrogen, TP-total phosphorous, SRP- soluble reactive phosphorous were measured in mg l^{-1}
*Correlation considered significant at the 0.05 level

The nutrients which positively correlated with fish abundance of with abundance of *L. altianalis* in the river were total nitrogen, total phosphorous, silicates and soluble reactive phosphorous while nitrites and nitrates were negatively correlated. None of the nutrients had a significant correlation with abundance of *L. altianalis* in River Kuja – Migori.

4.4.1 Spatial distribution of *L. victorianus* in River Kuja – Migori

The spatial distribution of *L. victorianus* in River Kuja - Migori is presented in Figure 5. A total of 486 fish specimens were analyzed for spatial distribution whose lengths were ranging from 7.5 to 35.7 cm TL with a mean (± SE) of 19.8 ± 0.31 cm TL. The catches increased from upstream station S1 to S2 then dropped in S3 and increased again from S4 to S5. The numbers of fish caught at station S2 were more than those in the other three stations where station S3 recorded the lowest number of fish. There were significant differences in catches among the five sampling stations in River Kuja-Migori (ANOVA, p = 0.00).

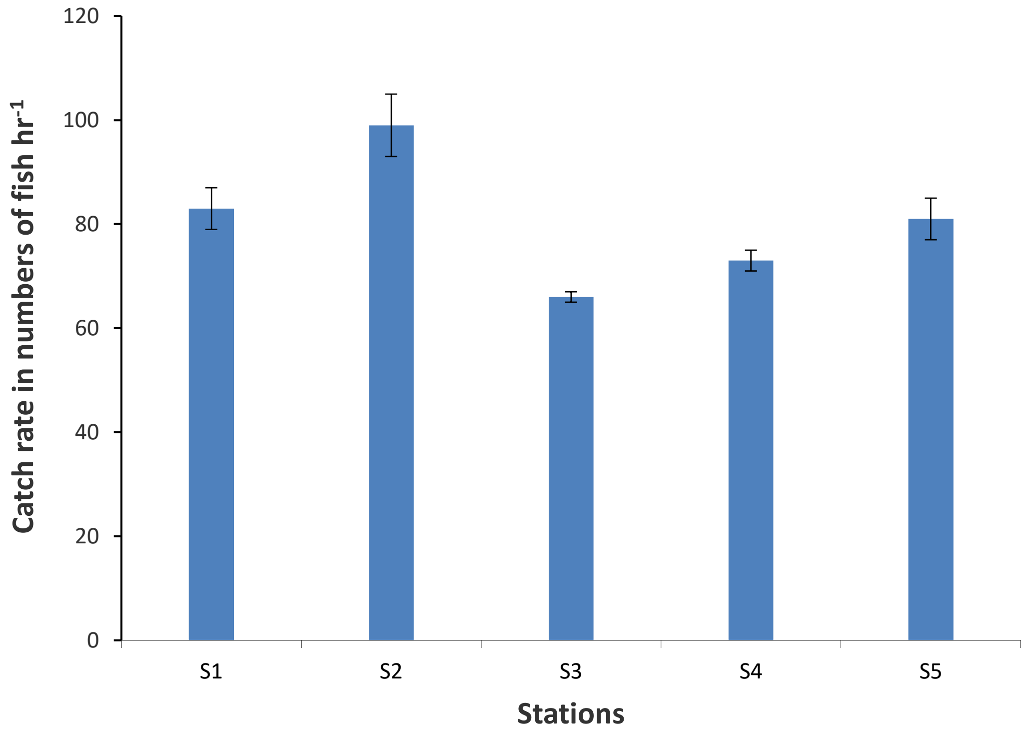

Figure 5. Spatial distribution in catches of *L. victorianus* in River Kuja – Migori from upstream station S1 to downstream Station S5 (vertical bars represent standard error of the mean)

4.4.2 Temporal distribution of *L. victorianus* in River Kuja - Migori

The fish catches increased from January 2018 to a peak in April and decreased to September 2018 (Figure 6). The catches then increased to a slight peak in October 2018 before decreasing thereafter to Febuary 2019 and increased again with a peak in April 2019 like that of the previous year. The trend reveals three peaks in catches of *L. victorianus* corresponding to the rainy seasons experienced in the region. In the year 2018 the lowest catches were caught in January, February, and September while in the year 2019 the lowest catches were caught in February, May, and June. The pattern of fish catches corresponded to the rainfall pattern during the study period. There were significant differences in catches among months in River Kuja - Migori (ANOVA, $p = 0.00$).

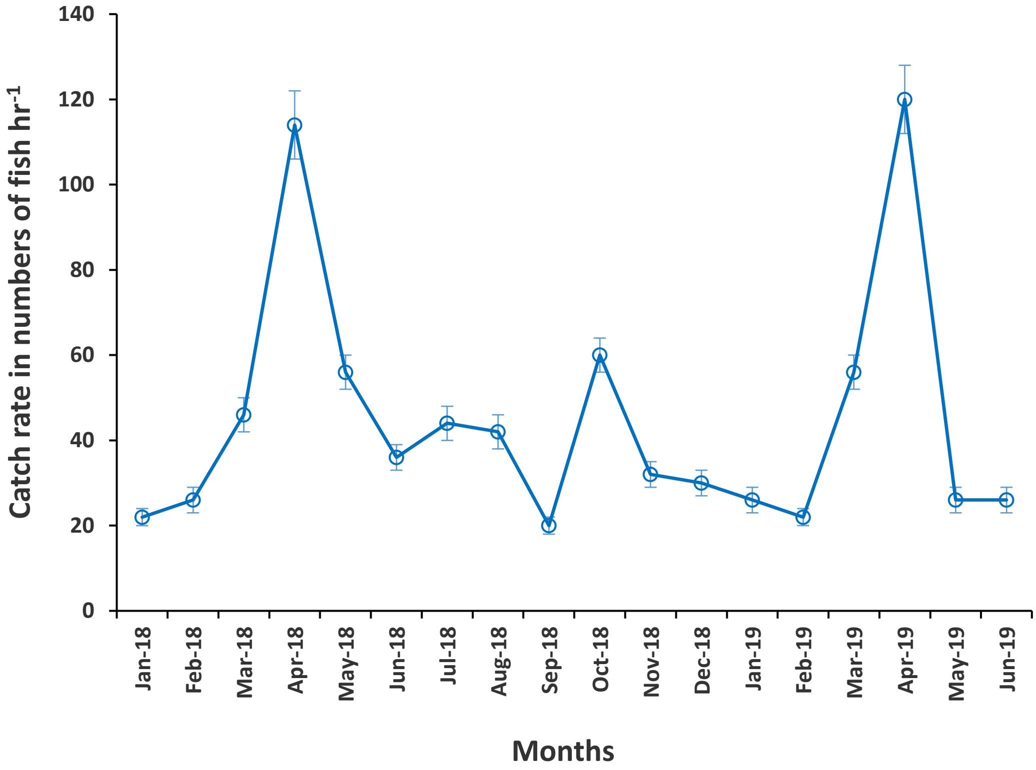

Figure 6. Temporal distribution in catches of *L. victorianus* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.4.3 Spatial distribution of *L. altianalis* in River Kuja – Migori

The spatial distribution in catch rates of *L. altianalis* in River Kuja - Migori is presented in Figure 7. The total number of fish analyzed were 1132 with lengths ranging from 2.6 cm TL to 41.5 cm TL with a mean (± SE) of 15.84 ± 0.21 cm TL. The distribution of catches showed a difference from upstream towards downstream compared to that of *L. victorianus*. The catches decreased from S1 to S3 and then increased towards downstream station S5. This indicated that most of *L. altianalis* were concentrated in the upstream and downstream habitats. ANOVA showed significant differences in catches among the five sampling stations (p = 0.01).

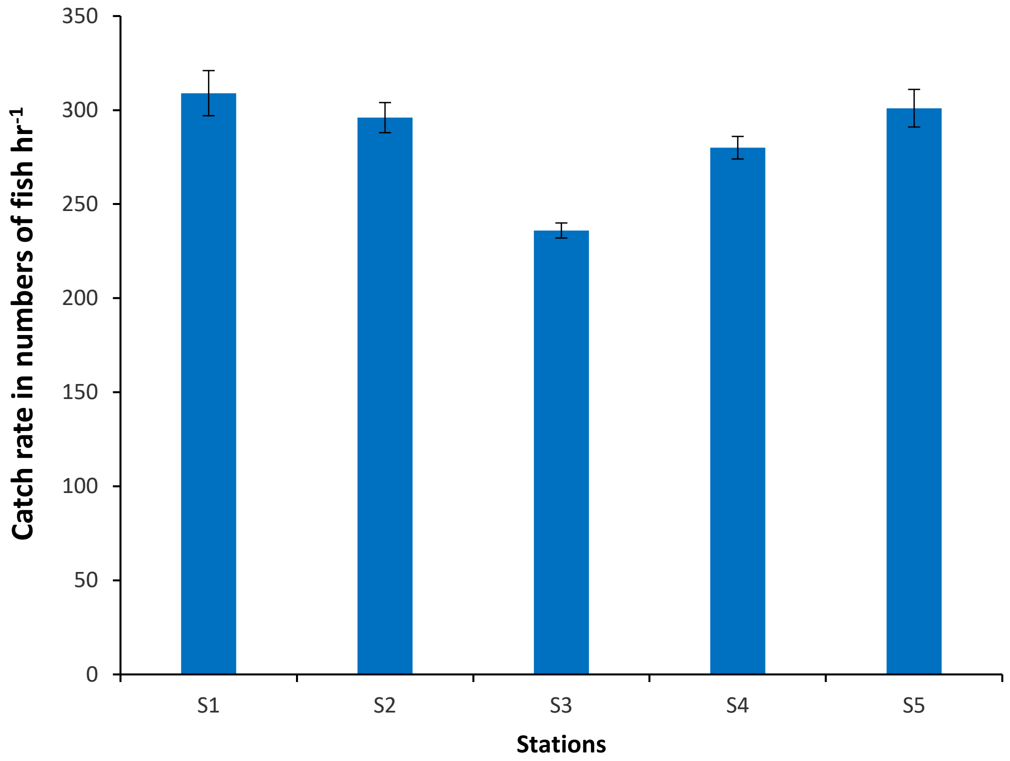

Figure 7. Spatial distribution in catches of *L. altianalis* in River Kuja – Migori from upstream station S1 to downstream Station S5 (vertical bars represent standard error of the mean)

4.4.4 Temporal distribution of *L. altianalis* in River Kuja –Migori

There were more numbers of *L. altianalis* caught throughout the year than those of *L. victorianus.* Peak catch rates were obtained during March to May and October to December 2018 and during March to May 2019. Both periods corresponded to the longer and shorter rain periods. Low catch rates were obtained in January to March and May to September both periods corresponding to dry seasons of the year (Figure 8).

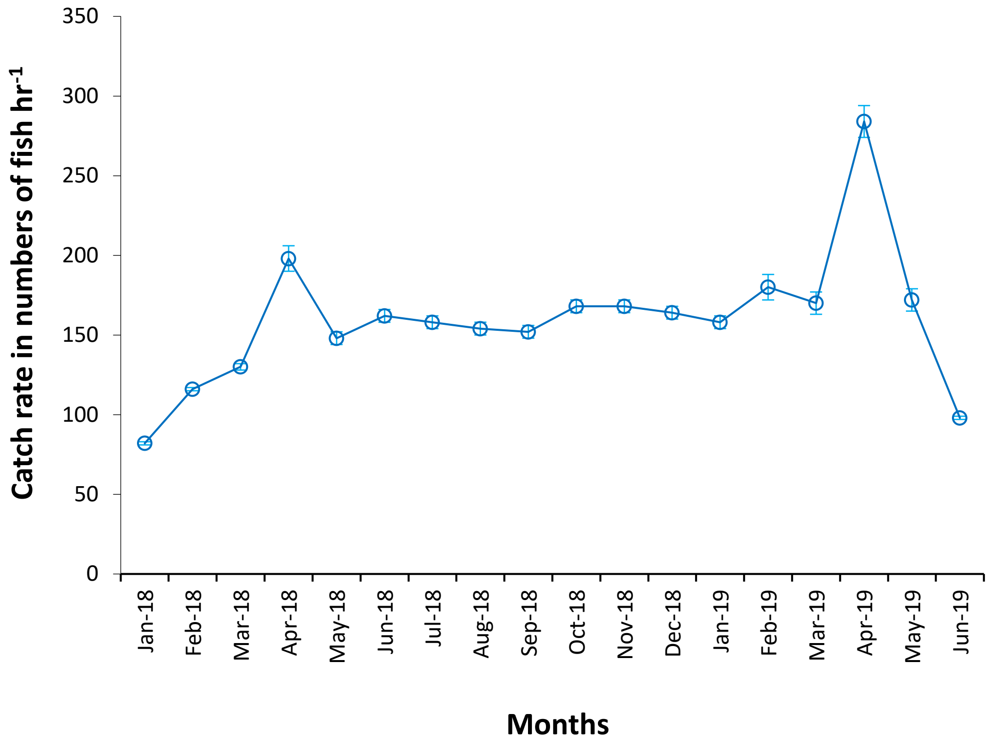

Figure 8. The temporal distribution in catches of *L. altianalis* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.5.1 Spatial distibution in mean lengths of *L. victorianus* in River Kuja – Migori

The spatial distribution of mean lengths of *L. victorianus* in the 5 sampling stations is presented in Figure 9. The sample size of fish analyzed was 486 with total lengths ranging from 7.5 cm TL to 35.7 cm TL with a mean (± SE) of 19.8 ± 0.31 cm TL. The total lengths decreased from a mean (± SE) of 22.3 ± 0.82 cm TL at the most upstream sampling station S1 in River Kuja - Migori to a mean (± SE) of 17.8 ± 0.57 cm TL at sampling station S4. Whereas the mean lengths declined downstream up to S3 they started increasing from S4 to S5. There were significant differences in *L. victorianus* mean lengths among the sampling stations (ANOVA, p = 0.00).

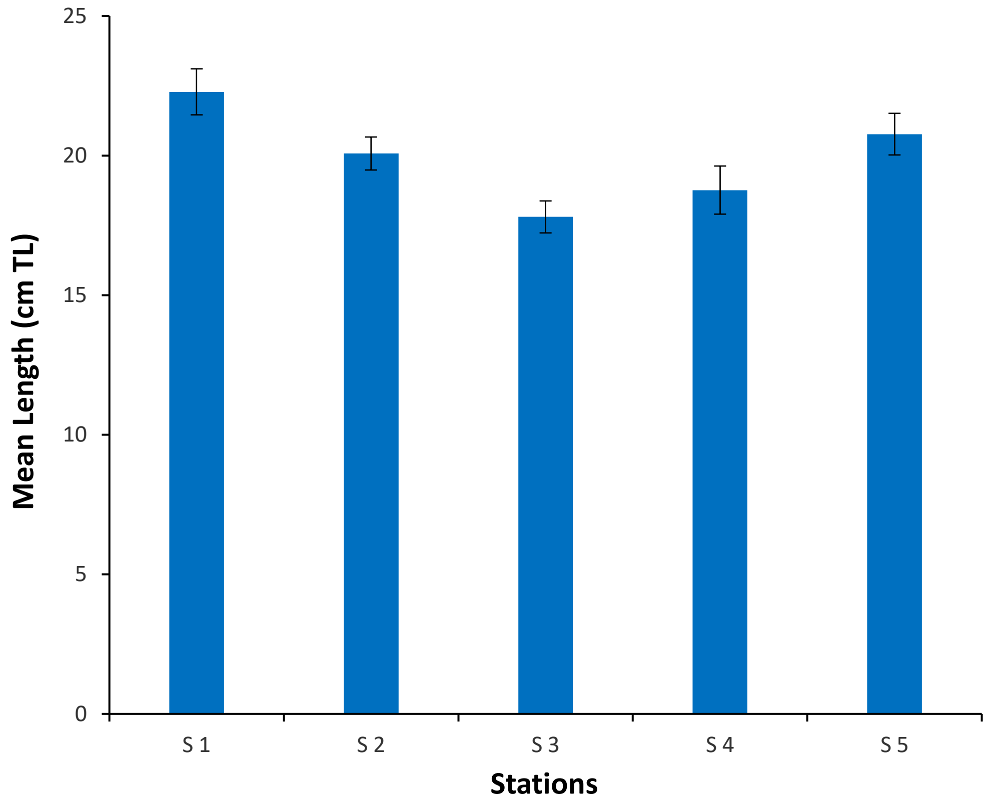

Figure 9. Spatial distribution of the mean lengths (± SE) of *L. victorianus* in River Kuja – Migori from upstream station S1 to downstream Station S5 (vertical bars represent standard error of the mean)

4.5.2 Temporal distribution in mean lengths of *L. victorianus* in River Kuja – Migori

The temporal distribution of mean lengths of *L. victorianus* in River Kuja - Migori is presented in Figure 10. The sample size analyzed constituted of 378 fish whose sizes ranged from 7.5 cm TL to 35.7 cm TL with a mean (± SE) of 19.8 ± 0.31 cm TL. There were two peaks of mean lengths in the month of April and October 2018. The peak observed in April 2019 confirms the first peak of mean lengths in the previous year. There were significant differences in mean lengths of *L. victorianus* in the different sampling months (ANOVA, p = 0.01).

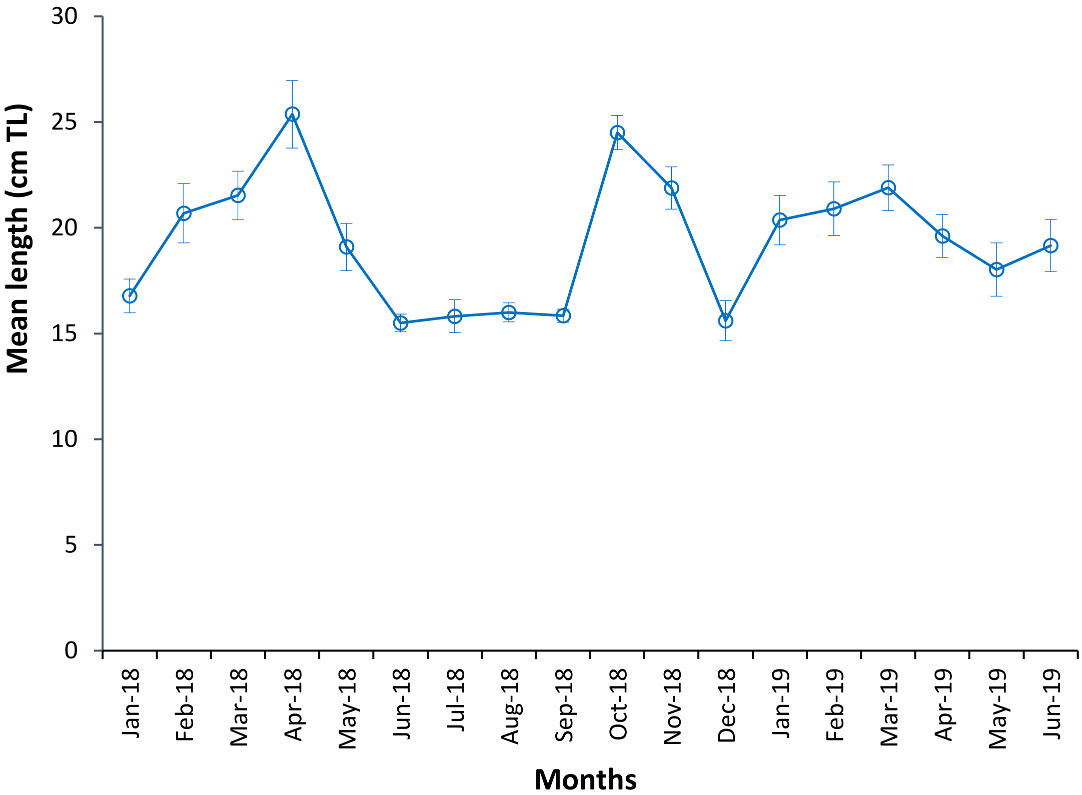

Figure 10. Temporal changes in mean (± SE) lengths of *L. victorianus* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.5.3 The spatial distribution of mean lengths of *L. altianalis* in River Kuja - Migori

Spatial distribution of the mean lengths of *L. altianalis* in River Kuja - Migori is presented in Figure 11. The sample size of 1217 fish of total mean lengths ranging from 2.6 cm TL to 41.5 cm TL were used for spatial distribution. The mean lengths decreased from a mean (± SE) of 21 ± 0.62 cm TL in the most upstream sampling station to (± SE) 16 ± 0.41 cm TL in sampling station S4. There were significant differences in mean lengths of *L. altianalis* among the 5 different sampling stations (ANOVA, $p = 0.02$).

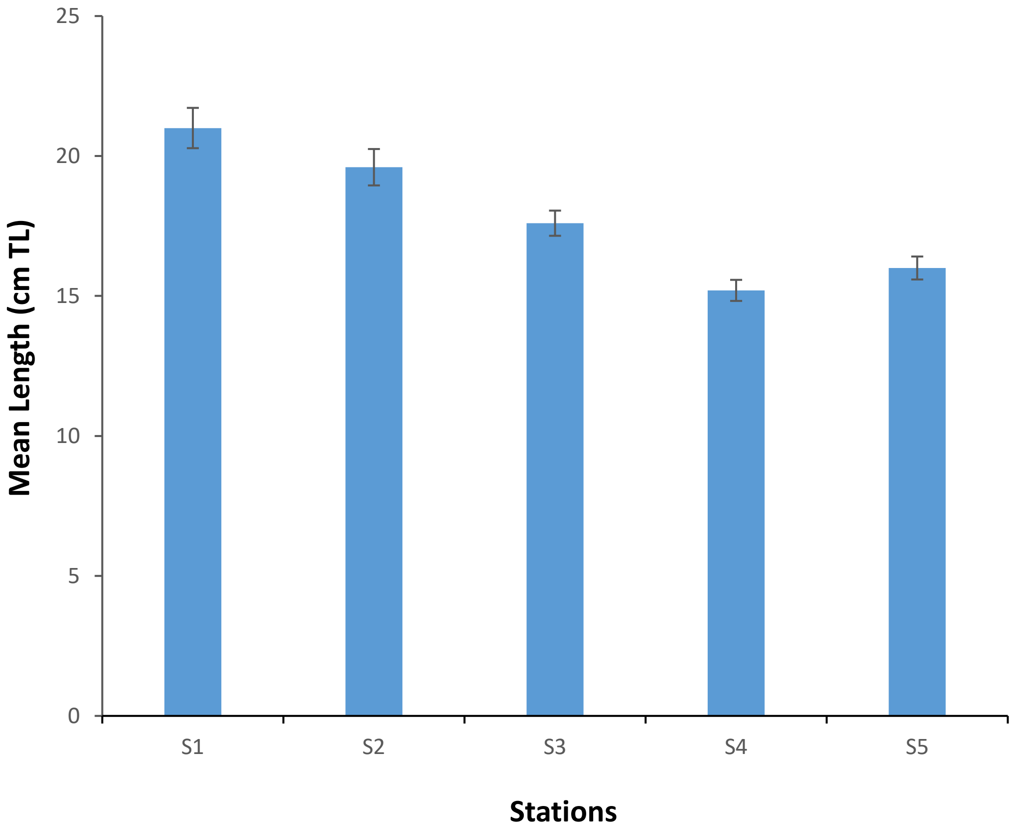

Figure 11. The spatial distribution of mean lengths (± SE) of *L. altianalis* in River Kuja – Migori from upstream station S1 to downstream Station S5 (vertical bars represent standard error of the mean)

4.5.4 The temporal distribution of mean lengths of *L. altianalis* in River Kuja - Migori

The temporal size distribution of *L. altianalis* in River Kuja - Migori is presented in Figure 12. The sample size analyzed constituted of 1217 fish of sizes ranging from 2.6 cm TL to 41.5 cm TL with a mean (± SE) of 15.84 ± 0.21 cm TL. The mean depicted two peak seasons, March - May 2018 and October to December 2018 and March - May 2019, confirming the first mean peak in the previous year. These two seasons corresponded to longer and shorter rains respectively (Figure 35). Small mean lengths of *L. altianalis* were estimated for the periods January to March 2018, May to September 2018 and January to March 2019, during the dry season respectively. There were significant differences among mean lengths of *L. altianalis* in different sampling months (ANOVA, $p = 0.00$).

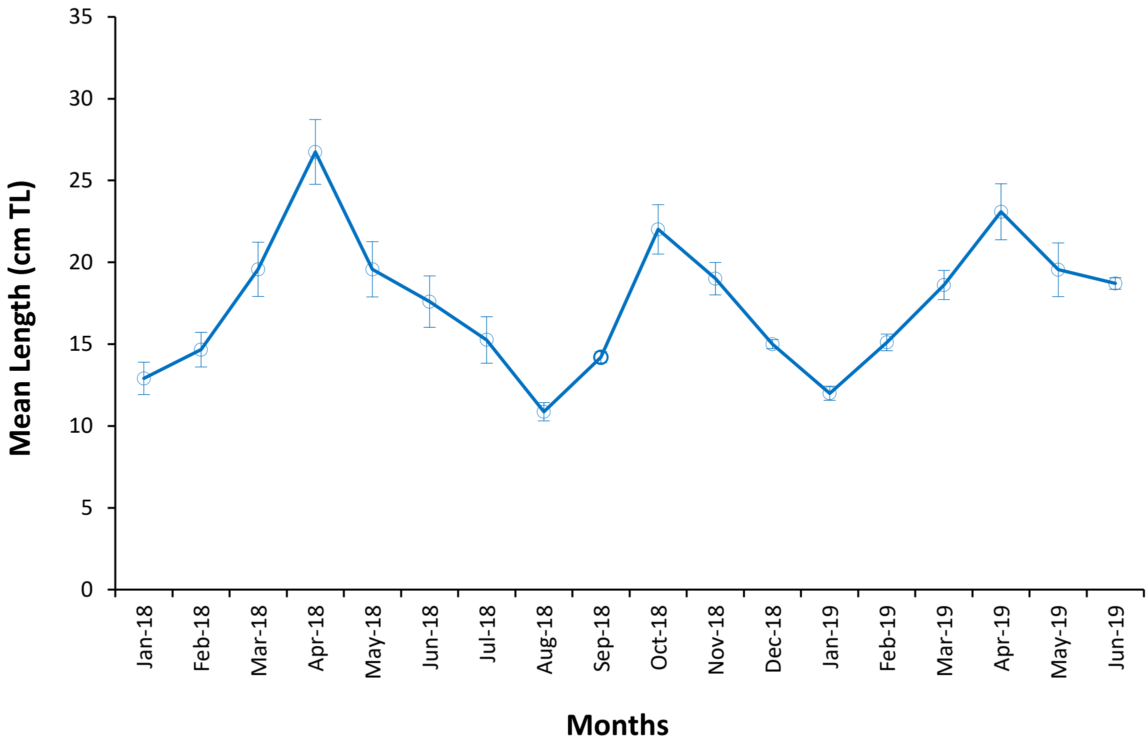

Figure 12. The temporal size distribution of mean lengths (± SE) of *L. altianalis* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.6 Length - weight relationship of *L. victorianus* and *L. altianalis* in River Kuja - Migori

A total of 378 specimens of *L. victorianus* constituting 172 males and 206 females and 773 specimens of *L. altianalis* constituting 417 males and 356 females were analyzed for length - weight relationship (Table 7). The size of *L. victorianus* analyzed for length -weight relationship ranged from 8.1 - 35.7 cm TL with a mean (± SE) of 19.91 ± 0.33 cm TL and 6.6 - 562.8 g with a mean (± SE) of 117.33 ± 5.81 g while the size of *L. altianalis* ranged from 2.6 - 41.5 with a mean (± SE) of 18.76 ± 0.21 cm TL and 1.1 - 647.1 g with a mean (± SE) of 96.88 ± 3.40 g. Both *L. victorianus* and *L. altianalis* showed an allometric growth in which increase in length was proportionate with growth in weight.

Table 7. Length - weight relationship of *L. victorianus* and *L. altianalis* in River Kuja – Migori from January 2018 to June 2019

Description	N	a	b	R^2	Equation
L. victorianus males	172	-1.87	2.92	0.79	W = 2.92TL - 1.87
L. victorianus females	206	-1.85	2.92	0.88	W = 2.92TL- 1.85
L. victorianus combined	378	-1.86	2.92	0.83	W = 2.92TL- 1.86
L. altianalis males	417	-2.16	3.15	0.87	W = 3.15TL - 2.15
L. altianalis females	356	-2.07	3.07	0.91	W = 3.07TL - 2.07
L. altianalis combined	773	-2.11	3.11	0.89	W = 3.11TL - 2.11

4.7 Condition factor of *L. victorianus* and *L. altianalis* in River Kuja - Migori

The condition factor of *L. victorianus* and *L. altianalis* are presented in Table 8. The range of the condition factor was narrower in *L. victorianus* than in *L. altianalis*. Thus, the variance of the latter was slightly higher than that of the former. The mean condition factors of both species were similar falling within a narrow range of 0.98 - 1.07. It can be noted that the sample sizes of both sexes for the two species were different with those of *L. altianalis* being higher than those of *L. victorianus.*

Table 8. Condition factors of *L. victorianus* and *L. altianalis* in River Kuja - Migori from January 2018 to June 2019

Species and sex	n	Range	Mean	SE
L. victorianus males	172	0.12-1.75	0.98	0.03
L. victorianus females	206	0.28-1.92	1.07	0.09
Both sexes of *L. victorianus*	378	0.12-1.92	1.02	0.04
L. altianalis males	418	0.12-1.84	1.04	0.06
L. altianalis females	358	0.28-1.97	1.05	0.07
Both sexes of *L. altianalis*	776	0.12-1.97	1.04	0.07

4.7.1 Temporal variation of the condition factor of female *L. victorianus* in River Kuja – Migori

The temporal variation of the condition factor of female *L. victorianus* in River Kuja - Migori is presented in Figure 13. The condition factor ranged from 0.84 - 1.40 with a mean (± SE) of 1.01 ± 0.04. When condition factor of fish is greater than 1.0 the fish is said to be in good health. The condition factor less than 1.0 was obtained in seven months out of the 18-month period of study. These months were January - February, June - August and November - December. The results depict two seasons when the condition factor was lowest constituting January and February, months falling in the dry season and June - August which were within the longer rainy season. There were significant differences in condition factor across the months (ANOVA, $p = 0.00$). The condition factor was higher starting from the onset of heavy rains in March to June and in September to November 2018, October 2018 and in April 2019.

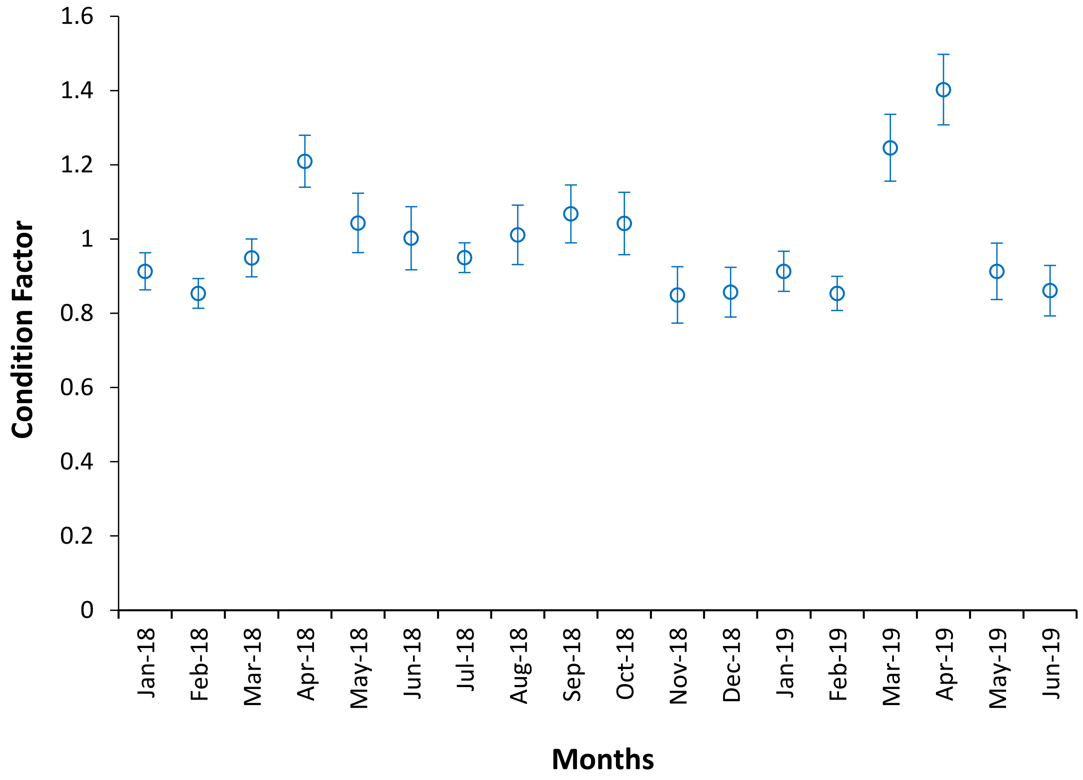

Figure 13. The temporal variation of the condition factor of female *L. victorianus* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.7.2 Temporal variation of the condition factor of male *L. victorianus* in River Kuja - Migori

The temporal variation of the condition factor of *L. victorianus* males in River Kuja - Migori is presented in Figure 14. The condition factor ranged from 0.76 - 0.99 with a mean (± SE) of 0.89 ± 0.01. The results showed that the wellbeing of male *L. victorianus* was poor since the indices for all the 18 months fell below 1.0 throughout the study period. There were significant differences in condition factor among months (ANOVA, $p = 0.00$). Months with lowest condition factors of males were January and February, May, August November, December 2018. The highest condition factor was in in April and October 2018 and in April 2019 and these are the same months during which the condition factors were highest in females. The months when the condition factor was lowest were mainly falling within the dry season more so in males than in females. The highest condition factor of male *L. victorianus* were mainly recorded during the wet months just as in females. The trend of the condition factor for both male and female *L. victorianus* is similar to that of the annual rainfall pattern in the region where the River Kuja - Migori is situated.

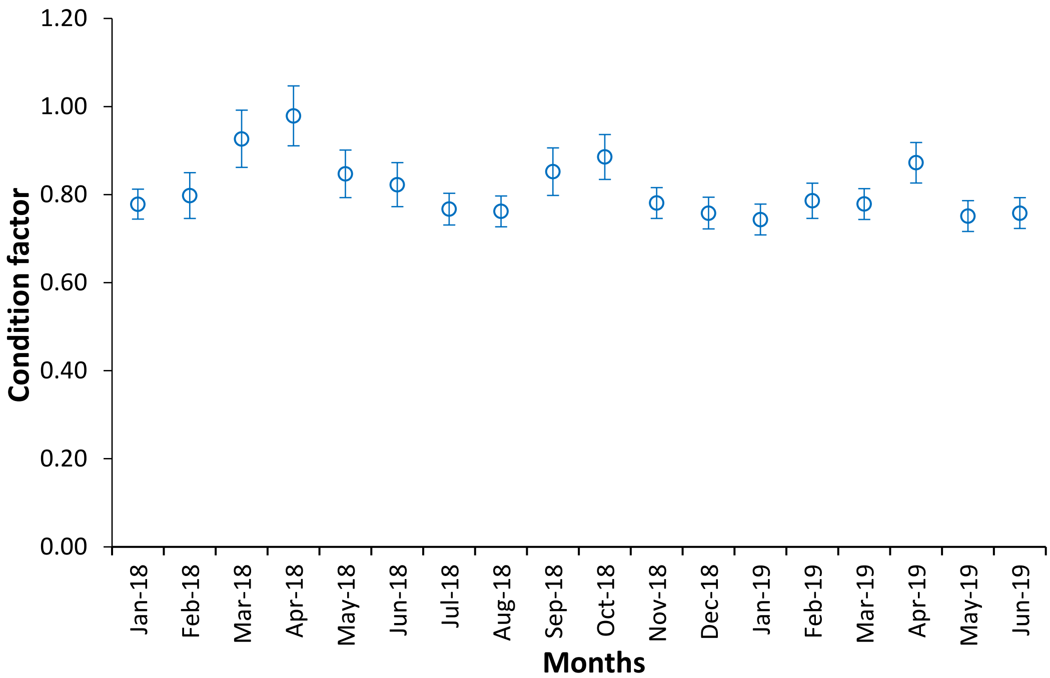

Figure 14. The temporal variation of the condition factor of males *L. victorianus* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.7.3 The temporal variation of the condition factor of female *L. altianalis* in River Kuja - Migori

The temporal variation of the condition factor of female *L. altianalis* in River Kuja - Migori is presented in Figure 15. The condition factor ranged from 0.89 - 1.45 with a mean (± SE) of 1.1 ± 0.04. The months with condition factors that were below 1.0 were January, February, May - July and November – December, that is 8 months out of the 18 months during the sampling period. Just as in female and male *L. victorianus* low condition factors were obtained for two different seasons that is in the dry period months of January – February and the wet months

May- June and in the low rain season during November to December. There were significant differences in condition factor among months (ANOVA, p = 0.00). The months with high condition factors were April and October.

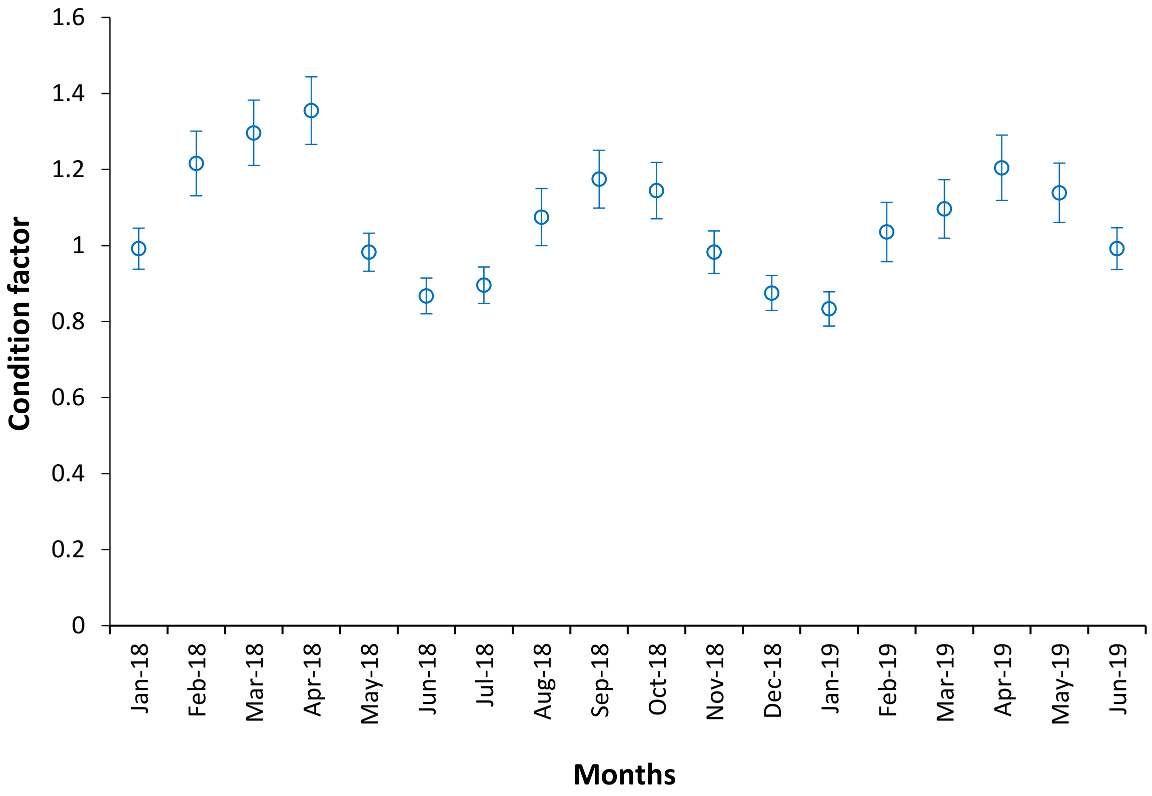

Figure 15. The temporal variation of the condition factor of female *L. altianalis* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.7.4 The temporal variation of the condition factor of male *L. altianalis* in River Kuja – Migori

The temporal distribution of the condition of male *L. altianalis* in River Kuja - Migori is presented in Figure 16.

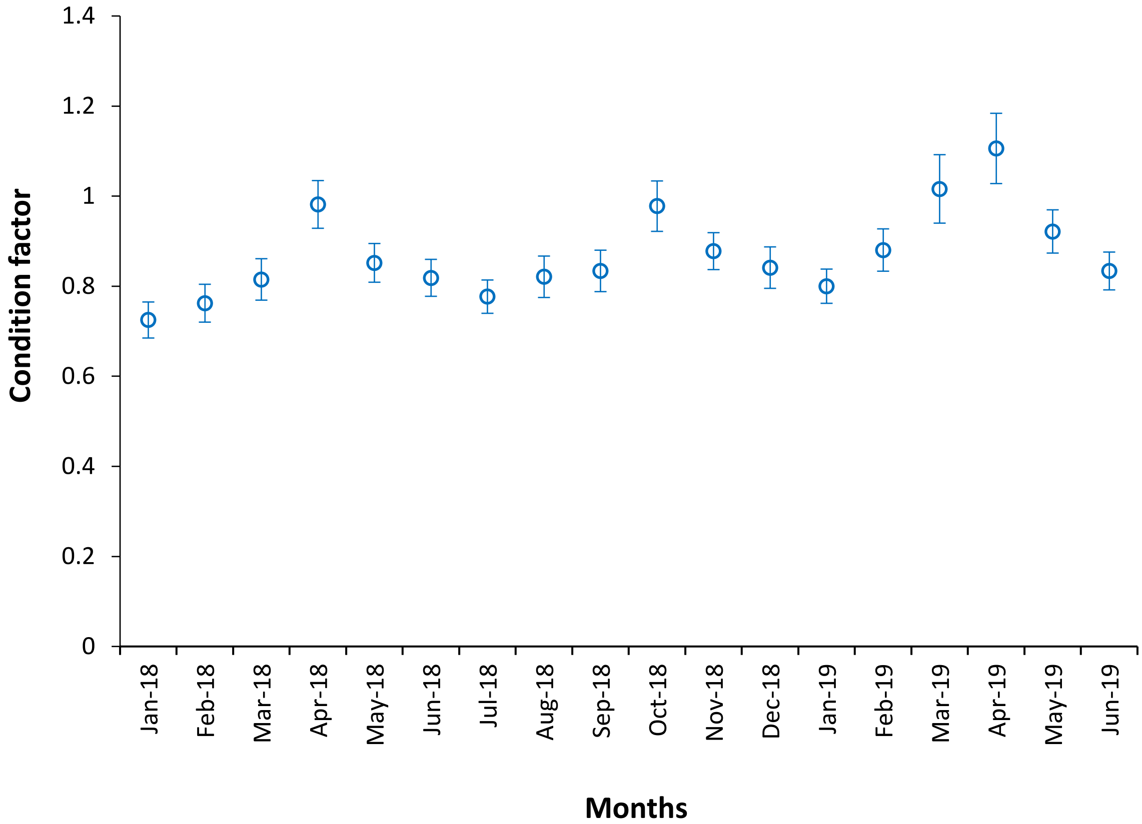

Figure 16. The temporal variation of the condition of male *L. altianalis* in River Kuja – Migori from January 2018 to June 2019 (vertical bars are standard error of the mean)

The temporal distribution of the condition factor of male *L. altianalis* was almost similar to that of male *L. victorianus* in that, most of the condition factors except in the months of April and October were below 1.0. The months with the lowest condition factors can be grouped into three seasons January – February, November – December during the dry months and May – July during the wet season. There were significant differences in condition factor among months (ANOVA, p = 0.0012). The months with the highest male condition factor were April and October which are the same months when the condition factors were also high in males and females of *L.victorianus.* Overally, the results depicts highest condition factors in the wet season in both males and females of both species.

4.8.1 Spatial variation of the condition factor of female *L. victorianus* in River Kuja - Migori

The spatial variation of the condition factor of female *L. victorianus* in River Kuja - Migori is presented in Figure 17. The condition factor ranged from 0.85 - 1.06 with a mean (±SE) of 0.97 ± 0.06. Starting from the most upstream station S1 the condition factor declined to a minimum in station S3 which was located at Migori town. Thereafter, the condition factor showed an increasing trend up to S5. There were significant spatial differences in the mean condition factors among stations (ANOVA, p = 0.00).

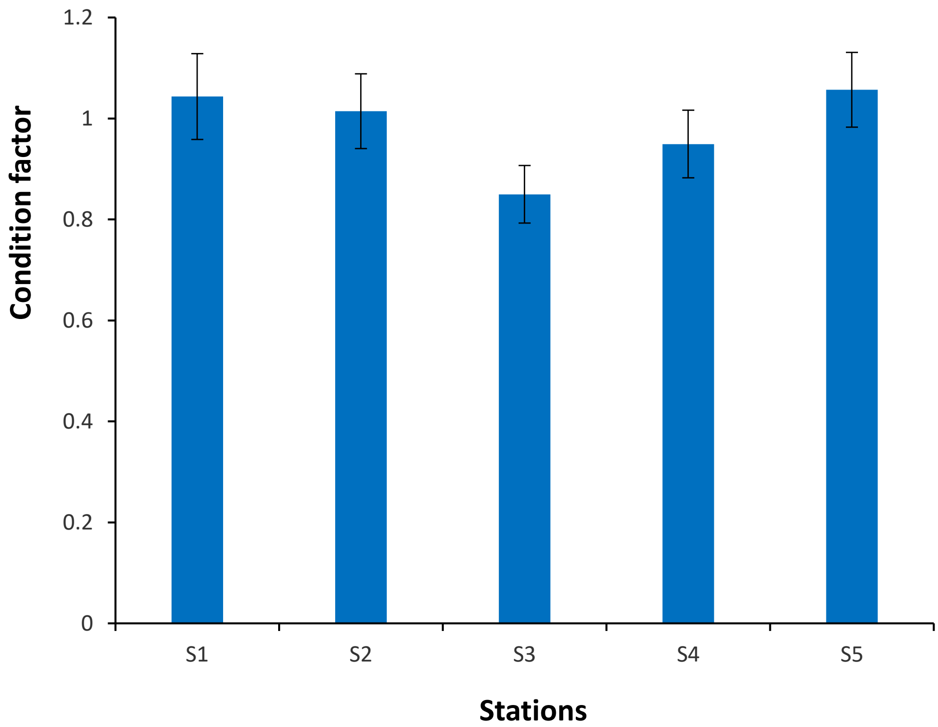

Figure 17. The spatial variation of the condition factor of female *L. victorianus* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.8.2 Spatial variation of the condition factor of male *L. victorianus* in River Kuja – Migori

The spatial variation of the condition factor of male *L. victorianus* in River Kuja - Migori is presented in Figure 18. The condition factor ranged from 0.83 - 0.92 with a mean (± SE) of 0.90 ± 0.03. The range of the condition factor is narrower than that of females. The same thing applies for mean condition factor which was lower in males than in females. The trend of the spatial distribution of males was the same as that of females with station S3 at Migori town having the minimum condition factor. The trend declined from the most upstream sampling station S1 to S3 and started to increase up to the last sampling station S5. There was a significant difference in the condition factor among the sampling stations (ANOVA, p = 0.05).

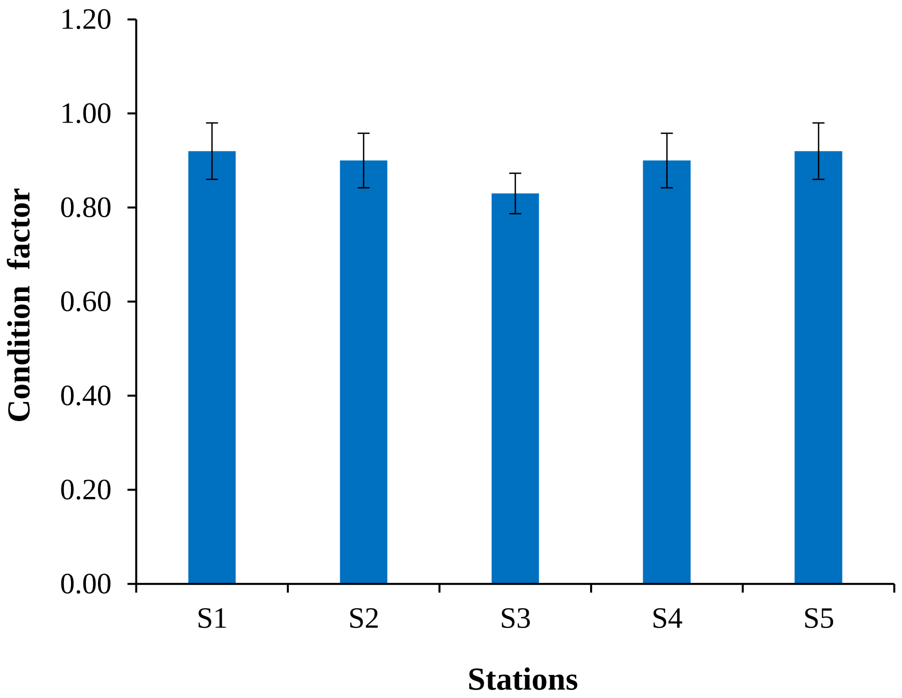

Figure 18. The spatial variation of the condition factor of male *L. victorianus* in River Kuja – Migori (vertical from January 2018 to June 2019 bars represent standard error of the mean)

4.8.3 Spatial variation of the condition factor of female *L. altianalis* in River Kuja - Migori

The spatial variation of the condition factor of female *L. altianalis* in River Kuja - Migori is presented in Figure 19. The condition factor ranged from 0.88 - 1.2 with a mean (± SE) of 0.98 ± 0.003. The range of the condition factors of female *L. altianalis* was slightly wider than that of females of *L. victorianus*. The mean condition factor decreased from the first sampling station S1 to station S3 in Migori town and increased up to station S5. One - way ANOVA was used to verify whether there was a significant difference among the condition factors in different sampling stations. The results revealed a significant difference among the stations (ANOVA, $p = 0.00$).

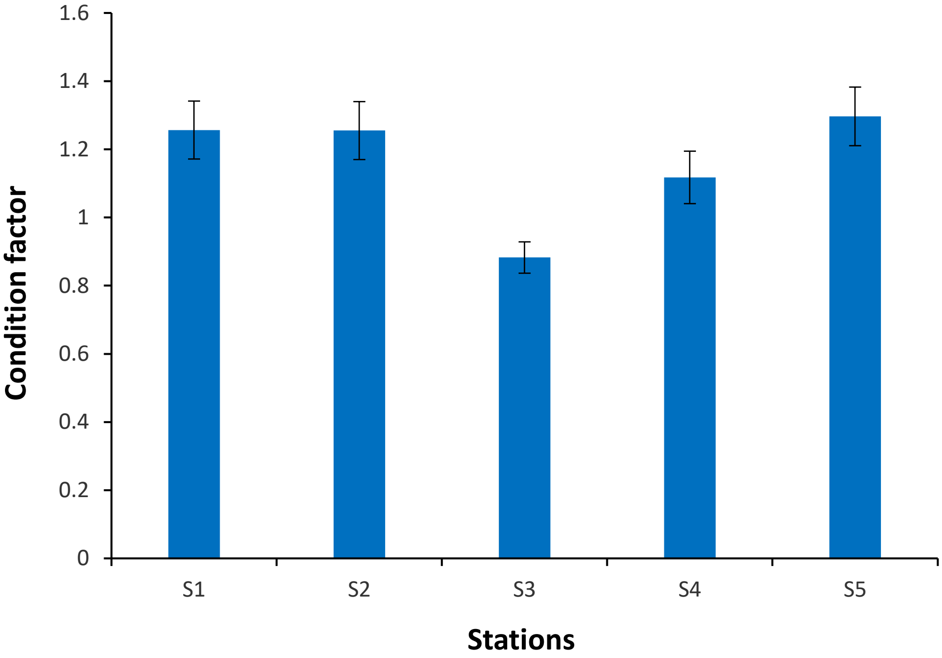

Figure 19. The spatial variation of the condition factor of female *L. altianalis* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.8.4 The spatial variation of the condition factor of male *L. altianalis* in River Kuja - Migori

The spatial variation of the condition factor of male *L. altianalis* in River Kuja - Migori is presented in Figure 20. The condition factor ranged from 0.81- 0.95 with a mean (± SE) of 0.89 ± 0.01. This range was much narrower than that of females but almost the same as that of male *L. victorianus*. The trend of the changes in condition factor is the same as that of all the others above with the minimum still at sampling station S3 (Migori town). The condition factors differed significantly among the different sampling stations (ANOVA, $p < 0.05$).

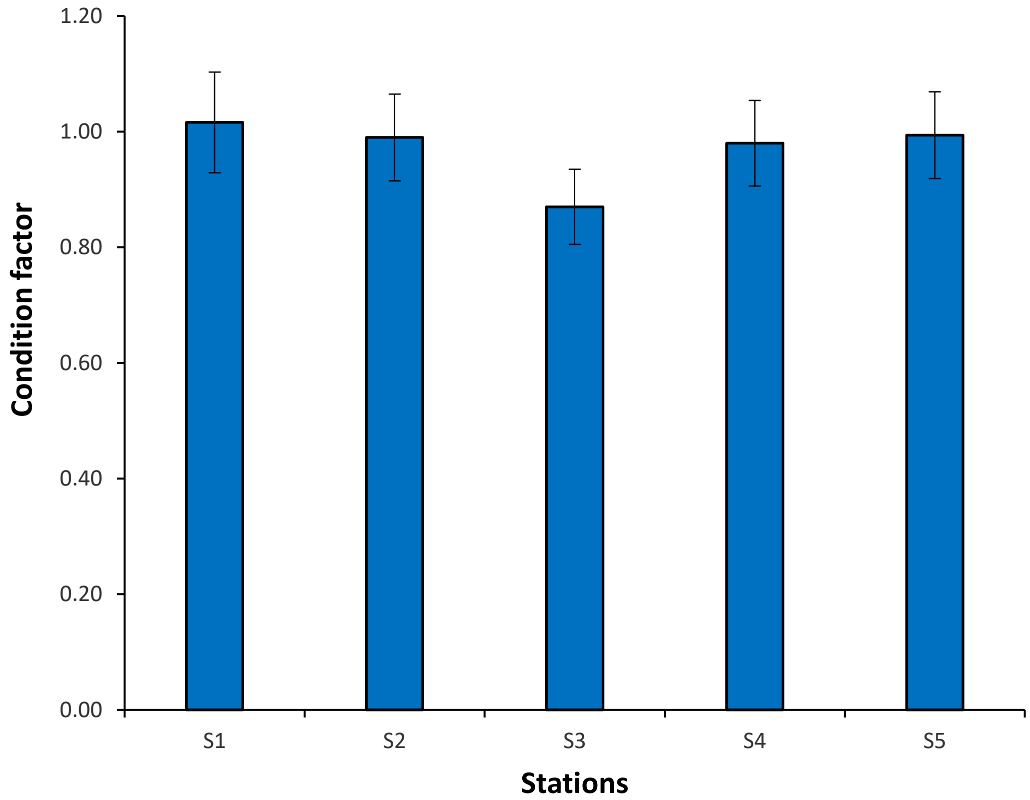

Figure 20. The spatial variation of the condition factor of male *L. altianalis* in River Kuja – Migori from upstream station S1 to downstream Station S5 (vertical bars represent standard error of the mean)

4.9.1 Fecundity-body size relationship of *L. victorianus* in River Kuja - Migori

The relationship between fecundity and total body length of *L. victorianus*, in River Kuja – Migori is shown on Figure 21. A total of 48 female *L. victorianus* of size ranging from 22.2 cm TL – 35.5 TL with a mean (± SE) of 27.2 ± 1.4 cm TL were analyzed for fecundity. Fecundity ranged from 47,842 - 101,902 eggs with a mean (± SE) of (83,663 ± 2605). Therefore, there was a high variance of the mean number of eggs. Fecundity increased with every unit increase in total length of female *L. victorianus* ($R^2 = 0.91$) (Figure 21).

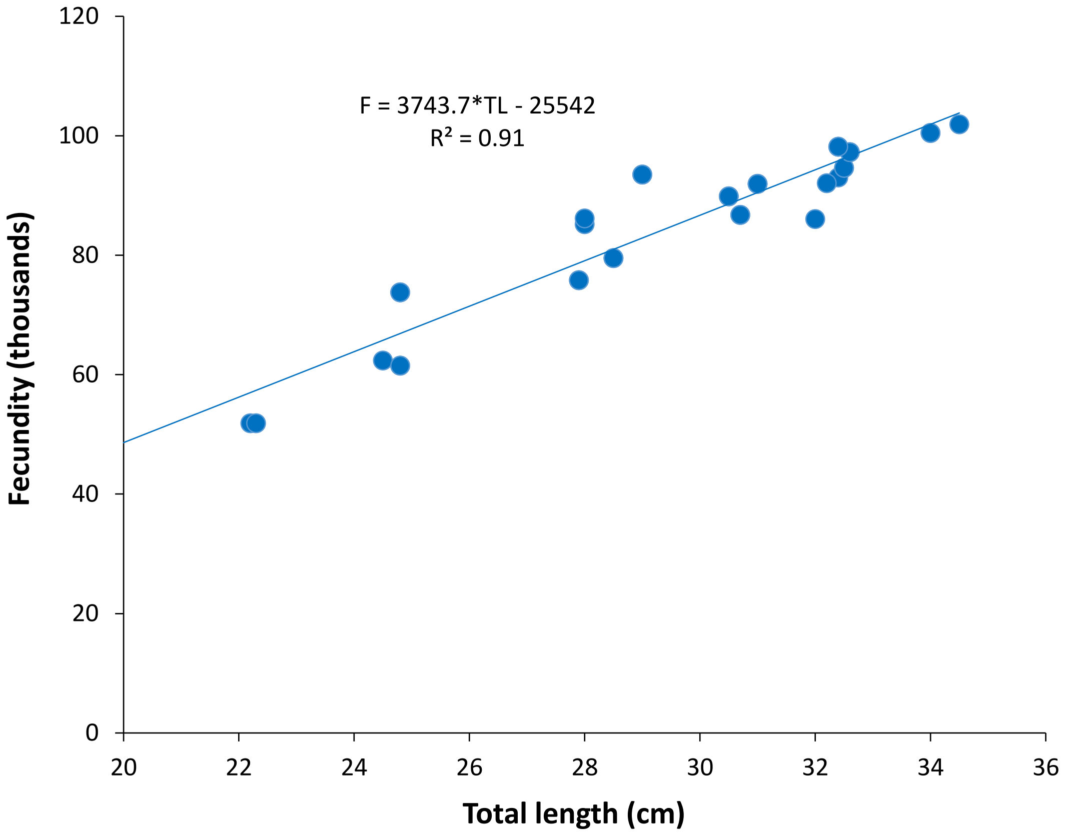

Figure 21. Relationship between fecundity and total length of *L. victorianus*, in River Kuja – Migori from January 2018 to June 2019

4.9.2 Fecundity body size relationship of *L. altianalis* in River Kuja - Migori

A total of 127 female *L. altianalis* of size ranging from 24.0 - 41.5 cm TL with a mean (± SE) of 28.09 ± 0.39 cm TL were analyzed for fecundity and its relationships with other reproductive parameters. Fecundity ranged from 1320 eggs in a female fish of size 25.2 cm TL to 2382 eggs in a fish of size 39.6 cm TL. The mean (± SE) fecundity was 1552 ± 23.3 eggs. The relationship between fecundity and body size of *L. altianalis* is depicted in Figure 22. There was a strong positive correlation ($R^2 = 0.99$) between fecundity and body size of female *L. altianalis*.

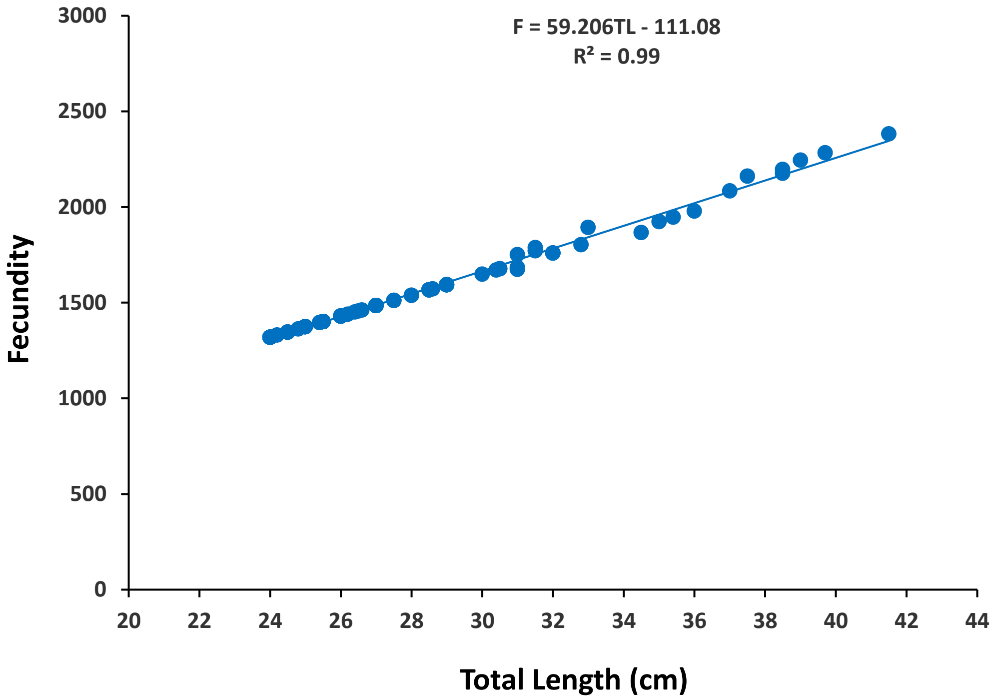

Figure 22. Relationship between fecundity and total length of female *L. altianalis*, in River Kuja – Migori from January 2018 to June 2019

4.10.1 Temporal variation of fecundity of *L. victorianus* in River Kuja - Migori

Figure 23 depicts the temporal variation of fecundity of female *L. victorianus* in River Kuja - Migori. A total of 136 females (26.5 cm TL to 34.5 cm TL) with a mean (± SE) of 29.5 ± 0.65 of *L. victorianus* were analyzed for fecundity. Peak fecundities were observed in the months of March, April, October, and November while low fecundity was observed in the months of January-February, September, and December 2018 and April – May 2019 (Figure 23). The results therefore depict that fecundity was lowest during the dry season and highest in wet season.

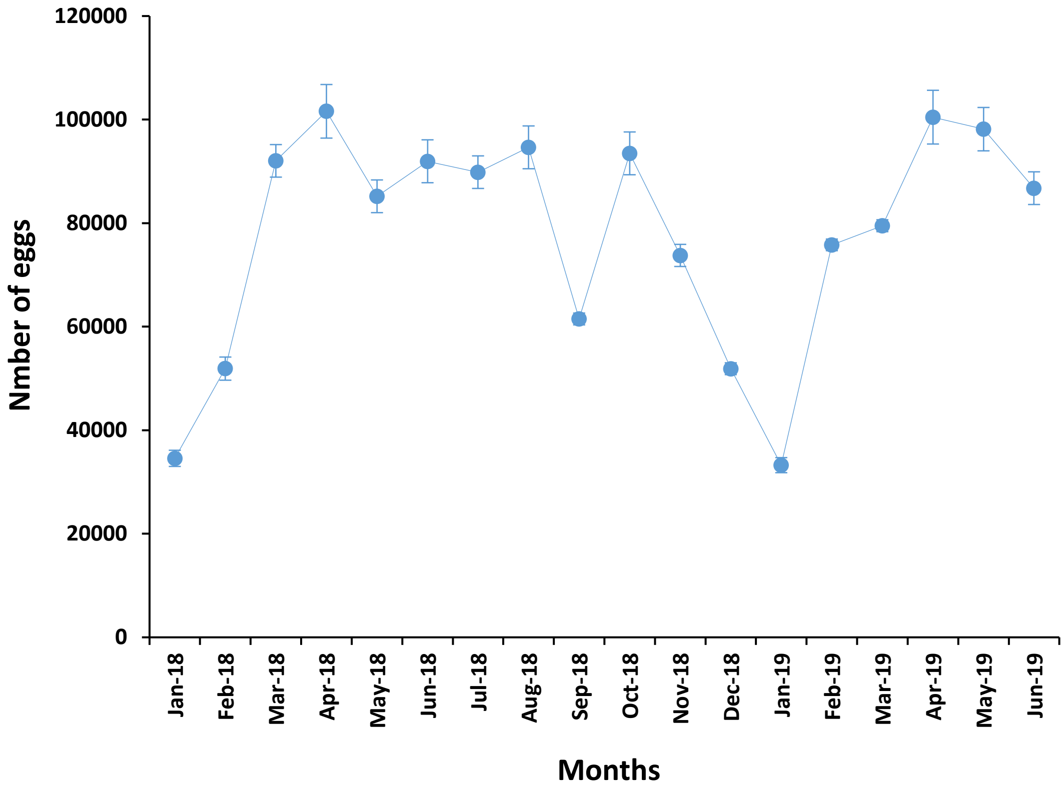

Figure 23. Temporal variation of fecundity of *L. victorianus* in river Kuja-Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.10.2 Temporal variation in fecundity of female *L. altianalis* in River Kuja - Migori

Figure 24 shows temporal variation of the fecundity of *L. altianalis* in River Kuja - Migori. The pattern of temporal variation of fecundity of *L. altianalis* was similar to the one for *L. victorianus* but it was much more well defined, with a prolonged period of high fecundity between the months of February to August followed by a less pronounced period of high fecundity between the months of September and November. The fecundities were high during the wet season and low in the dry season.

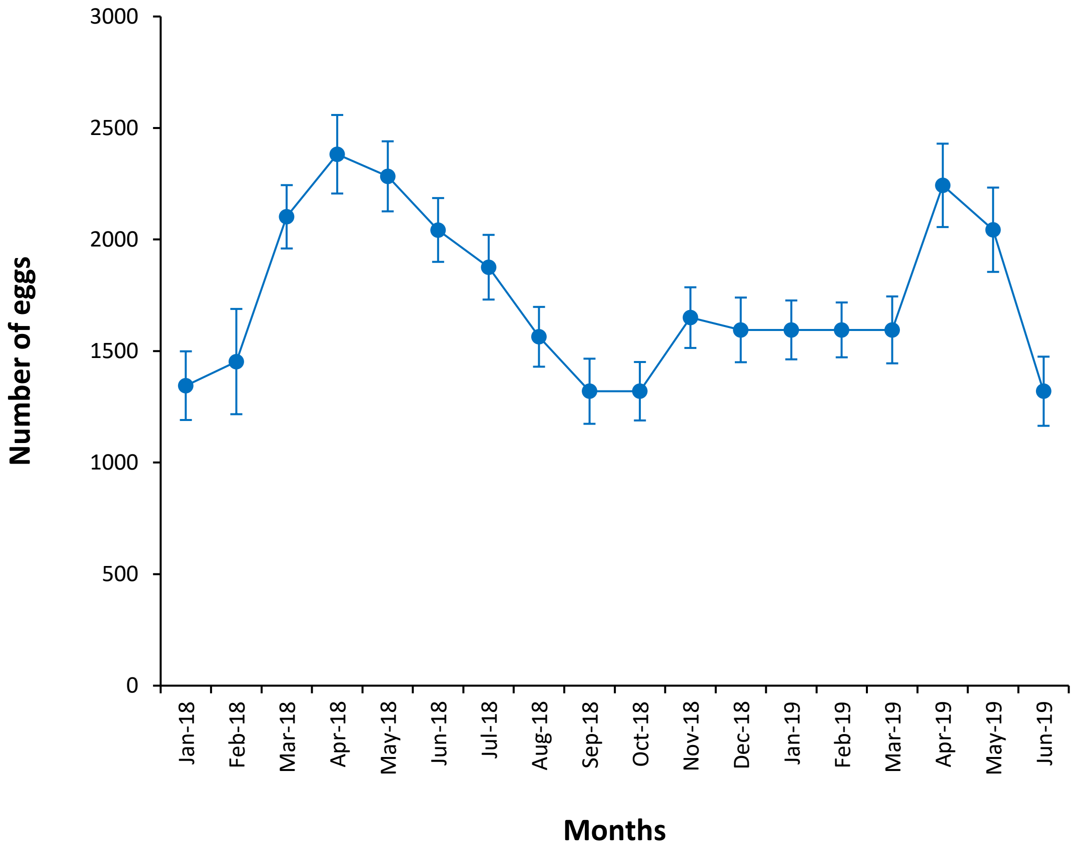

Figure 24. Temporal variation of fecundity of *L. altianalis* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.11.1 Temporal variation of egg size of *L. victorianus* in River Kuja - Migori

Figure 25 shows temporal variation of egg size of *L. victorianus* in River Kuja - Migori. Egg diameter ranged from 0.5 mm to 0.7 mm with a mean (± SE) of 0.65 ± 0.002. The modal frequency of eggs was those with a diameter of 0.5 mm. All the eggs which were measured to estimate the egg diameter were at stage 4 and above. This is because eggs below maturity stage 4 in both fish species presented difficulties in separation even when Gilson's fluid was used to dissolve the ovarian tissues. Ripe eggs occurred throughout the rain season with the smallest diameter being recorded in dry months.

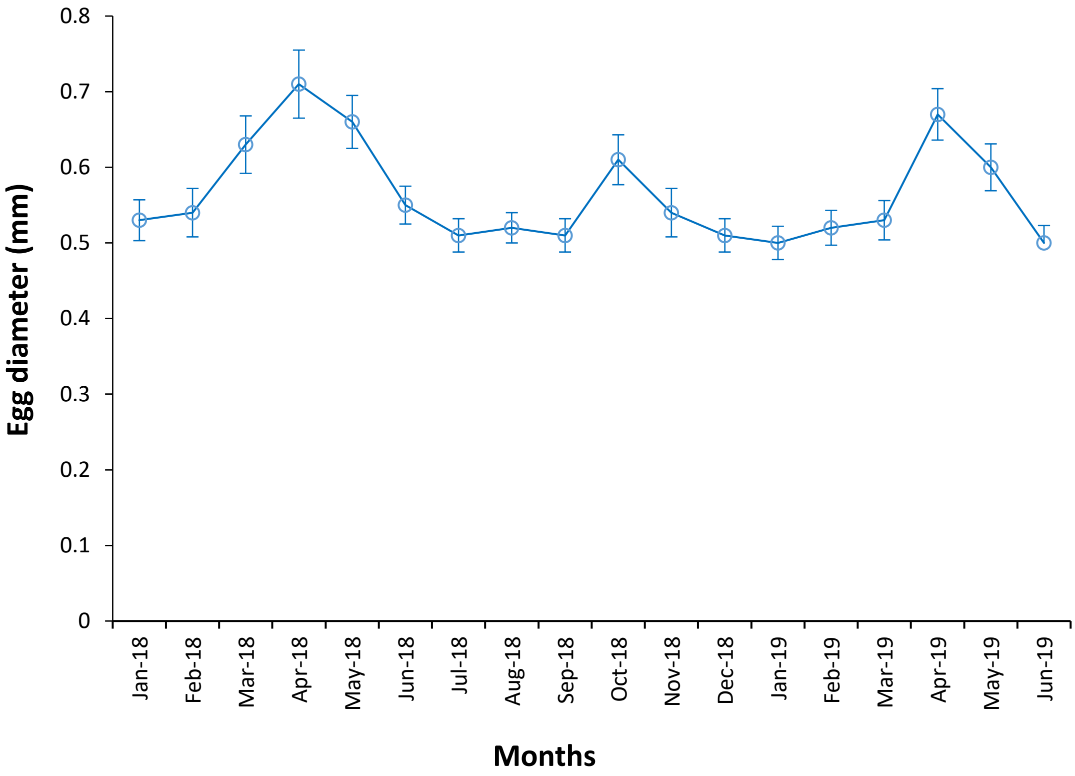

Figure 25. Temporal variation of egg size of *L. victorianus* in River Kuja – Migori (vertical bars represent standard error of the mean)

4.11.2 Temporal variation of egg size of female *L. altianalis* in River Kuja - Migori

The temporal variation of egg diameter of *L. altianalis* in River Kuja - Migori is presented in Figure 26. A total of 197 female fish specimen of size ranging from 24.0 – 41.7 cm TL were analyzed for egg diameters. The egg diameter was found to range from 0.89 mm to 1.27 mm in female fish of 24 cm TL and 41.5 cm TL respectively. The mean (± SE) egg diameter was 1.22 ± 0.007 mm. Many of the eggs had a diameter of 1 mm and most of these eggs were observed in the wet season. The highest egg diameter occurred in the months of April while the lowest were observed in the months of January and February 2018 (Figure 26). Comparatively, the eggs of *L. altianalis* were bigger than those of *L. victorianus* and the size range of the females of *L. altianalis* was comparably greater than in those of *L. victorianus.*

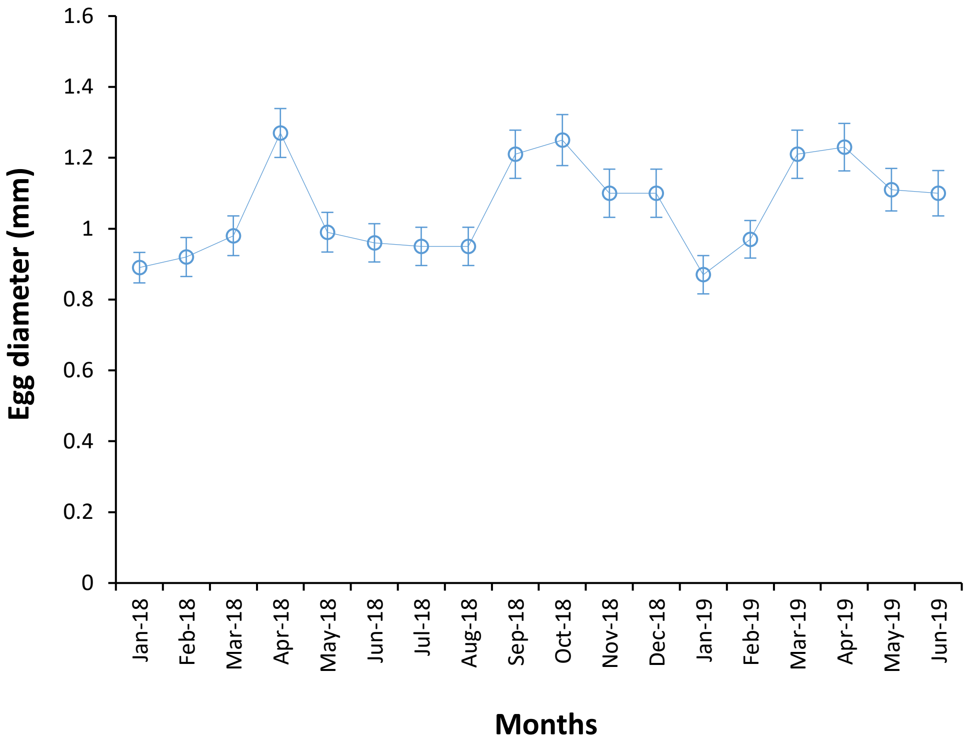

Figure 26. Temporal variation of egg size of female *L. altianalis* in River Kuja – Migori (vertical bars represent standard error of the mean)

4.12.1 Temporal variation of GSI in females and males of *L. victorianus* in River Kuja – Migori

A total of 91 fish constituting of both males (43) and females (48) were analyzed for GSI. The size range of females was 22.2 - 35.5 cm TL with a mean (± SE) of 27.2 ± 1.4 cm TL while that of males ranged from 25.0 to 32 cm TL with a mean length (± SE) of 28.3 ± 0.27%. GSI for females ranged from 5.8 % - 7.4% with a mean (± SE) of 6.3 ± 0.16% while the one of males ranged from 2.6% to 4.2% with a mean (± SE) of 2.8 ± 0.13%. Therefore, the mean GSI for males was lower than that of females by a factor of 2.3%.

The GSI of females and males of *L. victorianus* in River Kuja -Migori was high during the wet season and low in the dry season. The months with the lowest GSI were January – February, June - July and November – December (Figure 27). The period from January to February and November – December constituted months with rainfall minima in the annual cycle. Further, the variability of the GSI depicts a similar pattern as that of sexual maturity stages and abundance of ripe fish in the river, which depict the same annual pattern. There was a significant difference in mean GSI of females and that of males of *L. victorianus* in River Kuja -Migori (ANOVA, p = 0.00).

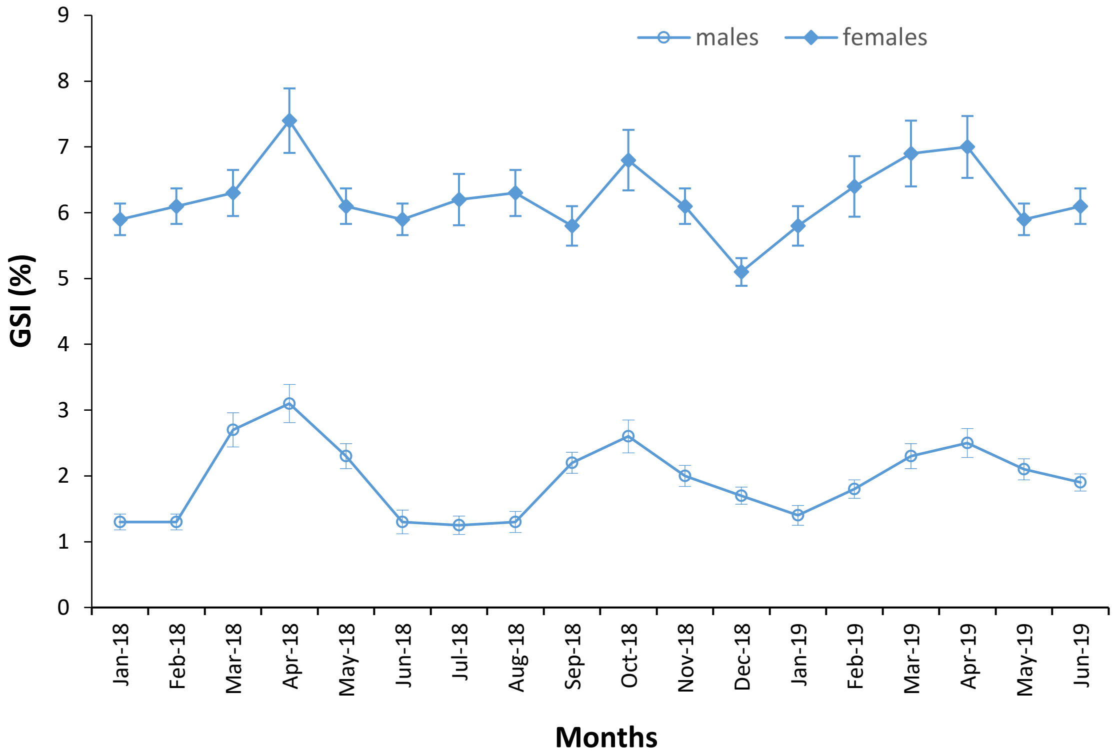

Figure 27. Temporal variation of GSI in females and males of *L. victorianus* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.12.2 Temporal variation of GSI in females and males of *L. altianalis* in River Kuja - Migori

The temporal variation of GSI of females and males of *L. altianalis* is presented in Figure 28. The GSI in females ranged from 1.70% to 8.55% with a mean (± SE) of 5.63 ± 0.34%. GSI was high during the wet season and low in the dry season. The GSI for females was low during the months of January – March in the dry season, June - August during the wet season and November - December during the dry season. The months with the highest GSI was March –

April at the onset of the wet season. This is the same period when the GSI and condition factor of females and males of *L. victorianus* were highest. Therefore, the trend of GSI of *L. altianalis* follows the same trend as that of the annual rainfall cycle. Other months with high GSI were September – November during the second annual rainy period.

The GSI in males of *L. altianalis* ranged from 1.3 - 3.1% with a mean (± SE) of 1.94 ± 0.13%. This range was wider compared to that of GSI in males of *L. victorianus.* However, the range of GSI of male *L. altianalis* was narrower than that of females of the same species. Generally, the GSI ranges of both male and female *L. altianalis* were wider than those of female and males of *L. victorianus.* The male GSI was low during January - March, July - September and November - December. The month with highest GSI was April at the onset of long rain season. The trend in the GSI of both sexes of *L. altianalis* was the same for wet and dry seasons respectively and follows the annual rainfall pattern in the Kuja - Migori basin. There was a significant difference in GSI of females and males of *L. altianalis* among months in River Kuja -Migori ($p = 0.02$).

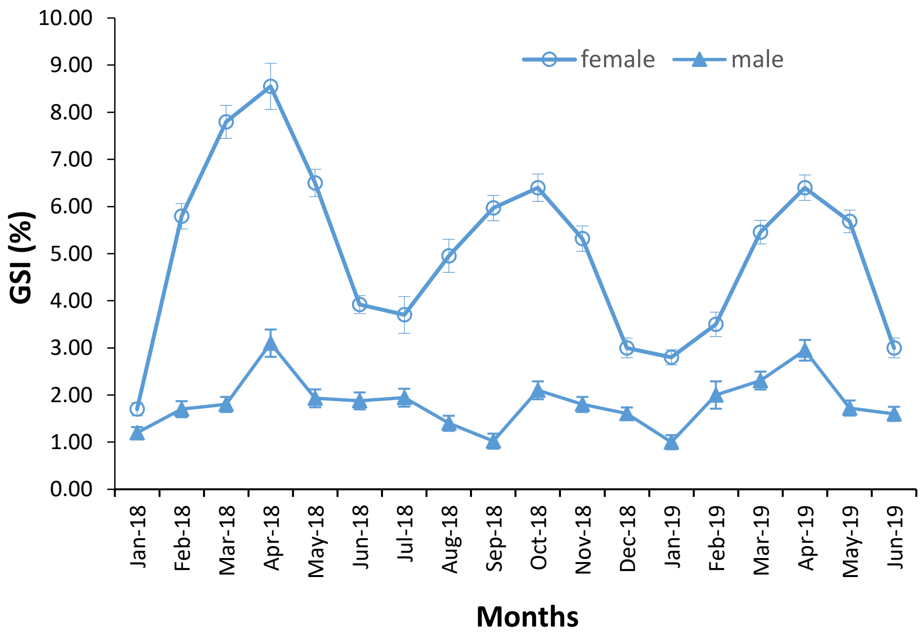

Figure 28. Temporal variation of GSI in females and males of *L. altianalis* in River Kuja – Migori from January 2018 to June 2019 (vertical bars represent standard error of the mean)

4.12.3 Spatial variation of GSI in females and males of *L. victorianus* in River Kuja – Migori

In females of *L. victorianus* the GSI ranged from 4.5 - 6.2% with a mean (± SE) of 5.6 ± 0.32%. GSI was almost similar in the two upstream stations (S1and S2) but decreased in station S3 and then increased in the two downstream stations (S4 and S5) (Figure 29).

In males of *L. victorianus* GSI ranged from 2.5 - 3.2% with a mean (± SE) of 2.94 ± 0.03%. The trend of mean GSI decreased from the most upstream sampling station S1 to S3 at Migori town and started to increase towards S5 next to the delta of the river before entering Lake Victoria. One - way ANOVA was used to verify whether there was a significant difference in GSI's among different sampling stations. The results revealed a significant difference among the stations (ANOVA, p = 0.00).

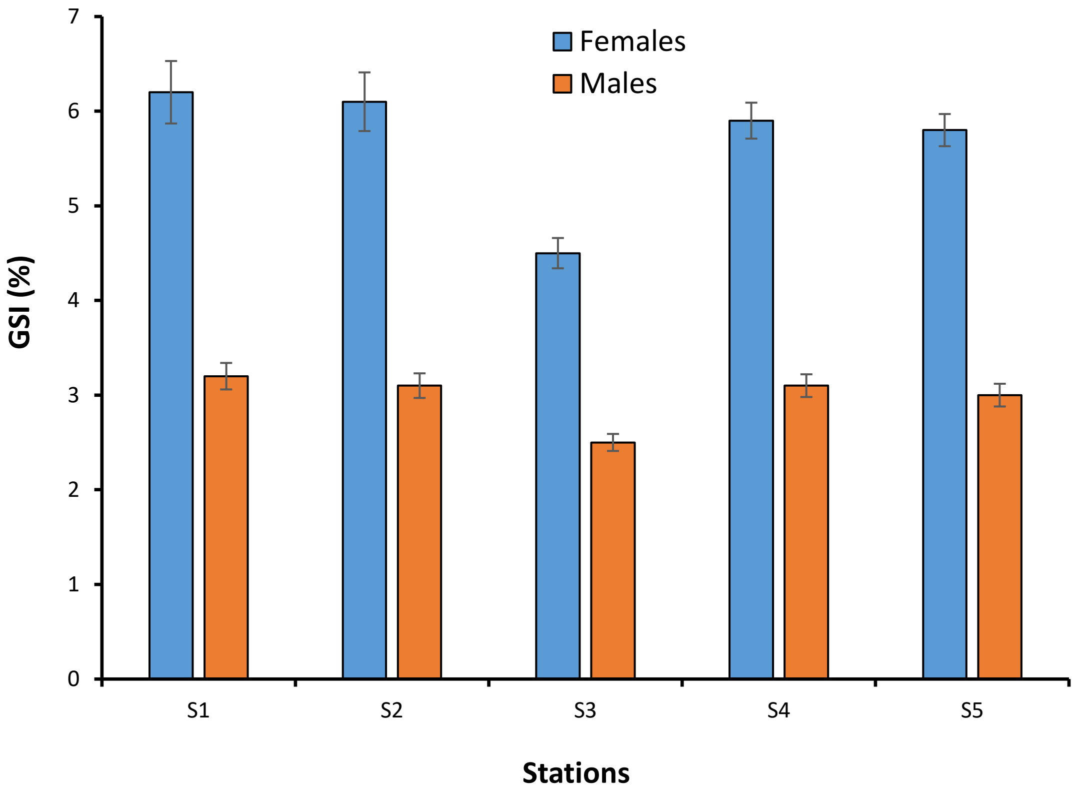

Figure 29. The spatial variation of GSI of female and male *L. victorianus* in River Kuja – Migori from upstream station S1 to downstream Station S5 (vertical bars represent standard error of the mean)

4.12.4 Spatial variation of GSI in females and males of *L. altianalis* in River Kuja - Migori

The spatial variation in GSI of females and males of *L. altianalis* in River Kuja - Migori is presented in Figure 30. The GSI in females ranged from 5.5 - 7.2% with a mean (± SE) of 6.6 ± 0.07%. The mean values of GSI of female *L. altianalis* were higher than those of *L. victorianus* but the ranges were of the same band width. However, the range of the GSI in male *L. altianalis* was wider and higher than in males of *L. victorianus.*

In males of *L. altianalis* GSI ranged from 2.5% - 4.2% with a mean (± SE) of 3.6 ± 0.04%. The range of GSI of male *L. altianalis* was lower than in females. The trend was the same as that of females and males of *L. victorianus* with the most upstream point having the maximum GSI declining to a minimum at sampling station S3 and increasing up to the last sampling station S5 next to the delta of the river. There was a significant difference in GSI's among different sampling stations (ANOVA, p = 0.00).

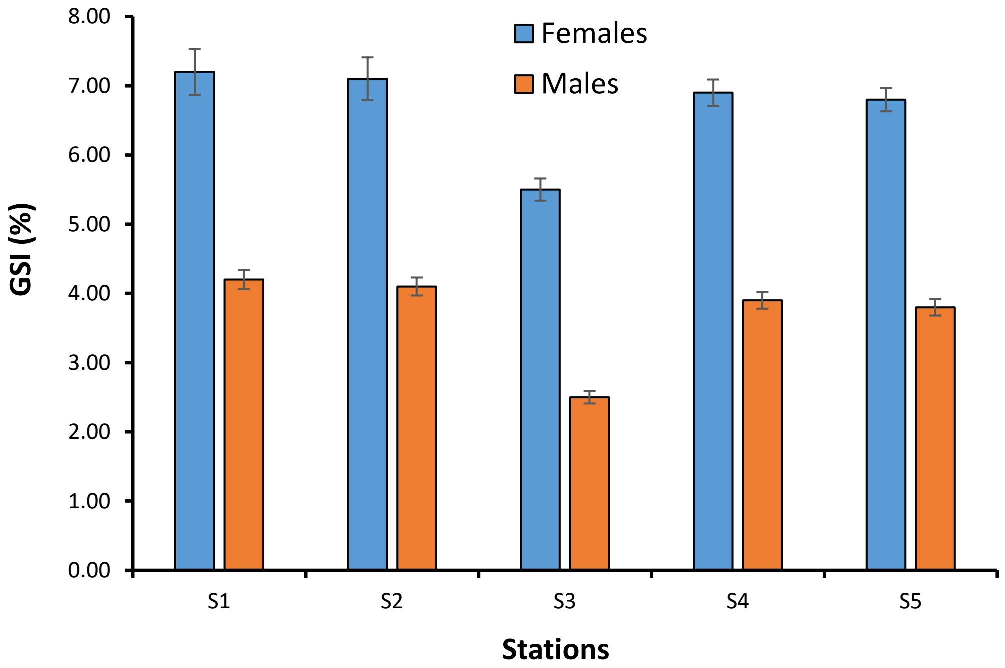

Figure 30. The spatial variation of GSI of female and male *L. altianalis* in River Kuja – Migori from upstream station S1 to downstream Station S5 (vertical bars represent standard error of the mean)

4.13.1 The relationship between gonadosomatic index and total body length of females and males of *L. victorianus* in River Kuja - Migori

The relationship between GSI and total body length of both females and males of *L. victorianus* is presented in Figure 31. The results indicate that the GSI is positively correlated with total body length with a coefficient of determination $R^2 = 0.92$ and $R^2 = 0.88$ for females and males respectively. The relationship of both sexes showed a more significant fit.

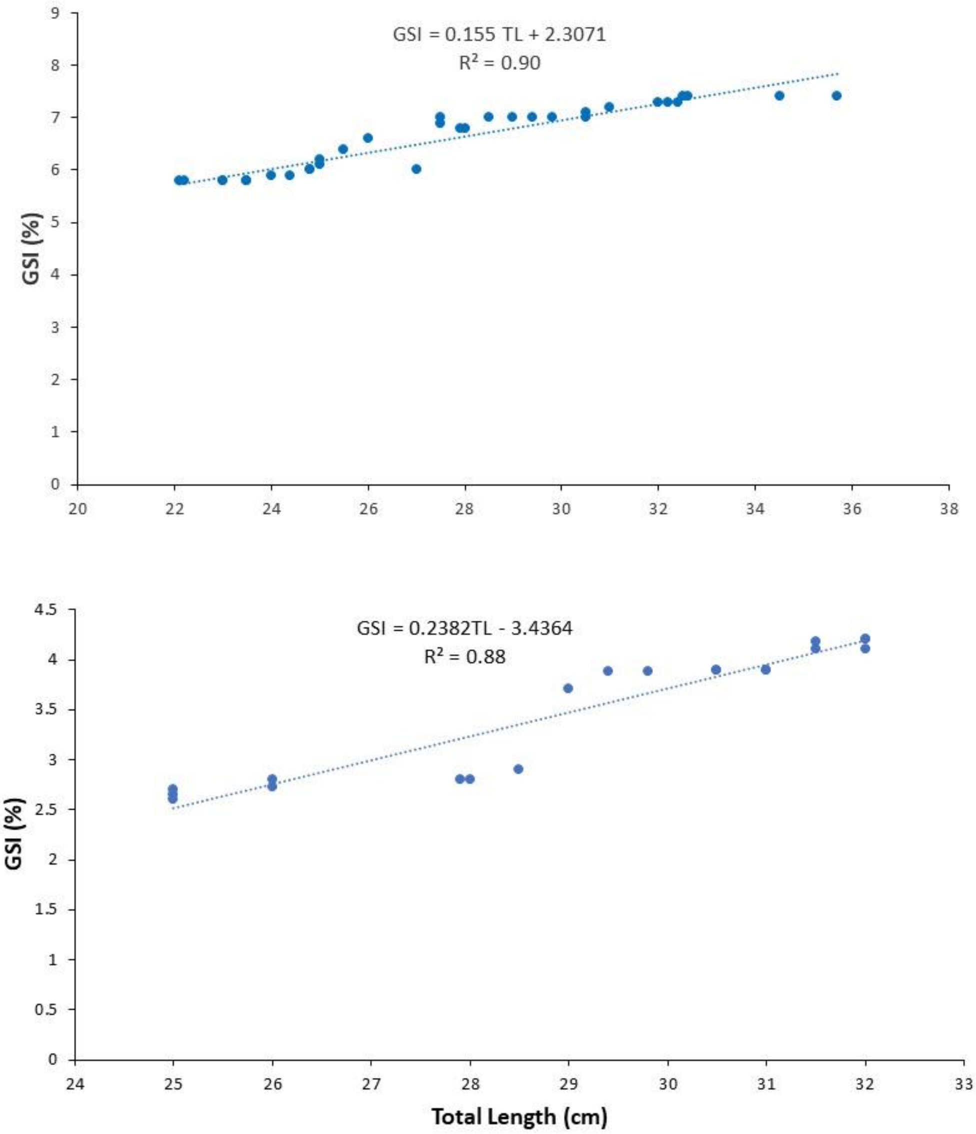

Figure 31. The relationship between GSI and total body length of female (top) and male *L. victorianus* (bottom) in River Kuja –Migori from January 2018 to June 2019

4.13.2 The relationship between gonadosomatic index and total body length for females and males of *L. altianalis* in River Kuja – Migori

The relationship between GSI and total length for females and males of *L. altianalis* is presented in Figure 32. The results indicate that GSI increase with total body length with a coefficient of determination $R^2 = 0.95$ and $R^2 = 0.79$ for females and males respectively. The relationship of females showed a more significant perfect fit than that of males.

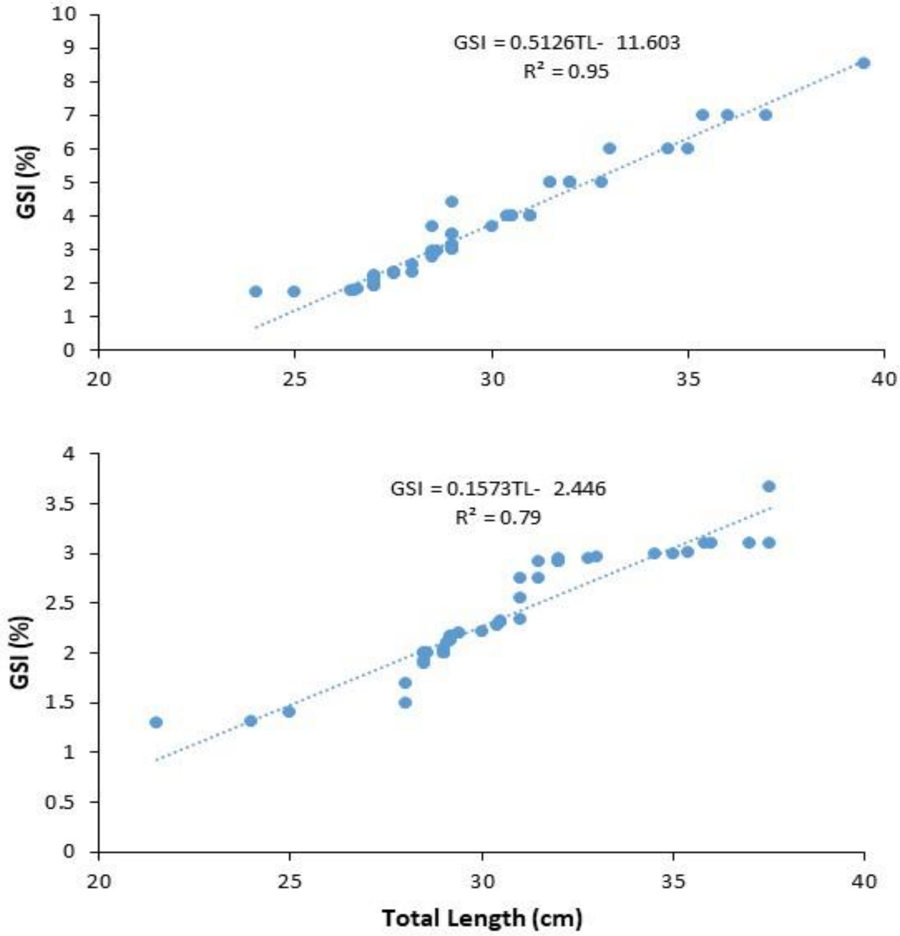

Figure 32. The relationship between GSI and total body length of female (Top) and male *L. altianalis* (bottom) in River Kuja – Migori from January 2018 to June 2019

4.14.1 Sex ratio and length at 50% (L_{m50}) maturity of *L. victorianus* in River Kuja - Migori

The total number of fish analyzed for sex ratio of *L. victorianus* was 256 comprising of 121 females and 135 males. This gave a sex ratio of 1:15 female to male respectively which was not significantly different from theoretical ratio of 1:1 (χ^2, $p < 0.05$). The size of male fish analyzed ranged from 12.4 to 35.7 cm TL with a mean (± SE) of 26.7 ± 3.2 cm TL while that of female fish ranged from 14.5 to 31.6 cm TL with a mean (± SE) of 27.8 cm ± 4.4 TL. The sexual maturity stages of *L. victorianus* males are shown on Table 9. Maturity stage 4 of males had the highest percentage frequency. The mean length of fish in this maturity stage was 22.15 cm TL. The proportion of all mature fish in stages 4 to 6 was 58.74% which indicated that most fish in River Kuja - Migori were mature. However, there was a proportion of immature males constituting of 41.65%.

Table 9. Frequency distribution of sexual maturity stages of male *L. victorianus* in River Kuja - Migori

Mean TL (cm)	Maturity stage	Frequency	Frequency %	Cumulative %
13.43	1	18	12.59	12.59
15.11	2	20	13.99	26.58
16.26	3	21	14.69	41.26
22.15	4	65	45.45	86.72
28.39	5	14	9.79	96.51
30.52	6	5	3.50	100.0

The sexual maturity stages of females of *L. victorianus* are presented in Table 10. The sexual maturity with the highest percentage frequency was stage 4 which had fish of mean (± SE) length 23.6 ± 2.64 cm TL. This length is slightly higher than that of females of *L. victorianus* that were in maturity stage 4 showing that males mature at a smaller size than females. The percentage of females that were mature that is all fish of maturity stage 4 to 6 was 62.16%. this indicated that, a greater percentage of female fish was mature than that of males. Just like in male *L. victorianus*, females in maturity stage 6 had the lowest percentage and that the percentage frequency dropped from that of stage 4 gradually to that of stage 6 in both sexes.

Table 10. Frequency distribution of sexual maturity stages of female *L. victorianus* in River Kuja - Migori

Mean TL (cm)	Maturity stage	Frequency	Frequency %	Cumulative %
12.4	1	15	10.14	10.14
15.9	2	20	13.51	23.65
19.1	3	21	14.19	37.84
23.6	4	66	44.59	82.44
30.8	5	23	15.54	97.98
35.2	6	3	2.03	100.0

The length at 50% maturity of *L. victorianus* in River Kuja – Migori is presented in Figure 33. It indicates that the Lm_{50} of males was 18.0 cm while that of females was 20 cm TL. Therefore, males of *L. victorianus* attain the length at 50% maturity earlier than females. At 30 cm TL both males and females had attained 100% sexual maturity.

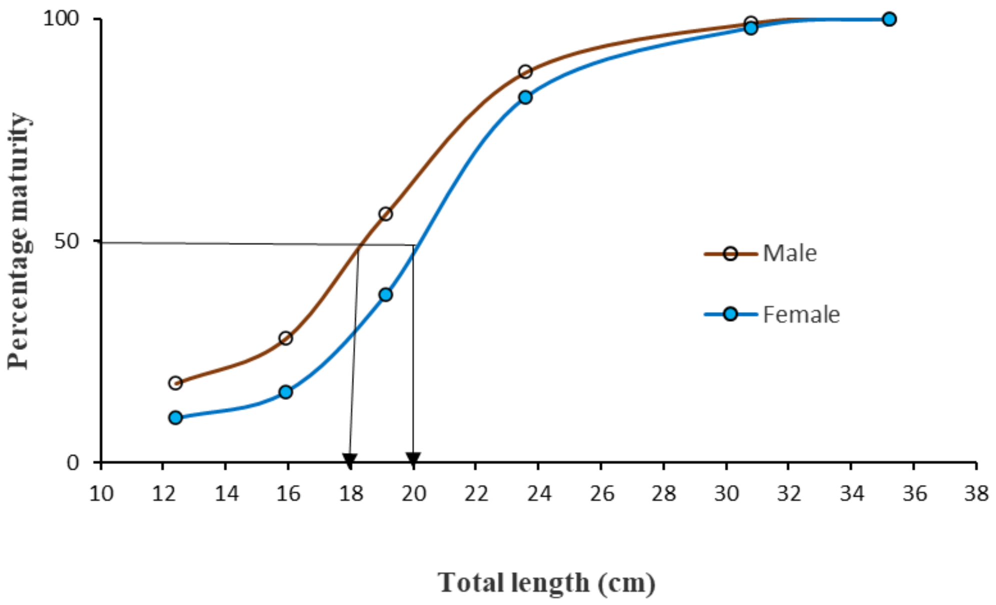

Figure 33. Ogives for determining length at 50% maturity of females and males *L. victorianus* in River Kuja – Migori. The ogive is fitted for estimation of length at 50% maturity of females and males shown by the arrows

4.14.2 Sex ratio and length at 50% (L_{m50}) maturity of *L. altianalis* in River Kuja - Migori

The total number of female and male *L. altianalis* analyzed for sex ratio was 356 and 417 respectively giving a sex ratio of 1:1.17. This did not deviate significantly from the hypothesized ratio of 1:1 (χ^2, $p < 0.05$). Frequency distribution of sexual maturity stages of male *L. altianalis* is presented in Table 11.

Table 11. The frequency distribution of sexual maturity stages of male *L. altianalis* in River Kuja - Migori

Range (cm TL)	Mean (cm TL)	Maturity stage	Frequency	Frequency %	Cumulative %
10.7-12.2	11.8	1	27	6.733	6.733
12.2-14	13.15	2	61	15.21	21.95
14-15.4	14.73	3	48	11.97	33.92
15.5-23	18.59	4	201	50.12	84.03
23-30.5	24.95	5	60	14.96	99.00
30.5-37.8	33.35	6	4	0.99	100.0

The frequency distribution of sexual maturity stages of female *L. altianalis* in River Kuja Migori is presented in Table 12. The highest frequency of 216 fish was observed at a mean length of 22.47 ± 1.21 cmTL. These were fish in maturity stage 4 at a frequency % of 65.65 and a cumulative frequency of 93.92%. The lowest frequency was observed in maturity stage 6 at a frequency % of 1.22 and a cumulative frequency of 100%.

Table 12. Frequency distribution of sexual maturity stages of female *L. altianalis* in River Kuja - Migori

Mean (cm TL)	Maturity stage	Frequency	Frequency %	Cumulative %
12.17	1	20	6.08	6.08
14.28	2	34	10.33	16.41
16.49	3	39	11.85	28.26
22.47	4	216	65.65	93.92
33.79	5	16	4.86	98.78
39.67	6	4	1.22	100.0

An ogive showing length at 50% maturity of females and males of *L. altianalis* is shown on Figure 34. Females attained length at 50% maturity at 18 cm TL and above 28 cm TL, the fish were 100% mature. The males attained 50% sexual maturity at 16.3 cm TL and attained 100% sexual maturity at 24 cm TL.

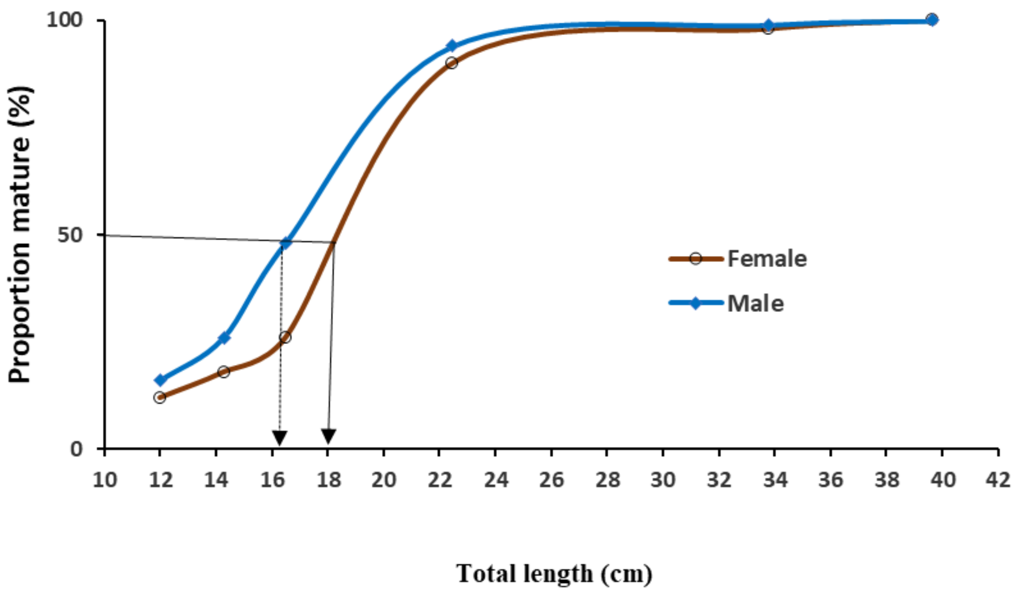

Figure 34. The ogives for length at 50% maturity of females and males of *L. altianalis* in River Kuja – Migori. The ogive is fitted for estimation of length at 50% maturity of females and males shown by the arrows

4.15.1 Breeding seasons of *L. victorianus* in River Kuja – Migori

The two fish species (*L. victorianus* and *L. altianalis*) are potamodromous meaning that they move up to the rivers within the Lake Victoria basin to spawn during the rainy season. There are two peak rain seasons in a year in the Lake Victoria basin Figure 35. The first rain season starts from March with a major peak in April and thereafter gradually declining to July. The second season begins in August with a minor peak in October.

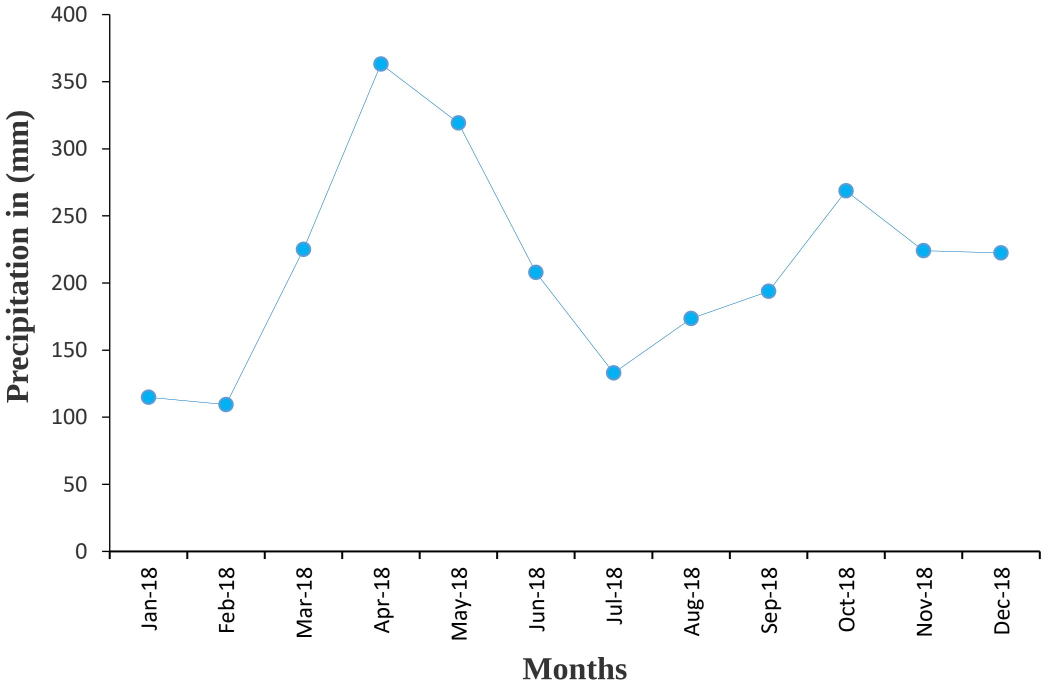

Figure 35. A graph showing rainfall on the River Kuja – Migori, south western Kenya region during the year 2018

Analysis of sexual maturity data indicated that both mature and immature fish were present in River Kuja - Migori almost throughout the year, with number of mature fish peaking during the two rainy seasons or with high numbers of mature fish during the two rainy seasons. Table 13 shows the parameters of immature and mature female *L. victorianus* caught in River Kuja - Migori.

Table 13. Characteristics of immature and mature female *L. victorianus* in River Kuja – Migori from January 2018 to June 2019

	Size range (cm TL)	Number	Mean size (cm TL)	SE	Ratio
Immature	8.1 - 17.8	56	15.3	0.24	1: 1.45
Mature	17.9 - 35.7	81	25.88	0.61	

*Ratio of immature to mature male *L. victorianus*

The ratio of immature to mature female *L. victorianus* was 1:1.45 with fish sizes ranging from 8.1-35.7 cm TL with a mean (± SE) of 15.3 ± 0.24 cm TL). This shows that the number of immature females was more than that of mature ones. The smallest size of a mature female *L. victorianus* was 17.9 cm TL. The size of mature females ranged from 17.9 cm TL to 35.7 cm TL with a mean (± SE) of 15.3 ± 0.24 cm TL. Therefore, the size at recruitment into the fishery should be above the smallest mature fish which should be the mean size of a fish of sexual maturity stage 4.

The characteristics of immature and mature male *L. victorianus* are presented in Table 14. The fish size range analyzed for both immature and mature male *L. victorianus* was ranging from 9.5 cm TL to 32.0 cm TL. The ratio of immature to mature fish was 1:1.10 showing that the number of mature males was slightly higher than that of immature ones. The smallest mature male was 12.0 cm TL which was lower than that of the smallest mature female. This implies that males mature at a relatively smaller size compared to females. Therefore, the size at recruitment into the population should be above this length so that the mean size of stage 4 mature fish should be taken as the recruitment length of 22.15 cm TL.

Table 14. Characteristics of immature and mature male *L. victorianus* in River Kuja – Migori from January 2018 to June 2019

	Size range (cm TL)	Number	Mean size (cm TL)	SE	Ratio
Immature	9.5 - 17	60	15.03	0.18	1: 1.10
Mature	17 - 32	84	23.69	0.42	

*Ratio of immature to mature male *L. victorianus*

The relative abundance of mature and immature female *L. victorianus* in River Kuja –Migori is shown on Figure 36.

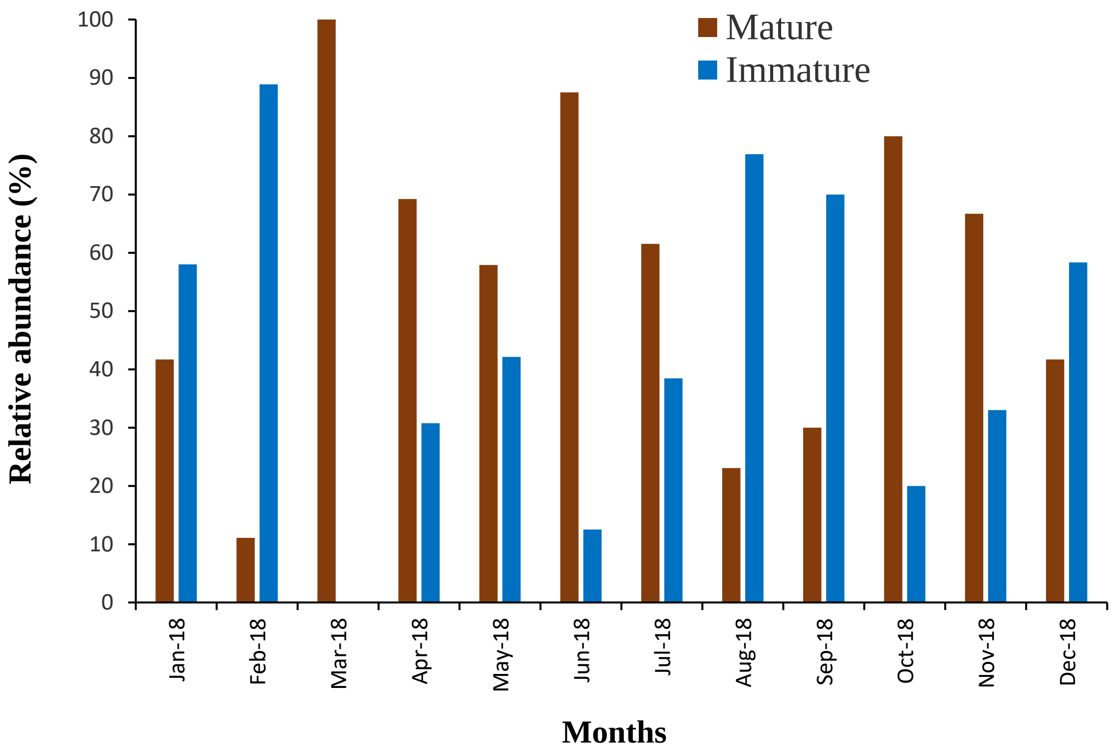

Figure 36. The relative abundance of mature and immature female *L. victorianus* in River Kuja – Migori from January to December 2018

There are two conspicuous breeding seasons for *L. victorianus* in River Kuja – Migori. The first one starting from March to August and the one from September to December. During these periods the population of mature females was mostly higher than that of immature ones. The two periods correspond to the longer and shorter rain seasons which occur in the Kuja - Migori basin annually (Figure 35). It can be deduced from the diagram that the population of immature female *L. victorianus* was higher than that of mature fish during the months of January, February, August, September, and December which correspond to the dry season when rainfall was at minimum (Figure 35). There were no immature female *L. victorianus* caught in the month of March. The annual relative abundance of mature and immature male *L. victorianus* in River Kuja - Migori system is presented in Figure 37.

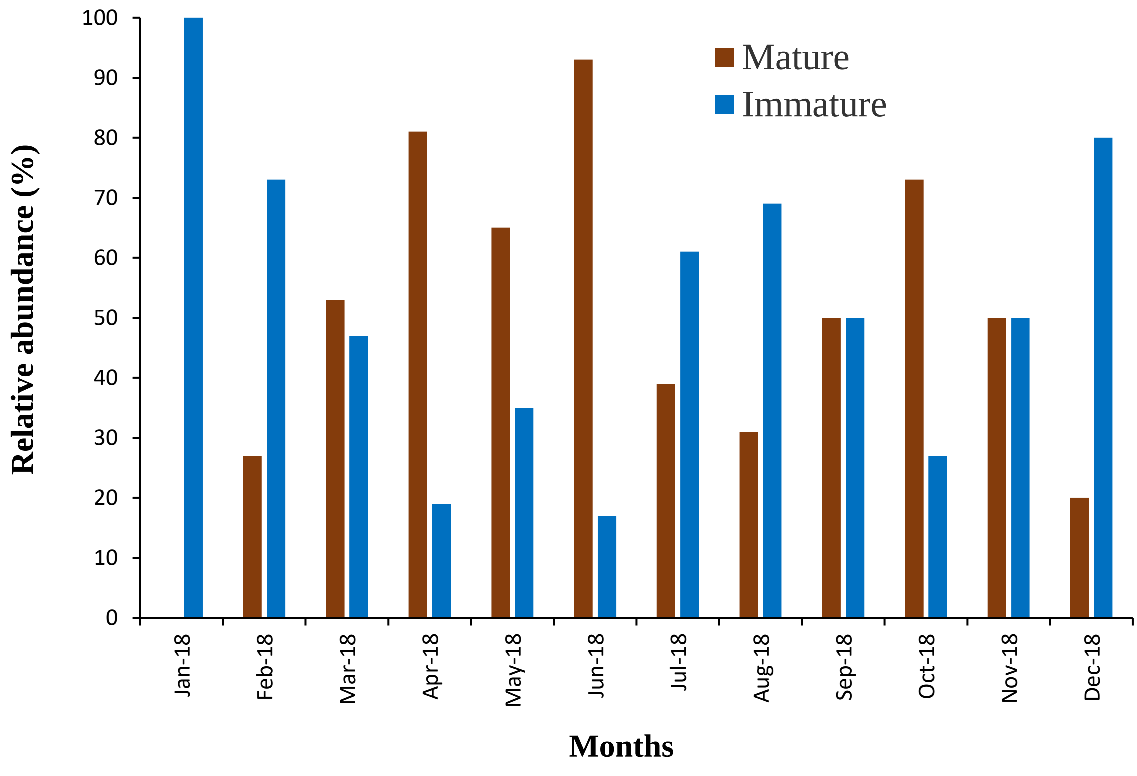

Figure 37. The relative abundance of mature and immature male *L. victorianus* in River Kuja – Migori from January to December 2018

The pattern almost mirrors that of the numbers of female fish in the river with most mature males being present in the river during the periods March - June and September – November while immature male fish were more during the months of January, February, July, August, and

December months during which rainfall is at minimum- the longer (December to February) and shorter dry seasons (July – September). There were no mature male *L. victorianus* caught during January 2018, the month at the peak dry season.

The combined relative abundance of both immature and mature *L. victorianus* in River Kuja – Migori is presented in Figure 38.

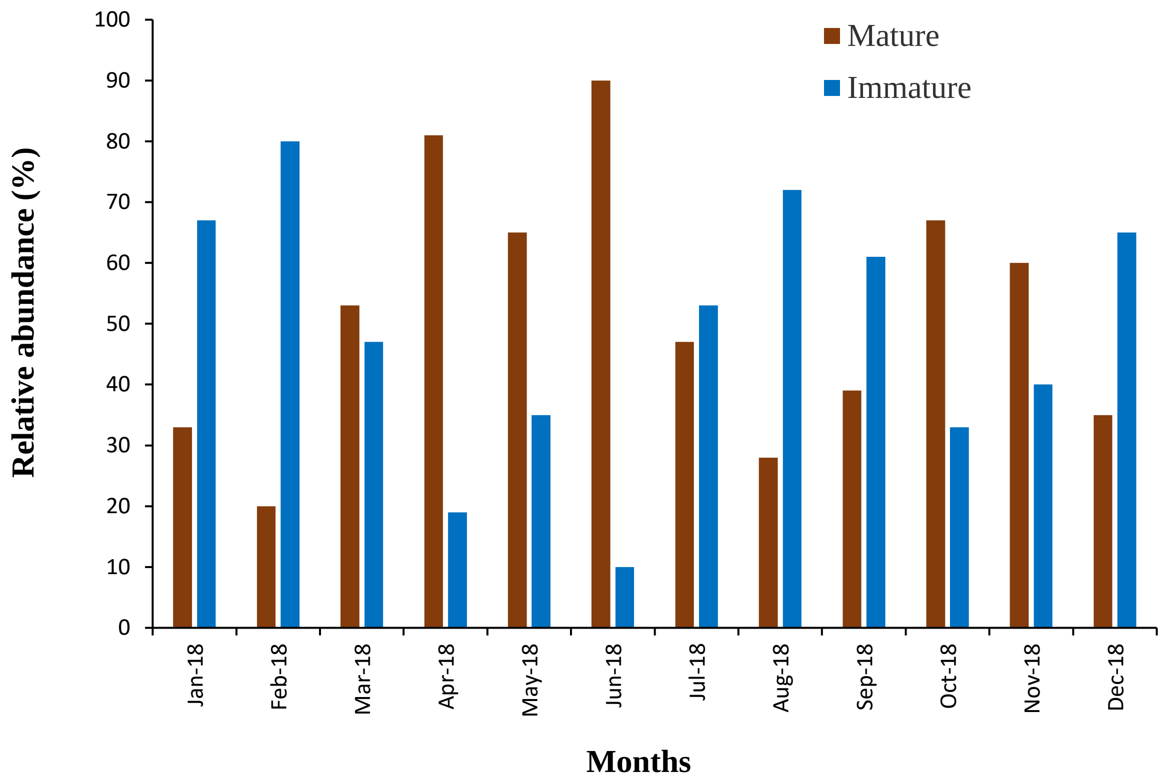

Figure 38. The relative abundance of mature and immature male and female *L. victorianus* in River Kuja – Migori from January to December 2018

The pattern resembles that of the male *L. victorianus* shown in Figure 51. It shows high populations of mature fish during the month of March to June and September to November. These periods correspond to the two annual rainy seasons (March -August and September - November).

4.15.2 Breeding seasons of *L. altianalis* in River Kuja – Migori

The annual spawning pattern of *L. altianalis* depicted the same trend as that of *L. victorianus*. In both species the numbers of mature fish in the river peaked during the two annual rainy seasons. Compared to the number of *L. victorianus* (281) the numbers of mature and immature *L. altianalis* (757) caught was by far higher than that of the former (1:1.10) at a ratio of 1: 2.6 out numbering *L. victorianus* by a factor of approximately 3. Sexual maturity characteristics of immature and mature female *L. altianalis* in River Kuja - Migori are presented in Table 15.

Table 15. Characteristics of immature and mature female *L. altianalis* in River Kuja - Migori from January 2018 to June 2019

Maturity state	Size range	Number	Mean size	SE	Ratio
Immature	11.40 -17.10	93	14.76	0.18	1: 2.62*
Mature	17.1 - 41.5	236	23.53	0.33	

*Ratio of immature to mature female *L. altianalis*

The size of the smallest mature female *L. altianalis* was 17.1 cm TL. Therefore, the length at recruitment for this species should be above the size of the smallest mature fish which should be the mean size of a stage 4 mature fish estimated at 22.5 cm TL. The pattern of abundance of immature and mature female *L. altianalis* in River Kuja - Migori is presented in figure 39. The figure depicts a slightly different pattern from that of female *L. victorianus* whereby in the former the difference occurred in the months of June, July, and August during the longer rainy season when the number of immature female fish were more than mature fish.

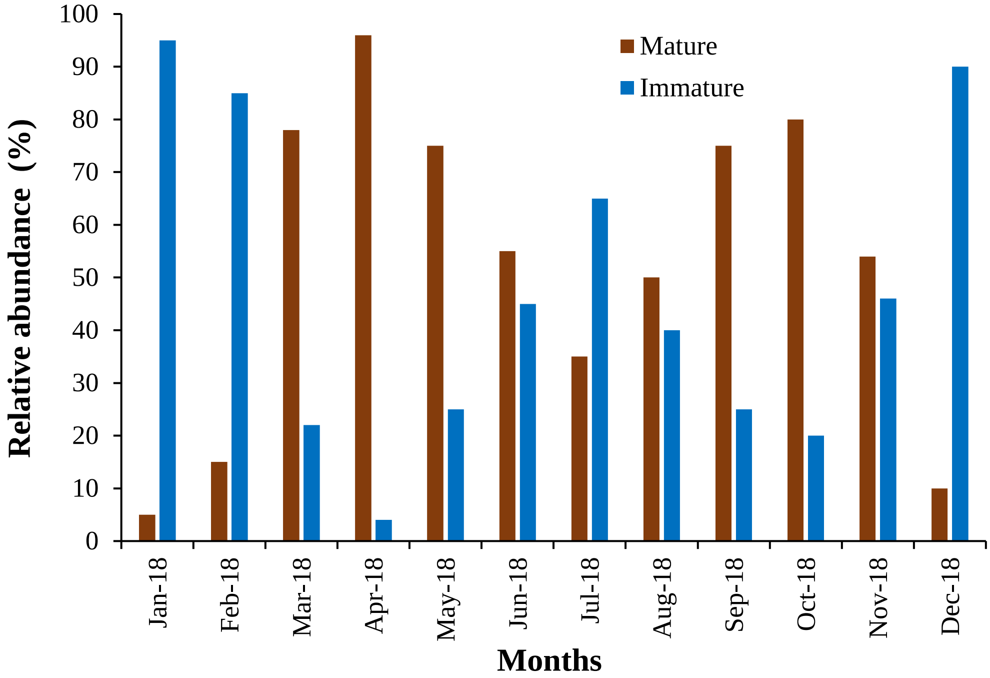

Figure 39. Annual relative abundance of immature and mature female *L. altianalis* in River Kuja - Migori from January to December 2018

The size range of the females analyzed for abundance pattern in the river was 2.6 cm TL to 41.5 cm TL with a mean (± SE) of 15.84 ± 0.21 cm TL. Immature females were more abundant than males during the dry season and as indicated above during the wet months of June, July, and August. Two peak breeding seasons can be discerned from the pattern, that is February to August and September to November indicating that the former is over a longer extended (major) period while the latter was more protracted (minor breeding season). The number of immature females was at their minimum during the month of April at the onset of the rainy season while they were at their maximum during the month of December during the dry season. The number of male *L. altianalis* analyzed for seasonal spawning pattern was 401 consisting of 136 immature and 265 mature. The sexual maturity characteristics of male *L. altianalis* are presented in Table 16.

Table 16. Sexual maturity characteristics of immature and mature male *L. altianalis* in River Kuja - Migori from January 2018 to June 2019

	Size range	Number	Mean size	SE	Ratio
Immature	10.75 - 15.4	136	13.36	0.11	1: 0.51*
Mature	15.5 - 37.8	265	20.27	0.23	

*The ratio of immature to mature males of *L. altianalis*

The smallest immature male was 15.4 cm TL which is smaller than the largest immature female of 17.8 cm TL. The smallest mature male was 15.5 cm TL meaning that the length at recruitment of this species into the fishery should be greater than these lengths. This should be taken as the mean length of a stage 4 mature fish which is estimated at 22.47 cm TL. The annual pattern of abundance of male *L. altianalis* in River Kuja - Migori is presented in Figure 40.

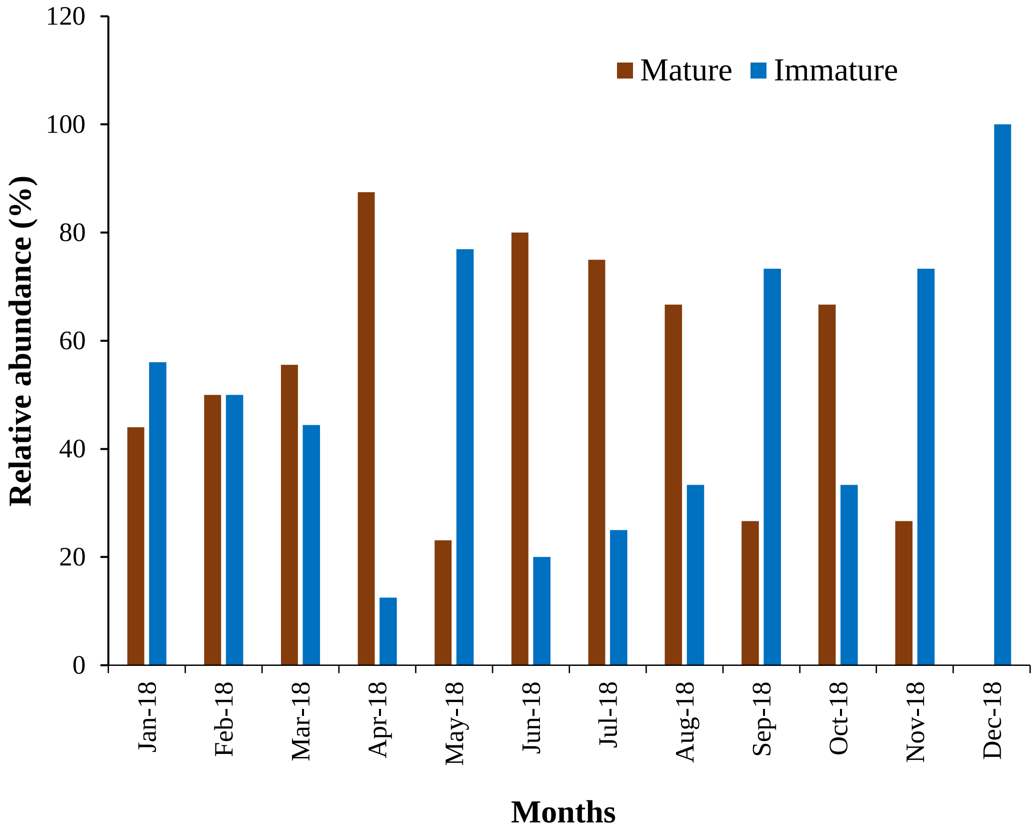

Figure 40. The relative abundance in male *L. altianalis* in River Kuja – Migori from January to December 2018

As in *L. victorianus* the proportion of immature *L. altianalis* was highest during the dry season months (January- May, August, November, and December). The figure depicts two spawning seasons, corresponding to the two annual rainy seasons with a major one extending from March to August and September and a minor one extending from September to November. The time during which mature males dominated in numbers compared to immature fish. The combined abundance of mature and immature male and female *L. altianalis* is presented in Figure 41. The pattern was similar to that of the combined male and female *L. victorianus*. Both fish species show an earlier extended peak spawning season starting in March to August followed by a minor one commencing in September to November. In both species males mature at a smaller size than females, however, the male to female ratio was higher in *L. altianalis* than in *L. victorianus*.

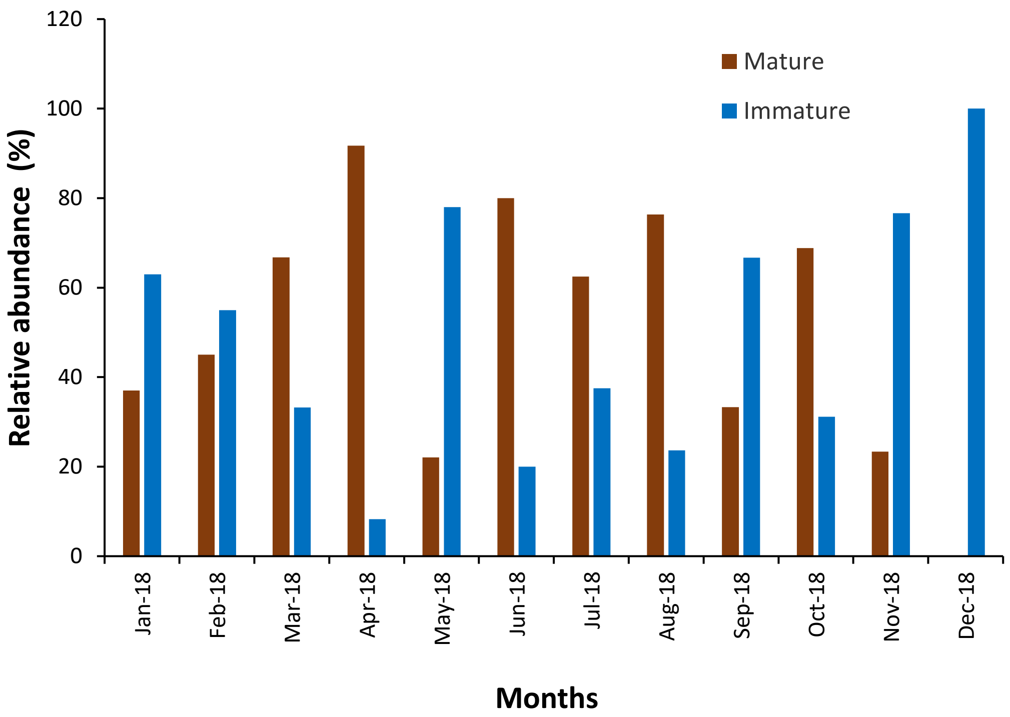

Figure 41. The combined relative abundance of mature and immature male and female *L. altianalis* in River Kuja – Migori from January to December 2018

4.16 Population dynamics of *L. victorianus* and *L. altianalis* in River Kuja - Migori

This subsection presents results on population dynamic aspects of both species except the results on reproduction. The aspects dealt with here include growth constant (K), asymptotic length (L_∞), maximum age, maximum length, growth performance indices, total mortality, fishing and natural mortality, recruitment patterns, virtual population analysis, yield and biomass per recruit

4.16.1 Length frequency distribution of *L. victorianus* in River Kuja - Migori

The length frequency distribution of *L. victorianus,* were developed by merging data (total length in cm) which was obtained for a period of 18 months from January 2018 to June 2019 to produce an annual frequency representing a calendar year of 12 months. The size distribution of fish ranged from 7.5 - 35.7 cm TL with a mean (± SE) of 23 ± 1.88 cm TL. The frequency increased to a peak at length class of 21- 23.9 cm TL and reduced gradually to length class 33-35.9 cm TL (Figure 42).

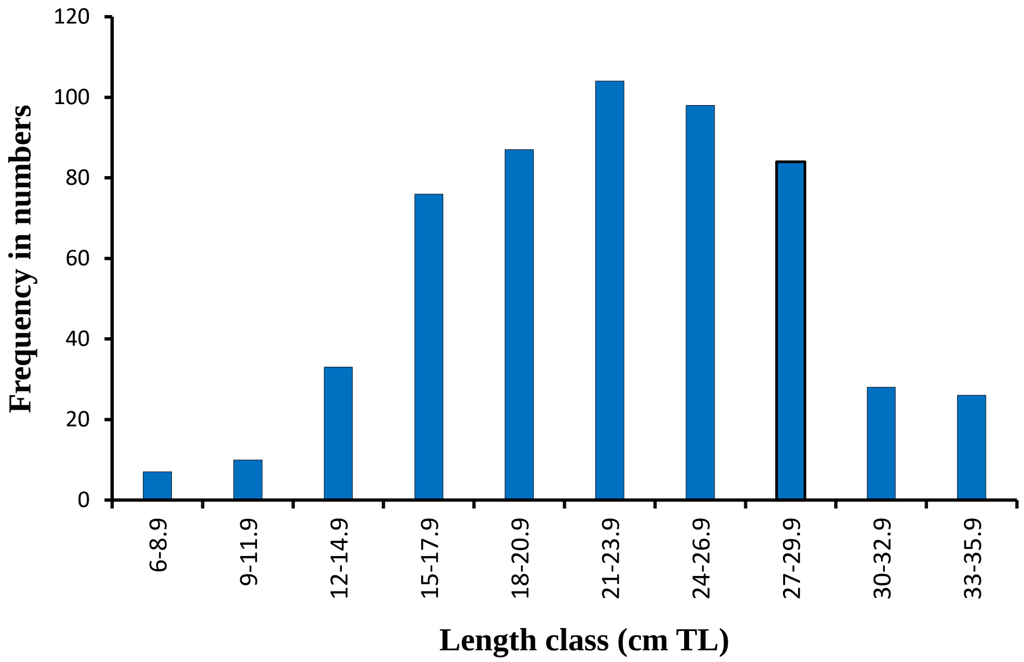

Figure 42. Length frequency distribution of *L. victorianus* in River Kuja - Migori used to estimate population parameters

There was a unimodal distribution of length between 15 cm TL and 27 cm TL. The modal length class was that of 21.0 to 24 cm TL showing that the majority of *L. victorianus* caught were adults.

4.16.2 Length frequency distribution of *L. altianalis* in River Kuja - Migori

The length frequency distributions were developed by merging data (total length in cm) which was obtained for a period of 18 months from January 2018 to June 2019 to produce an annual frequency representing a calendar year of 12 months. The length frequency of *L. altianalis* increased gradually to a peak in class size of 18 - 23.9 cm TL and then decreasing to length class size of 39 - 41.9 cm TL showing a unimodal distribution between 12 cm TL and 21 cm TL with the modal length at 18 cm TL (Figure 43).

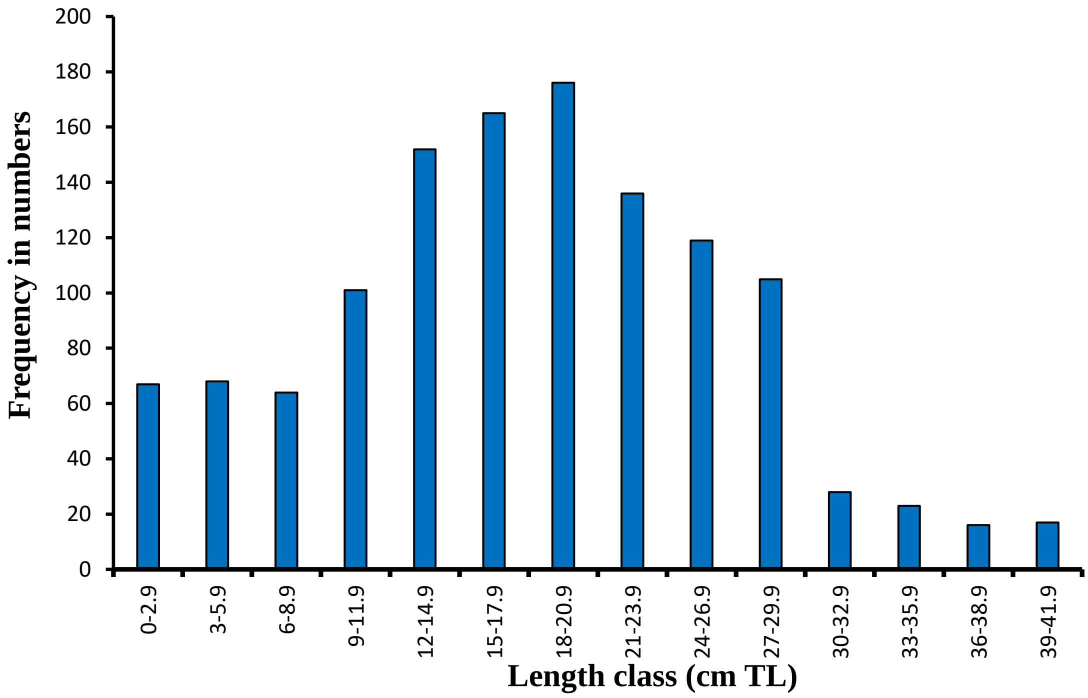

Figure 43. The length frequency distribution of *L. altianalis* in River Kuja - Migori used for estimation of growth parameters

4.17.1 Estimation of growth parameters of *L. victorianus* in River Kuja - Migori

The size range of *L. victorianus* used was 7 .5 to 35.7 TL cm, having a mean length of (±SE) 23 ± 1.88 cm TL (n = 481). The results obtained from the Powell-Wetherall method showed that the species has an asymptotic length (L_∞) of 36.89 cm TL. The parameter Z/K that is the ratio of instantaneous rate of mortality (Z) to the instantaneous growth rate (K) was estimated to be 2.1. This were obtained using a cut - off length of 5.3 cm TL (Figure 44).

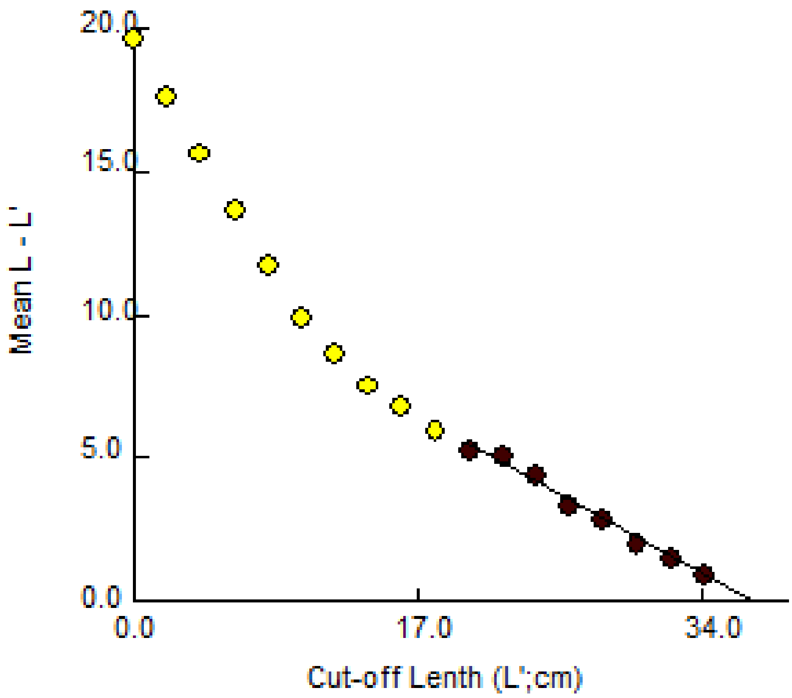

Figure 44. Estimation of growth parameters of *L. victorianus* from River-Kuja Migori using Powell-Wetherall method

To disaggregate Z and K from Z/K, the rate of mortality was estimated using the mean lengths method. A value of Z of 0.65 yr^{-1} and K value of 0.31 yr^{-1} were obtained. Natural mortality estimated using the Rikhter and Efanov's method was found to be 0.15 yr^{-1} with a fishing mortality of 0.498 yr^{-1}.

4.17.1 Estimation of growth parameter of *L. victorianus* using the ELEFAN 1 method

Estimation of growth parameter of *L. victorianus* using the ELEFAN 1 method is presented in Figure 45. Using the asymptotic length obtained in Powell - Wetheral method as seed input, the asymptotic length was estimated as 36.89 cm TL while the instantaneous growth constant k was 1.0 yr^{-1}.

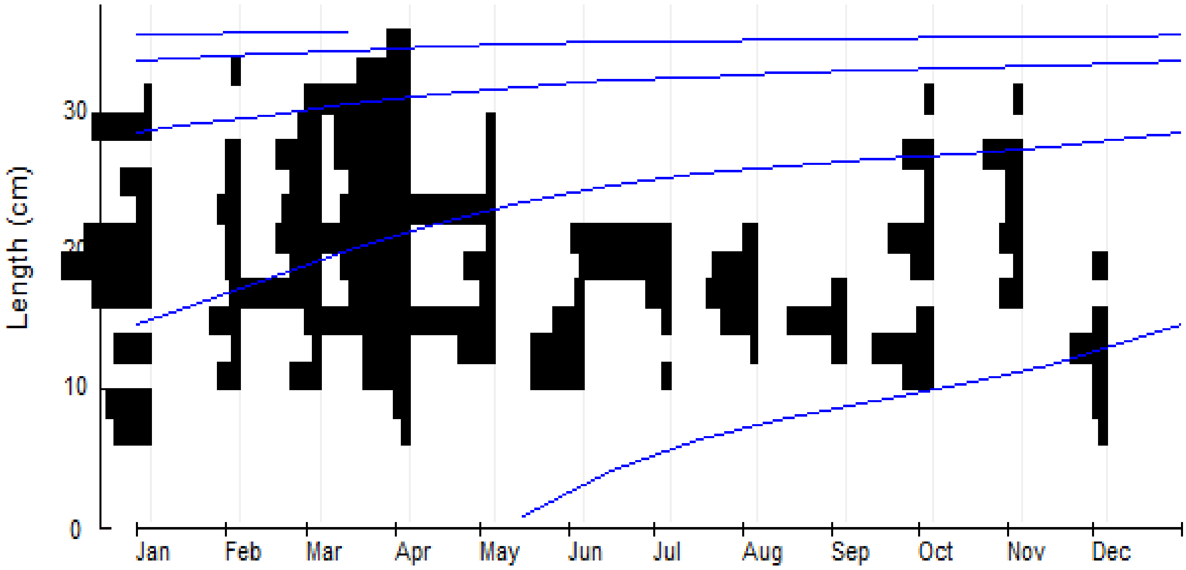

Figure 45. Estimation of growth parameters of *L. victorianus* using ELEFAN 1 method. Von Bertalanffy growth curves superimposed on the restructured length-frequency histograms

4.17.2 Estimation of growth parameters of *L. altianalis* in River Kuja - Migori

Figure 46 shows the estimation of growth parameters of *L. altianalis* using Powell- Wetherall method. A total of 1217 *L. altianalis* with size ranging from 2.6 to 41.5 cm TL with a mean (± SE) of 28.5 ± 2.7 cm TL were analyzed. The modal class length was that of 18 to 21 cm TL, showing that the majority of *L. altianalis* in the river were adults. The size range of the modal class is greater than the size at first maturity of approximately 15 cm. The analysis of growth parameters of *L. altianalis* was done using, the Powell -Wetherall and the ELEFAN 1 methods both in the FiSAT software.

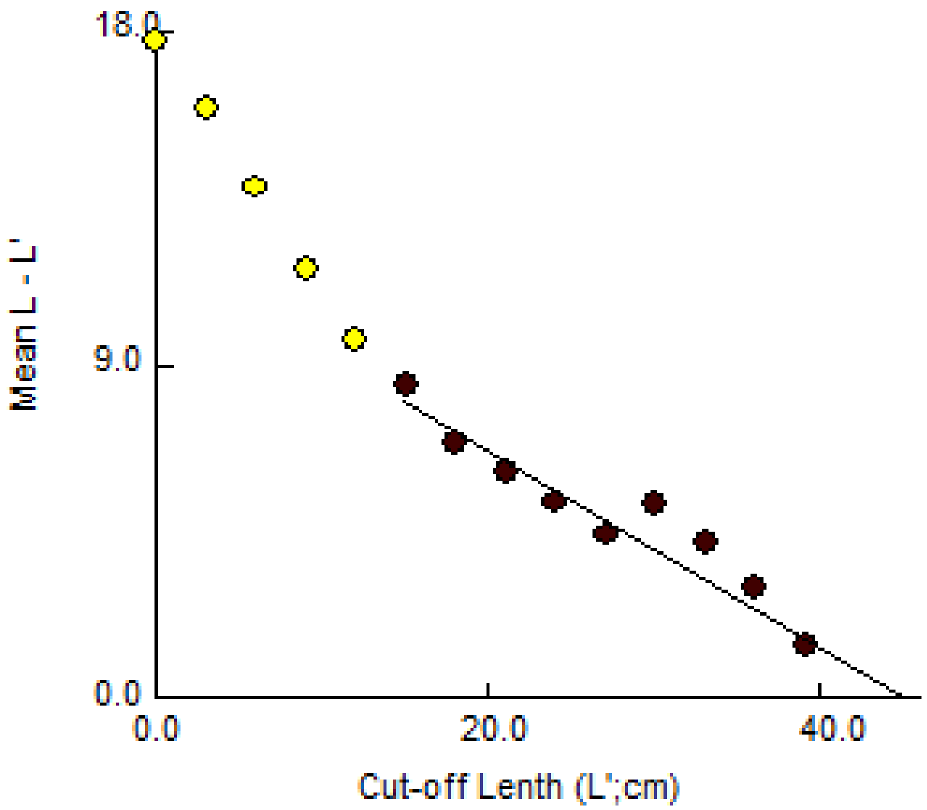

Figure 46. Estimation of growth parameters of *L. altianalis* from River Kuja – Migori using Powell-Wetherall method

The estimated asymptotic length (L_∞) was 44.94 while the ratio of the instantaneous total mortality to the growth constant K was 1.47 yr $^{-1}$. The regression model from which the parameter Z/K was estimated was given by the formula L_{mean} - L' = 12.0 (-0.33) * L; r = -0.98. The cut off length used was 5.3 cm TL while the mean length of the fish analyzed was 30 cm TL. To disaggregate Z and K from Z/K, the total mortality rate was estimated using the mean lengths method. Values of Z of 0.42 yr $^{-1}$ and K of 0.16 yr $^{-1}$ were obtained. Natural mortality estimated using the Rikhter and Efanov's method was 0.15 yr $^{-1}$. A fishing mortality of 0.50 yr $^{-1}$ was obtained by subtracting M from Z to give a value of M = 0.28 yr $^{-1}$.

4.18.1 Growth performance indices of *L. victorianus* in River Kuja – Migori

The growth performance index (Ø') of *L. victorianus* based on asymptotic length was 2.86 while the growth performance index based on asymptotic weight (Ø) was 1.54. Thus, the length-based index exceeded the weight based by a factor of 1.86.

4.18.2 Estimation of growth parameters of *L. altianalis* using ELEFAN 1 method

The ELEFAN 1 analysis output of growth parameters of *L. altianalis* are presented in Figure 47.

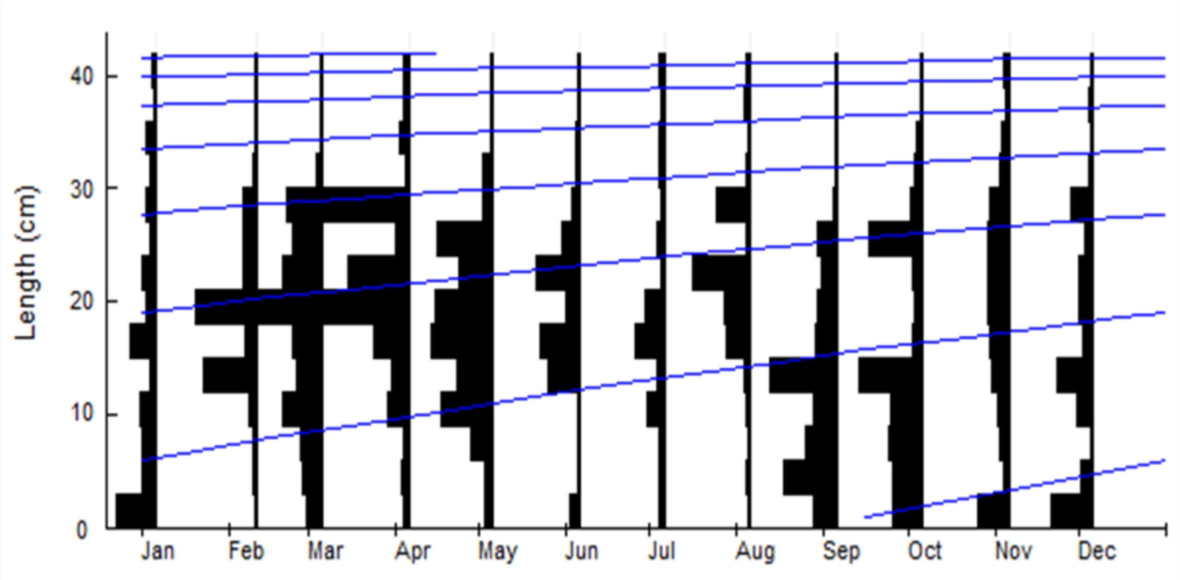

Figure 47. Estimation of the growth parameters of *L. altianalis* from River Kuja -Migori using ELEFAN 1 method

The estimated asymptotic length (L_∞) was 44.94 cm TL while the instantaneous rate of growth (K) was 0.15 yr^{-1}. These were obtained using an oscillatory function C of 0.2 and a winter point parameter of 0.5.

4.18.3 Growth performance indices of *L. altianalis* in River Kuja - Migori

The growth performance index (Ø') of *L. altianalis* based on asymptotic length was 3.03 while that based on asymptotic weight (Ø) was 1.74. Thus, the length-based index exceeded the weight based by a factor of 1.73. The results shows that the growth performance of *L. altianalis* was better compared to that of *L. victorianus* since the indices of the former were higher than those of the latter.

4.19.1 Estimation of total mortality rate of *L. victorianus* using length converted catch curve

Estimation of the instantaneous total mortality rate of *L. victorianus* is presented in Figure 48. The estimated Z value was 1.55 yr^{-1} with a confidence interval CI of Z = 1.53 to 1.57. The longevity (t_{mass}) of the species was estimated at 6 years. Using Pauly's formula at a mean temperature of 18° C, M = 0.91, the fishing mortality calculated from the total mortality Z was F = 0.65. Since fishing mortality is calculated from the parameters obtained from length frequency analysis, the suggested fishing mortality (F) is considered the most appropriate. The exploitation rate (E) for *L. victorianus* in River Kuja-Migori was estimated as F/Z = 0.42 yr^{-1}.

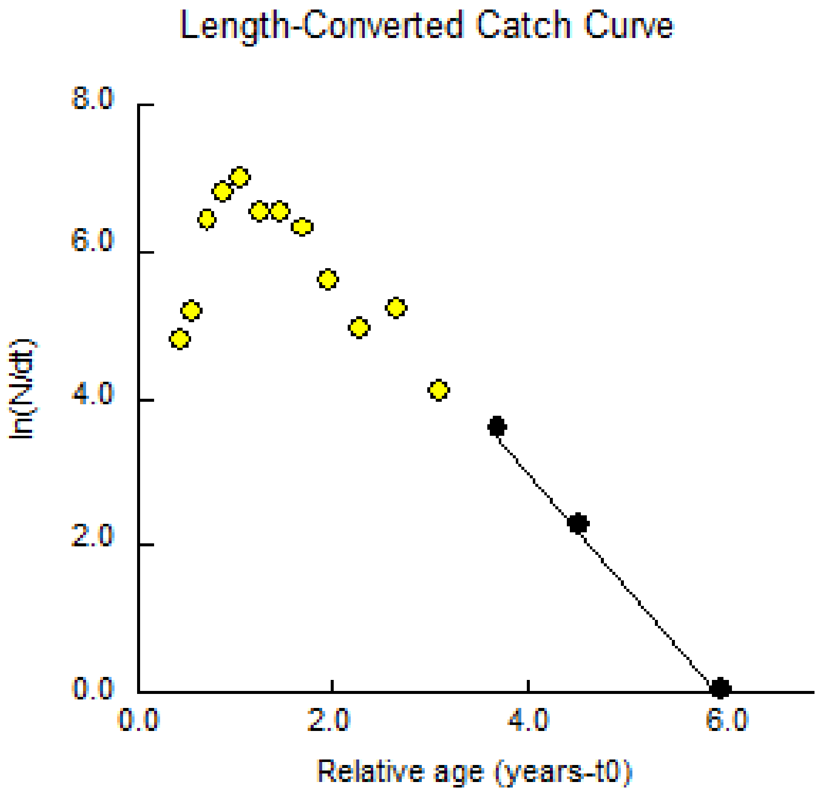

Figure 48. Estimation of total mortality rate of *L. victorianus* from River -Kuja Migori using length catch curve analysis

4.19.2 Estimation of total mortality rate of *L. altianalis* using length converted catch curve.

The exploitation rate (E) of *L. altianalis* was estimated as F/Z = 0.84 yr^{-1}. The natural mortality calculated using Rikhter and Efanov's method was 0.37. Subtracting the natural mortality from the total instantaneous rate of mortality suggests a fishing mortality (F) of 0. 298. The catch curve for estimation of the instantaneous total mortality rate of *L. altianalis* is presented in Figure 49.

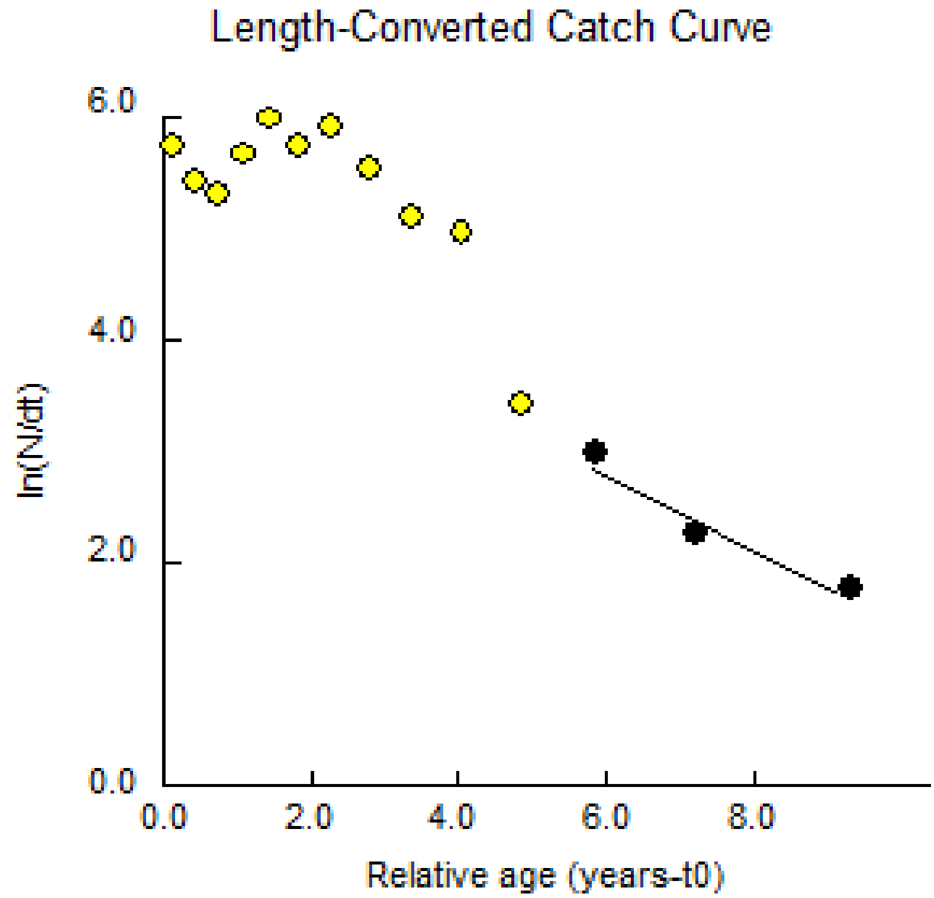

Figure 49. Estimation of total mortality rate of *L. altianalis* from River Kuja- Migori using length catch curve analysis

4.20.1 Recruitment pattern of *L. victorianus* in River Kuja – Migori

The recruitment pattern of *L. victorianus* is presented in Figure 50. The pattern is bimodal indicating that there are two recruitment seasons every year, the first recruitment is major occurring between March and August while the minor one occurs between September and November. This confirms the earlier observation which indicated that most of the sexually mature *L. victorianus* were most abundant twice in a year with a major peak between March and August and a minor peak between September and November.

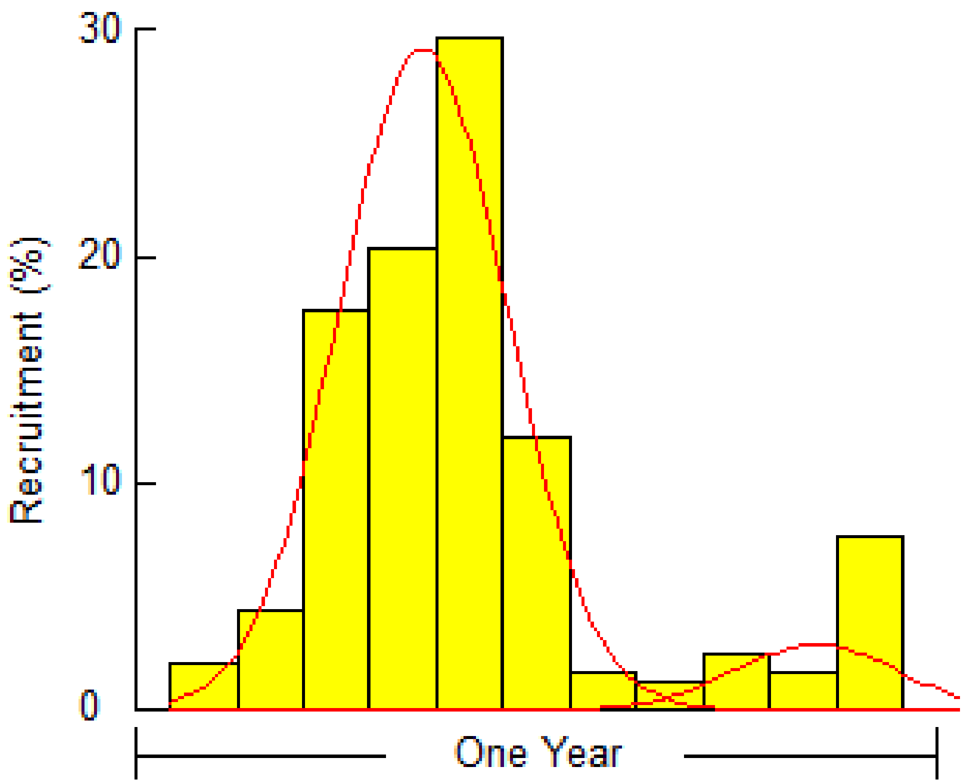

Figure 50. The recruitment pattern of *L. victorianus* in River Kuja - Migori of the Lake Victoria basin

4.20.2 Recruitment pattern of *L. altianalis* in River Kuja – Migori

The recruitment pattern of *L. altianalis* is presented in Figure 51. The pattern has a bimodal pattern indicating two annual recruitment periods. The first recruitment is the longer one taking place between March and July while the second takes place between September and November.

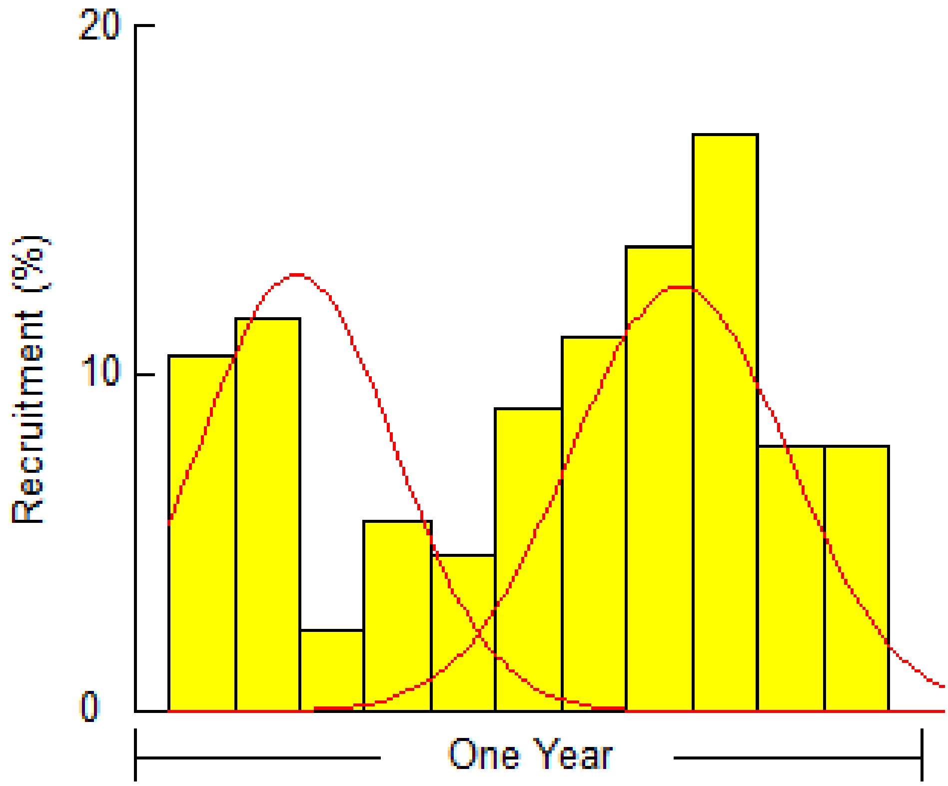

Figure 51. The recruitment pattern of *L. altianalis* in River Kuja - Migori

4.21 Virtual population analysis for *L. victorianus* and *L. altianalis* in River Kuja - Migori

Virtual population analysis is a technique used in fisheries studies to estimate historical fish numbers at age using yearly mortality. Fish mortality is broken down into fishing mortality and natural mortality which is usually caused by predation, diseases, age, and natural adverse environmental events. The calculated fish numbers are not directly observed but back calculated to a projected population size that should have existed in the past to provide evidence of the observed fish catches and an assumed natural mortality. The parameter needed for the reconstruction of historical numbers, catches and mortality are the final mean catches in numbers of fishing in the final year, and the terminal mortality F_t.

4.21.1 Virtual population analysis of *L. victorianus* in River Kuja - Migori

The virtual population analysis output for *L. victorianus* is depicted in Figure 52. The results indicate the estimated numbers of fish surviving per length class (survivors), estimated number of fish lost to natural causes (natural mortality), the number of fish caught by by a particular gear (catches) and estimated mortality due to fishing per year (fishing mortality).

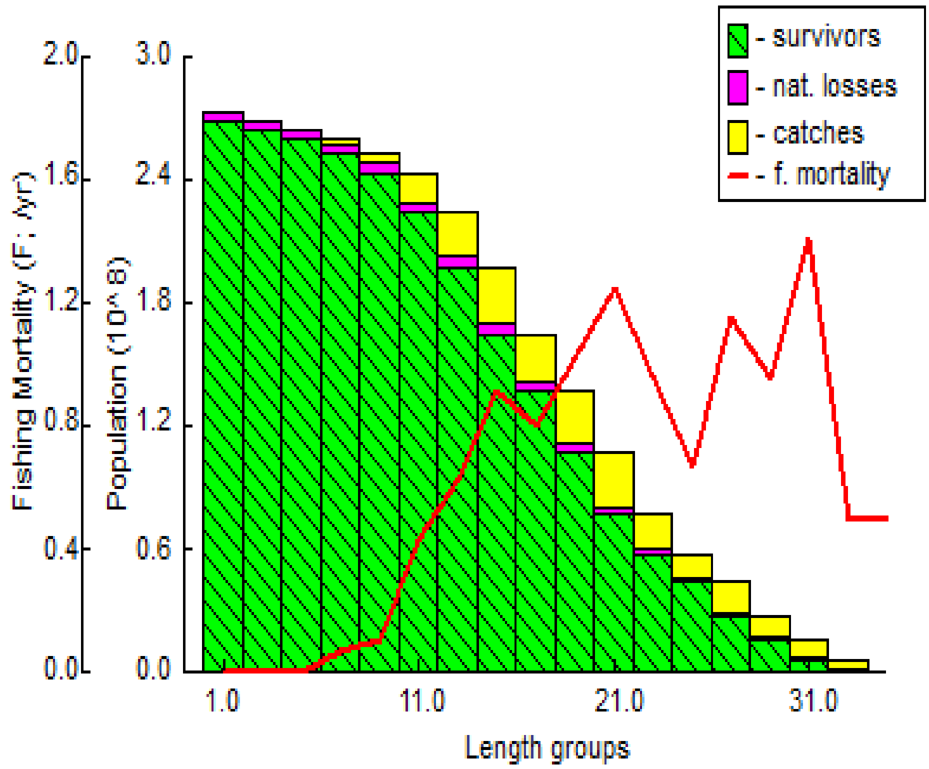

Figure 52. Length based virtual population analysis of *L. victorianus* in River Kuja - Migori

Fish sizes below 11 cm TL did not experience any fishing mortality, while those above this length experienced an increasing fishing mortality up to 21 cm TL and started to decline to 31 cm TL due to decrease in the number of large fish specimen. Natural mortality was high in small fish and declined as fish size increased. The model predicted fish catches ranging from 4.4 x 10^6 tonnes of fish in the size class of 11 cm TL and 2.9 x 10^7 tonnes of fish in the size class of 31 cm TL. The model also predicted natural mortality of 0.069 per year in fish of class size 31cm TL. The model further predicted steady - state biomass ranging from 2.26 tonnes in fish of class size 7 cm TL to 51 tonnes in fish of class size 27 cm TL.

4.21.2 Virtual population analysis of *L. altianalis* in River Kuja - Migori

Figure 53 shows the virtual population analysis of *L. altianalis* in River Kuja - Migori based on length.

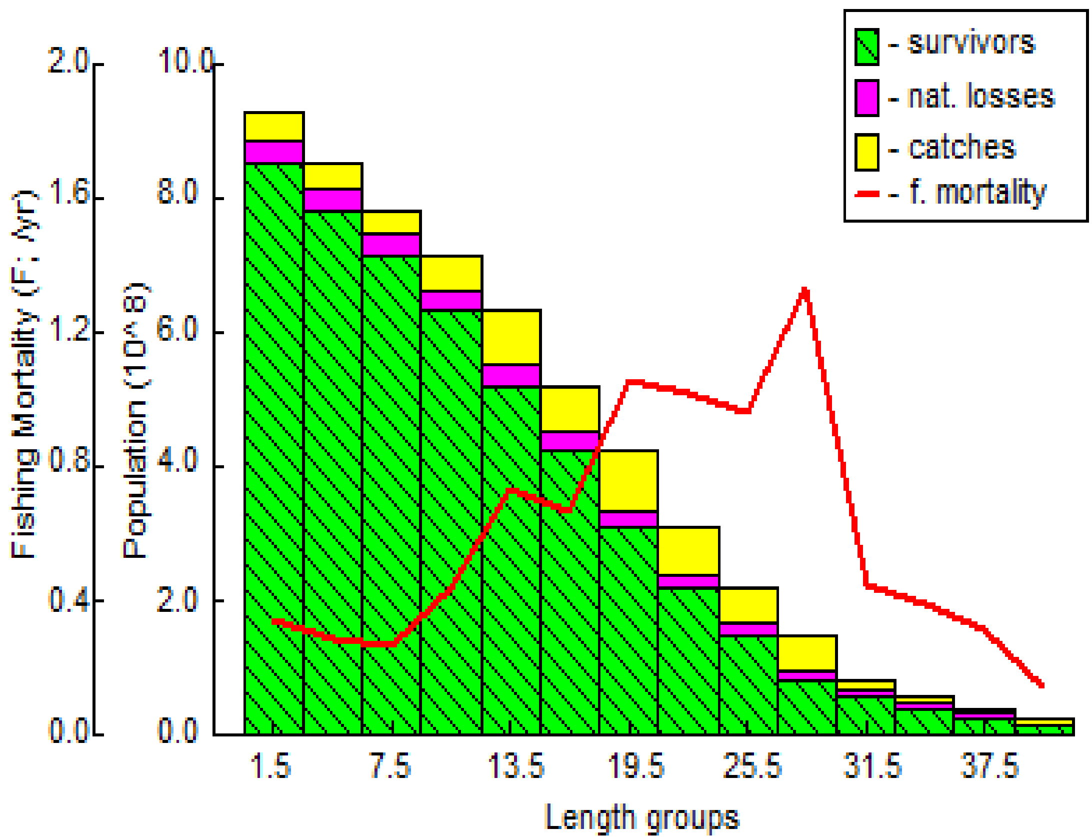

Figure 53. Length based virtual population analysis of *L. altianalis* in River Kuja - Migori

Fish of all sizes experienced fishing mortality. Fishing mortality increased to 31.5 cm TL and then declined drastically due to decrease in number of large fish specimens caught. Natural mortality was high in small fish and declined as fish size increased. The model predicted fish catches ranging from 4.5 x 10^6 of fish in the size class of 33 cm TL and 4.9 x 10^7 of fish in the size class of 13.5 cm TL. Further the model predicted natural mortality of 0.069 per year in fish of class size ranging from 5 to 14 cm TL and fish in class size 31.5 cm TL. Finally, the model predicted steady - state biomass ranging from 0.26 tonnes in fish of class size 1.5 cm TL to 51 tonnes in fish of class size 40.5 cm TL.

4.22 Food and feeding habits of *L. victorianus* and *L. altianalis* in River Kuja - Migori

Observations of the diet of both species indicated that they are omnivores mainly feeding on invertebrates during their juvenile life and invertebrates, detritus, and plant material, during their adult life. The results further showed that there could be competition between the two fish species on similar food resources, both feeding exactly on the same type of food items. Algae and diptera were the food items with the lowest percentage occurrence and composition in fish guts.

4.22.1 Food and feeding habits of *L. victorianus* in River Kuja –Migori

A total of 254 *L. victorianus* of size range 2.6 – 35.7 cm TL with a mean (± SE) length 23.7 ± 1.7 cm TL were analyzed for food habits. The percentage composition of major food items consumed in the dry and wet season is presented in Figure 54.

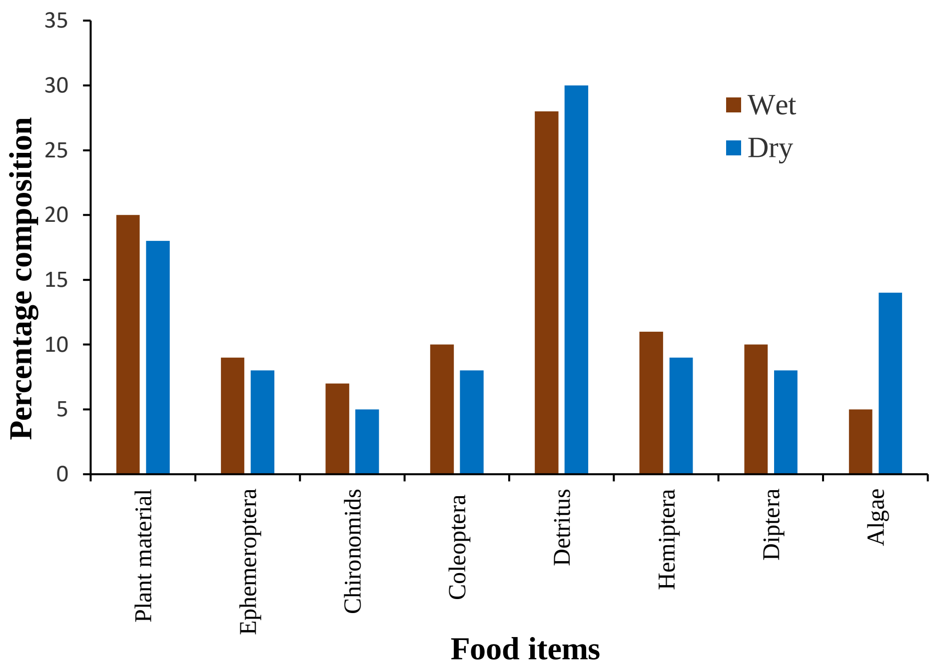

Figure 54. Percentage composition of food items in the guts of *L. victorianus* in River Kuja – Migori during the dry and wet seasons

A total of 8 food items consisting of ephemeroptera, diptera, coleoptera algae, hemipteran, detritus, chironomids, plant material were identified in fish guts. Of these, detritus and plant material consisted of the most dominant food items contributing 50% that is 30% and 20% respectively of the total food items in the wet season. During the dry season, the food items plant material, detritus, algae, chironomids were consumed in much lower proportions than in the wet season. The consumption of ephemeroptera, diptera and coleoptera showed little change in the amounts consumed between the dry and wet season. The relationship between food items consumed by various length classes of *L. victorianus* from River Kuja - Migori is shown of Figure 55.

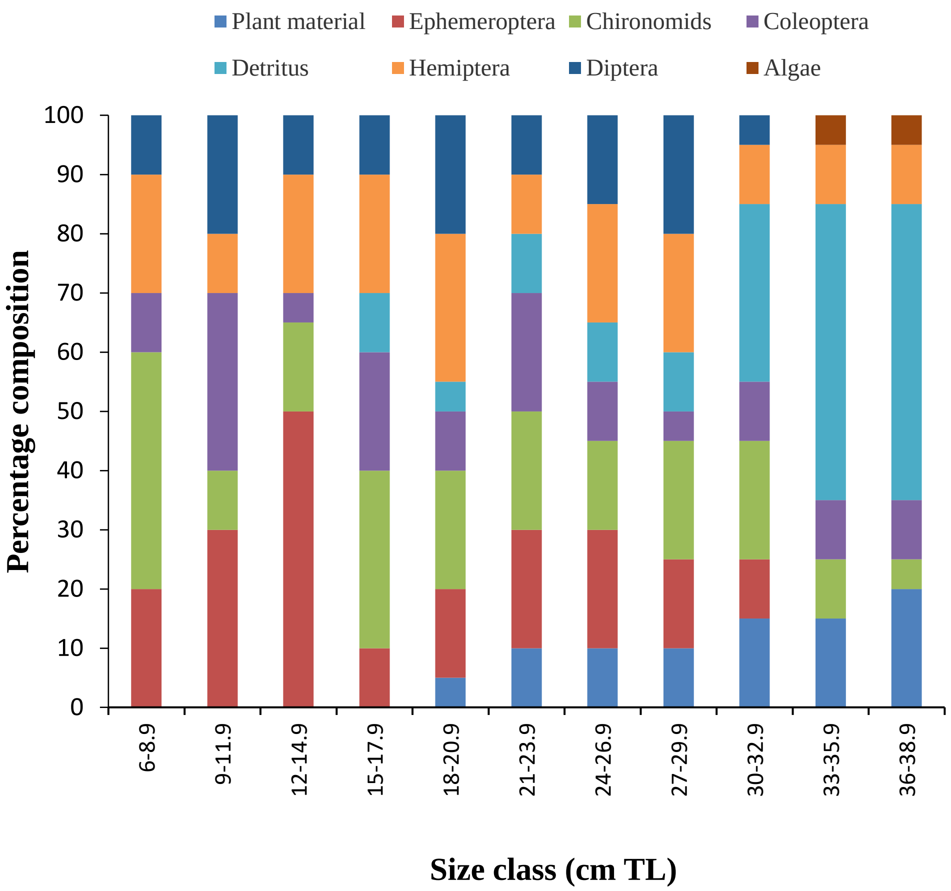

Figure 55. The various food items consumed by different length classes of *L. victorianus* in River Kuja – Migori

The results depict a shift of preference of food items as the fish grows from juvenile stages to adults. In juvenile fish the major food items consumed were mainly insects of the type ephemeroptera, chironomids, coleoptera and hemiptera contributing 86% of all the food items consumed. In adult fish above 18 cm TL the major food items consumed were plant material, ephemeroptera, chironomids, coleoptera, detritus and hemiptera. The most important food items consumed when all sizes of *L. victorianus* are considered are chironomids, coleoptera, and hemiptera which contribute 79%. The results showed that insects play a major role in supporting *L. victorianus* in River Kuja - Migori.

4.22.2 Food and feeding habits of *L. altianalis* in River Kuja – Migori

A total of 186 *L. altianalis* of size range 2.6 – 41.5 cm TL with a mean (± SE) of 28 ± 2.7 cm TL were analyzed for food and feeding habits. Figure 56 depicts the changes in food composition between the dry and wet seasons respectively. Just as in *L. victorianus* the total number of major food items were eight namely, ephemeroptera, diptera, coleoptera algae, hemiptera, detritus, chironomids, plant material. There were significant changes in the quantity and type of food items consumed between the dry season and wet season, in the dry season the major food items consumed were plant material, detritus and hemiptera contributing 78% of the items. During the wet season the most important food items were detritus and plant material that consisted of 48% of the total food items. It was similarly observed that food items consumed in dry season were in much lower proportions than those of the wet season, implying that food resources were scarce during the dry season.

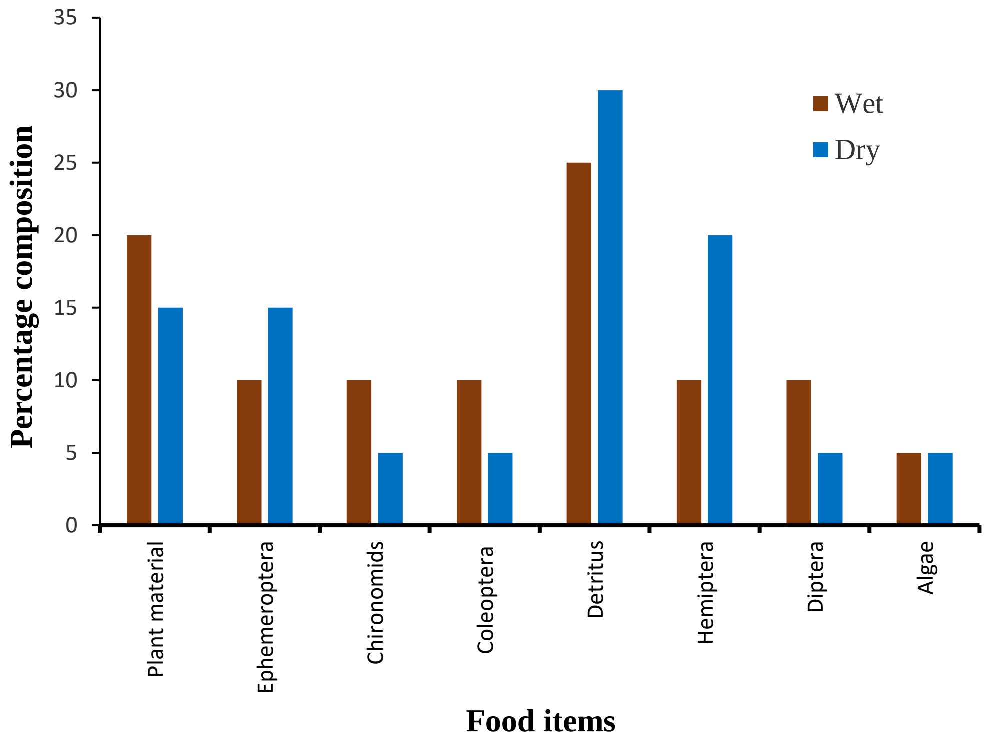

Figure 56. Changes in food composition in *L. altianalis* in River Kuja – Migori in the dry season and wet seasons

The relationship between food items consumed and size of *L. altianalis* is presented in Figure 57. Fish sizes below 15 cm TL did not consume any plant material compared to diet of *L. victorianus* above. Young fishes of *L. altianalis* therefore started consuming plant material as a food item at a smaller length than those of *L. victorianus* in the case of the former it was above 18 cm TL. Plant material became increasingly important as food item in the guts as fish size increased. The results indicate that there is a partitioning of food resources with an overlap of invertebrates between juvenile and adult fish. The most important food items consumed by *L. altianalis* were plant material and detritus contributing 56.8%. Results indicate differences in the percentage composition of various food items in both *L. victorianus* and *L. altianalis*. Also, differences were observed on the percentage occurrence of major food items in both species. In *L. victorianus* the percentage occurrence of detritus was 28.6% while that of plant material was 23.9%. The items ephemeroptera, coleoptera and hemiptera increased in prominence in the guts of fish as size increased in total length. However, plant material became increasingly more prominent as fish size increased in adult stages. Therefore, the changes in the content and type of food items consumed reflect the different requirements by *L. altianalis* at different sizes indicating that fish at different stages and sizes of their life derive energy sources from specific food items for specific physiological processes or requirements.

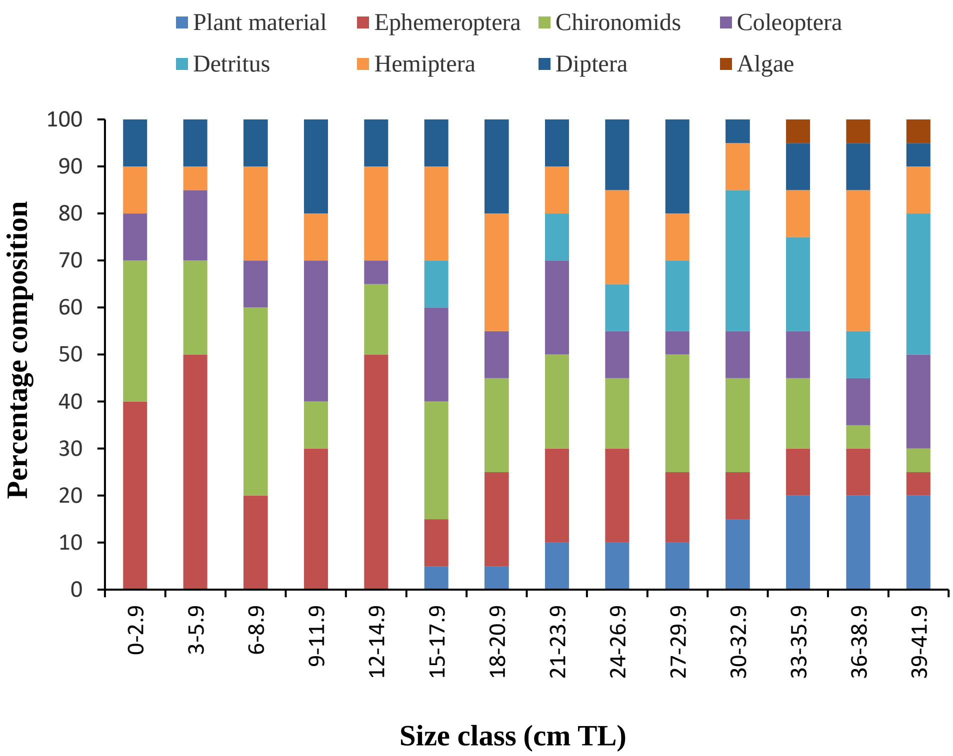

Figure 57. The various food items consumed by different length classes of *L. altianalis* in River Kuja – Migori

CHAPTER FIVE

DISCUSSION

5.1 *Labeo victorianus* and *Labeobarbus altianalis* in relation to life history strategy models

A number of life history strategies have been advanced by several authors, Northcote (1997) discusses four life history types in potamodromous fishes, classified into fluvial (fish which spawn and rear their young ones in large rivers and streams), fluvial-adfluvial (fish which spawn in tributaries and rear their young in streams, rivers, and tributaries), lacustrine-adfluvial (fish which spawn in tributaries and rear their young primarily in lakes), and allacustrine (fish which spawn in outlets of lakes and rear primarily in lakes. The two fish species studied here that is *L. victorianus* and *L. altianalis* have a potamodromous life history strategy partially in line with four potamodromic life histories of Northcote (1997). Both species display to a larger extent the life history strategies of migrating upstream to rivers and tributaries of major rivers to spawn and rear in the rivers and streams draining into Lake Victoria. This was evidenced by samples of mature fish of both species in maturity stages 4 to 6 containing ripe eggs which were caught throughout the river Kuja- Migori draining into Lake Victoria. Also, presence of sub adult specimen obtained at all sampling stations lends more support to the kind of life history strategy depicted by the two fishes. Specifically, *L. victorianus* is known to breed in backwaters and temporal pools of large rivers which form and desiccate soon after the rains stop (Rutaisire & Booth, 2005). During the heavy rains the pools provide plenty of habitat for the fish to breed. Despite this the population of *L. victorianus* is too low as the fish is listed as endangered (Bayona, 2006). The main reason could be that most of the fish are caught at the river mouth before they reach spawning grounds upstream.

The other life history strategies are the *r* - *k* continuum and triangular life history model proposed by Winemiller (2005). In the triangular model there are 3 end point strategies namely opportunistic, periodic and equilibrium while in the *r* - k continuum the *r* and *k* are extreme endpoint strategies. Going by above models it's difficult to place these two species at any endpoint pure strategy. This is because there are few species which can display the purely endpoint strategies proposed in the models. A pure *r* strategist fish species has the following characteristics: high growth rate, high number of off-spring, minimal parental care, high mortality rate, shorter life span while a purely *k* - selected strategy fish species has the following characteristics: low number of off-springs, longer life span, low mortality and have high parental investment. Data obtained in this study indicates that *L. victorianus* matures at a size of approximately 16 cm TL, it has a medium sized body and attains a maximum length of 36.89 cm TL, a low instantaneous growth constant K of the Von Bertalanffy growth function of 1.0 yr^{-1} and a moderate annual fecundity in the range of 80,000 - 210,000 eggs with an assumption that the fish spawns twice a year during the two annual rain periods. *Labeo victorianus* has a short lifespan of 6 yrs and an instantaneous mortality of 0.65 yr^{-1} and a natural mortality of 1.55 yr^{-1}. This is neither a pure *r* nor *k* strategist but tends more to *r* strategy than *k*. Similarly, data obtained in this study for *L. altianalis* shows that the species grows to a slightly large size of 44.94 cm TL, matures early at a small size approximately 18 cm TL and has a low instantaneous growth constant of the Von Bertalanffy growth function of 0.5 yr^{-1} with an annual fecundity ranging from 2640 - 4764 eggs. It also has an instantaneous mortality rate of 0.15 yr^{-1}, natural mortality rate of 0.28 yr^{-1} and K = 1.47 yr^{-1} and a longevity of 9 years. This species is also not a pure *r* or *k* - strategist but tends more to the *r* strategy than *k*. Regarding the triangular model of life history strategies an opportunistic strategist has a short life span, early maturation, and a low fecundity. A periodic strategist has a long-life span, later maturation, and high fecundity.

The two fish species in this study can be categorized into life history strategies which lies between periodic and opportunistic.

The life histories of the two fish species are comparable to the extent that both attain a medium body size, they have slow growth constants K of the Von Bertalanffy growth function, mature at a relatively small size, have a short lifespan and spawn in similar habitats. The breeding activity occurs during similar periods of the year that is during the two annual rainfall seasons and have low total mortality as well as low natural mortality. Despite these, they differ significantly in terms of fecundity and in terms of egg size with *L. altianalis* having bigger and fewer eggs. The two species are further known to breed in environments which experience catastrophic episodes of heavy and short-lived unprecedented flooding alternating with long periods of desiccation.

Winemiller (2005), explains that the triangular model predicts qualitatively the responses of fish populations to their hypothetical carrying capacity, which means that the relative strength or frequency of density dependence such as that which regulates fish populations. Density dependence entails behavior, physiology, and demographic responses to predators and interspecific and intraspecific competition for resources. Populations with opportunistic strategies such as the two fish species studied here tend to be below *r* - *k* continuum most of the time and frequently are subject to density-independent sources of mortality. In the triangular model the two fish studied in River Kuja - Migori tend more to periodic life history strategy than to opportunistic.

Potamodromous fishes are known to show habitat-use patterns and complex life cycles integrated with the diversity of the various stages in their life and associated body sizes. Northcote (1984) observes that migration behavior originates from seasonal, spatial, and ontogenetic separation of optimal habitats for reproduction, growth, and survival. The potamodromous fishes migrate to various distances throughout their cycle of life (Anteneh et al., 2012). Benefits of potamodromous migration can be classified into three parts: survival benefits to migratory fishes, benefits to the functioning of the entire ecosystem and benefits to humans. This means that they migrate between different freshwater habitats mainly to spawn and other survival needs. Thus Northcote (1984) identified three types of potamodromous migrations namely trophic, refuge, and reproductive. Therefore, potamodromous behavior in fish can be summarized as a cyclic sequence of migrations or movement for purposes of refuge, feeding and reproduction among different habitat types. Studies on Lake Victoria fishes have rarely addressed trophic and refugia type of migrations. Movements and migration are strategies widespread in migratory fishes and consequently lead to fish changing their habitats. Preferred habitats into which fish migrate are sometimes not the same ones visited during their migrations in the past years. This may change as the fish grow, age, and need different habitat requirements. Fish migration is important for it ensures that the breeding of the fish in the riverine environment leads to regular recruitment into the fishery which ultimately provides the catch. Therefore, they have developed adaptations which make them undertake the spawning migrations. It's also not clear whether the spawning migrations wholly originate from Lake Victoria into River Kuja - Migori. There are suggestions that there could be resident riverine populations of both species alluding to the believe that intra riverine spawning migrations could be taking place (Ojwang et al., 2007).

It follows then that there are different types of migration made by different fish species in their lifetime. Therefore, Northcote (1978) distinguished two types of fish migrations and suggested four main features: (1) migration resulting in fish alternating between two or more separated habitats; (2) that which occur with a regular periodicity usually seasonal within the lifespan of an individual fish; (3) that which involves a greater fraction of the fish population; and (4) being directed instead of passive drift or random wandering. The two fish species being studied here have type 1 and 2 migrations though literature on how they perform these migrations is scanty. Earlier studies in the 1950s and 1960s indicated that *L. victorianus* and other indigenous potamodromous fishes congregate at the major river mouths shortly before the rain periods to undertake spawning migrations upstream (Cadwalladr, 1965). These studies attempted to explain the stimuli which cause spawning migrations in the fishes. Therefore, these fishes seem to have developed adaptations that assist them in picking up stimuli signals in the river that trigger their migration. Factors influencing migration include physical factors; bottom materials, depth of water, temperature, turbidity and photoperiodism; chemical factors pH, smell, taste of water, quality and quantity of pollutants and dissolved gases; biological factors; sexual maturity, blood pressure, food, memory and endocrine glands; availability of food; temperature; for instance high temperature of water in summer provides stimulus for migration while a fall in temperature of fresh water in lakes provide a stimulus for migration upstream for spawning purpose (Thorstad et al., 2008; Nabi et al., 2014; Zhang et al., 2020; Pfauserova et al., 2022).

However, Dingle (1996) argues that migration is not a proximate response of fishes to resources, nor does it keep fish in their various habitats. Rather, fish migration activity results in movement of fish from one habitat and relocating to another habitat out of their home range. Dingle (1996) further argues that the most prominent feature of fish movement is that migration activity in fish is not stimulated by sensory cues from resources such as shelter and food.

This study demonstrated that the numbers of the two species were higher in the river during the rainy season when they are known to breed. However, bottom trawl studies conducted by the Kenya Marine Fisheries Research Institute at the river mouths do not show any significant aggregations of the two species even at the onset of the rain season. For a long time, there has been no evidence of fish congregating at river mouths and making spawning migrations upstream. This could be because the mesh sizes of the trawl net used are large above 4 inches while the girth length of the two fish species that is *L. victorianus* and *L. altianalis* are much smaller than the mesh sizes meaning that the trawl is not able to retain the two fish species. The use of small mesh size gillnets by fishermen at the river mouths is banned with an overall objective of conserving the riverine fish species. Despite this, there could be some overfishing by unscrupulous fishermen using small, meshed nets which could be responsible of catching smaller immature sizes of the species. On the other hand, the lack of high numbers of these fish within the river mouth could be due to predation by introduced Nile perch which has been regarded as one of the causes of the decline of the indigenous riverine fish species. Evidently, the catches of the two species have been very low with occasional several specimens being caught infrequently when the cod end, small, meshed bag is used in the trawl net. Recently, there has been observed a decline of Nile perch catches in Lake Victoria and the appearance of specimens of *L. victorianus* and *L. altianalis* in the catches, thus lending support to the fact that Nile perch predation has been one of the major factors responsible for the decreasing number of the indigenous fish species in the Lake Victoria basin.

Turning to the aspect of the stimuli that trigger spawning migration in the two fish species, there has been no clearly demonstrated single stimulus that is known to trigger migration. Past research has indicated that it could be a set of stimuli including temperature, and the early inflows of flood water due to the onset of the rain season from the riverine catchment into the lake that could be responsible. But Forsythe et al., (2012) suggests that the riverine fish species have sensory mechanisms which receive the stimuli that trigger the process of upstream migration.

Information collected during this study indicated that *L. victorianus* and *L. altianalis* were present at all sampling stations along the river. It is not well documented on what stimuli elicits the return migration into lacustrine environment. It is here suggested that falling water levels changes in temperature and reduction of food resource supplies particularly those of allochthonous material from the river catchments are responsible for the return migration. Further, physiological changes due to hormonal regulation of the fish reproduction cycle could be responsible since the urge of spawning by fish cease after spawning (Thurow, 2016). Probably, spawning migrations of both lacustrine and riverine migrations could be taking place at the same time and there may be sharing of the breeding grounds. Whether there is mixing of both lacustrine and riverine populations during migration is not known. It was not possible to sample the full length of the river due to the great distance it covers. However, the observation that mature fish could be picked far upstream indicates that the fishes make long distance migrations to reach their spawning grounds. This is comparable with Anteneh et al., (2012) who reported that about seven species of the genus *Labeobarbus* migrate over 50 km from Lake Tana (Ethiopia) upstream to tributary rivers to spawn during the rainy season. Fishing at some of the sampling stations only revealed fingerling stage of *L. altianalis.* Larvae and fry of both species were not present at all the sampling stations in the river. This, therefore, shows that both species do not breed in the river since sampling was conducted over a period of 18 months without evidence of early stages of these two species. There is no record of habitats that have been sampled and found to have egg and larval stages of both species. Hence, specific breeding grounds of the two species are not known going by the suggestion that both fish spawn in back flood waters and temporary streams that form during rains. These habitats are largely being replaced by farmland to give way for cultivation of subsistence crops and cash crops. This was consistently observed particularly on wetlands along the river whereby cultivation of crops was done on riverbanks and at the Kuja - Migori delta where cultivation of subsistence crops such as cassava, maize and traditional vegetable was being conducted. Hence, future existence of populations of the two species together with those of indigenous riverine species is threatened with extinction from anthropogenic activities which also include discharge of pollutant effluents from urban and industrial activities. Whereas degradation of riverine habitat has been going on since the 1960s due to expansion of the human population, urban and agricultural sectors (Olaka et al., 2019), existence of the two species in the rivers suggest that they have evolved resilient mechanisms to withstand the effects. This is evidenced from occurrence of both juvenile and adult stages of fish in the riverine habitat. This indicates that the fish have maintained their recruitment and feeding against adverse environmental conditions, effects of pollutants such as silt, high turbidity among others. Thus, the fishes have the capacity to withstand adverse environmental stressors in their lifetime, but this capacity may not be unlimited. Macroscopic examination of gonads indicated that fish of all sexual maturity stages 1 to 6 were present in the river for extended periods during the rainy season. Further examination of the gonads indicated that there were large fish which were repeating the process of maturation. This was evidenced from the observation that smaller sizes of fish had mature eggs at stages 4 and 5 while much larger fish of diverse sizes were having eggs of stages 2 and 3. The number of times the fish could be laying eggs over the extended period during the rainy season is not clear, but observations indicate that this could happen several times. This implies that the fish have evolved the capacity of multiple breeding in the riverine environment over their lifetime. Therefore, there is need to conduct research to elucidate the frequency of spawning of both species in the river. Further, not all the eggs in the ovaries were in the same stage of development. There was evidence of eggs being one developmental stage behind others implying that not all eggs are laid at the same time. This was observed particularly for *L.*

altianalis and could be one of the reasons the species has proven to be more successful and surviving at higher numbers in the riverine environment than *L. victorianus*. There is need to carry out detailed analysis of egg developmental stages to find out how its related to fish survival and recruitment in the river. However, differential maturation of eggs could be conferring survival advantage to the species since not all egg laying periods occur under favourable environmental conditions.

From the results of this study, it appears that *L. altianalis* could be much more well adapted to the riverine environment than *L. victorianus.* However, there is no published information on factors that make both *L. victorianus* and *L. altianalis* to adapt to riverine habitats. Both species appear to withstand flood water conditions whereby siltation loads, and turbidity are high.

Results from this study indicated that both *L. victorianus* and *L. altianalis* have small to medium size bodies and that they mature early in their life history. Comparably, *L. altianalis* mature at a smaller size than *L. victorianus.* Results of this study indicated that female and male *L. altianalis* mature earlier compared to females and males of *L. victorianus*. In both cases males mature earlier than females and that both males and females of *L. altianalis* mature earlier than those of *L. victorianus.* It should also be noted that *L. altianalis* attains a much higher L_∞ or L_{max} approximately 90 cm TL compared to L_{max} of *L. victorianus* of 60 cm TL. This clearly demonstrates that *L. altianalis* has a reproductive advantage over *L. victorianus* since it can spawn for a much longer period over its bigger size range. Another factor that has made it more successful in colonizing the riverine habitats where it's the most dominant fish species. The same differences are reflected in the length at 50% maturity of both species.

5.2 Correlation of physical and chemical parameters to fish abundance

The interactions between fish species life history strategies, ecology and natural selection takes place within the fish habitat or environment (Lawson, 2011). Therefore, it was pertinent that the environmental characteristics of the two fish species whose life history strategies are studied here be analyzed. The health of an aquatic ecosystem is highly depended on the physical, chemical, and biological characteristics of water (Omondi et al., 2014). Fish population dynamics are good indicators of the health of an aquatic ecosystem. Fish species richness is highly associated with the physico-chemical properties of water. When the quality of water is compromised it affects fish populations by impacting their habitat and availability of food which influence their potential for growth and ability to reproduce (Akongyuure &Alhassan, 2021). Changes in physico- chemical parameters such as dissolved oxygen, temperature, conductivity, nitrates, nitrites, phosphorous and silicates provide important information on water quality and their correlation with fish abundance in rivers (Larsen et al., 2019). Results of this study showed that there were few significant correlations between the physico-chemical parameters and abundance of *L. victorianus* and *L. altianalis* in River Kuja - Migori. The abundance of *L. victorianus* had a significant negative correlation with pH. This is an indication that *L. victorianus* was more sensitive to pH which probably may be the reason of it being less abundant in the river. On the other hand, *L. altianalis* had a significant positive correlation with hardness. Hardness which is a measure of calcium and magnesium ions in water, is important for reproduction, embryo development and during the early life stage processes including egg hatchability, survival, and larval growth (Romano et al., 2020). While studying the relationship between water quality parametres and abundance of *Oreochromis niloticus* Akongyuure & Alhassan, (2021) did not find any positive correlation except for chloride.

5.3 Distribution and abundance of *L. victorianus* and *L. altianalis*

Results from this study indicates that *L. victorianus* and *L. altianalis* are not uniformly distributed along the River Kuja – Migori. *Labeobarbus altianalis* was found to be more abundant. Achieng et al., (2021) while studying fish from Rivers; Mara, Nzoia, Yala and Nyando all within the Lake Victoria basin found that *L. altianalis* was more dominant followed by *L. victorianus* compared to the rest of fish species present in the rivers. The high dominance of *L. altianalis* in the riverine habitats shows that it has resilience to the anthropogenic and climatic stressors in the riverine habitats of the Lake Victoria basin. This is an indication that *L. altianalis* is less affected by ecological and environmental changes. These two fishes seem to have specific habitat preferences probably due to differences in intra riverine migrations. Thurow (2016) noted that there is a phenomenon of fish migration among refugia for a variety of purposes which include avoiding unfavorable environmental conditions. These conditions include very low water temperatures or shallow water levels and dissolved oxygen deficits in the floodplains during the dry season. Other types of migration include alimental migration for the search of food and water; gametic migration for reproduction purposes; climatic migration to secure more suitable climatic conditions and osmoregulatory migration for maintenance of osmoregulation.

In literature, *L. victorianus* and *L. altianalis* are indicated to occur in the river only for breeding purposes. However, the sizes caught during this study indicate the contrary. All size ranges which were breeding, and non-breeding were caught throughout the year. The occurrence of both mature and immature fish in the river is explained by Thurow (2016) who observed that sub adult fish show a unique migration that may be associated with movements of adult fish. Thurow (2016) termed this phenomenon 'Pied Piper' migrations where immature, sub-adult fish follow mature adults as they migrate to breeding grounds. Schill et al., (1994) found that sub-adult bull trout migrated upstream in Rapid River together with adult bull trout starting in the month of April - July. As August approached, the sub-adult bull trout completed their migration before getting to their sites for spawning and reversed their migration back to other downstream habitats. This suggests that downstream migrations may be attributed to searching for feeding habitats and thermal refugia. Observations from this study suggests that there could be resident riverine populations of both species occurring in specific habitats which are not documented or known. It appears that there are certain riverine refugia where these fishes stay well protected from their predators and fishermen especially the inaccessible points along the river. It also seems that the lake-riverine interface which constitute the riverine wetlands, deltas and estuaries could be serving this purpose. Similarly, other wetlands upstream may be serving the same function. However, this needs to be established scientifically. It is also believed that *L. victorianus* and *L. altianalis* breed in upstream rivers inside pools, but the exact locations have not been established. The present information, therefore, can be used for conservation and management of these two fish species by identifying the actual locations where the eggs are laid and detail their ecological characteristics for the purpose of conservation. The need for the conservation of the two species is pertinent, since *L. victorianus* is an endangered fish species and is listed in the IUCN red list as a critically endangered species (Bayona, 2006). However, recent research indicates that there are considerable numbers of this species in all the rivers in the Kenyan basin of Lake Victoria (Masese et al., 2020; Achieng et al., 2021). *Labeobarbus altianalis* was previously believed to be threatened with extinction but several studies together with this study has shown that the species occurs in considerable numbers in the riverine habitats of Lake Victoria basin (Chemoiwa et al., 2017; Masese et al., 2020; Achieng et al., 2021).

The survival of both species is threatened by anthropogenic activities within the Kenyan sector of the Lake Victoria basin. There are poor agricultural practices which affect the distribution and abundance of these fish (Olaka et al., 2019). For example, there is evidence of farming close to the riverbanks leading to the destruction of the habitats where fish breed (Ochumba &

Manyala, 1992). This was evident in this study where in many areas there was tilling of the riverine riparian zone which reduced areas occupied by side pools. Here, both agro chemical substances and silt smoother the breeding habitats of the fish both within the river and in the flood plain areas (Aura et al., 2020). Earlier studies conducted on the highland regions of southwestern Kenya show presence of organochlorine residues in sediments and water samples of tributaries of River Kuja – Migori (Nyaundi et al., 2019). Fish mortality has been observed in the past in the same river probably due to discharge of agricultural effluent from agro processing factories within the region (Nyaundi et al., 2019). Further, there has been continuous deposition of silt and encroachment of land towards the lake at the Kuja - Migori delta. The process of encroachment started to accelerate from the early 1960s. This is when most of the communities in the rivers in the sub catchments upstream started transiting from livestock rearing to crop husbandry which was further enhanced by farming of introduced cash crops such as cotton, coffee, tea, sugarcane, and tobacco. It was also observed in this study that wetlands both at the delta of River Kuja - Migori and upstream were being destroyed to pave way for agricultural activities, a process which leads to similar ecological perturbations. Other anthropogenic activities which affect the riverine fish species include disposal of urban wastes such as sewage and mining. In the Migori tributary of river Kuja gold mining activities at Macalder introduce mercury in the water which is toxic to fish and aquatic live (Odada et al., 2004). Climatic changes during periods of scarcity of rainfall; lead to reduction in annual precipitation which could also lead to shrinkage of the flood prone areas along the river where the fish breed. This could be one of the factors affecting recruitment of these two species in the river. Whereas flooding may be enhancing the breeding of the two species it was observed during this study that other large species such as *Clarias gariepinus* and *Protopterus aethiopicus* remain in the flood plain areas when the water recedes thus encouraging fishermen and predators to partake in the catch.

5.4 Length - weight relationships of *L. victorianus* and *L. altianalis*

In this study, the relationship between the length and weight was linear for both *L. victorianus* and *L. altianalis.* This finding was in line with the general formula expressing the length and weight relationship of fishes (Froese et al., 2013; Ogamba et al., 2014; Abobi, 2015). The value of *b* (the slope of regression) in both sexes of the two species were within the range recommended by Bagenal and Tesch, (1978) of 2 to 4. The values obtained for the coefficient of determination were higher indicating a good linear regression prediction for the two fish species (Hossain et al., 2011). Therefore, extrapolation for similar fish size ranges in future catches of these species in the river is possible. Growth for both species was allometry where the fish increased in body weight as well as increase in length (Lederoun et al., 2020). The *b* value of 2.92 and 3.11 for *L. victorianus* and *L. altianalis* respectively was obtained, expressing allometric growth in their life history strategy. Aruho et al., (2018) obtained similar results for *L. altianalis* from Lake Edward and Upper Victoria Nile in Uganda. The length - weight relationship can be used to identify differences in population units of a species, studied using fully standardized methodology, to estimate the condition factor of fish, which is useful in the comparison of health of different fish populations (Oliveira, et al., 2020).

5.5 Condition factor of *L. victorianus* and *L. altianalis*

In this study it was observed that the condition factor was higher in the wet season than in the dry season. This can be associated to the fact that during the wet season there is abundant and diverse food items at the disposal of the fish to forage in the river. Another reason could be that the fish were caught during spawning time when fish especially females are egg laden which consequently improves their condition factor. The average condition factor in the present study was slightly more than one. This shows that these two fish were physiologically stable in the river during the period of study. The slight differences in condition factor obtained in the study can be attributed to differences in sample sizes and size ranges between the two species. The size range of *L. altianalis* analyzed was wider than that of *L. victorianus* and the sample sizes of *L. altianalis* were higher than those of *L. victorianus*. The condition factor is related to life history of a fish through growth, reproduction potential and survivorship or longevity. Condition factor is influenced by variation in the availability, abundance, diversity, and quality of food in the environment, the intensity of feeding of fish and the status of reproduction (Abobi 2015; Yongo et al., 2019). Inadequate supply of food can lead to a poor condition factor. Secondly, if the quality of fish food in the environment is poor, it can lead to poor condition factor. Thirdly, if there is competition for food with other fish species then the species which are fitter in the same environment will out compete other fishes and lead to low condition factor and ultimately lead to extinction. When the quantity of food is low, and the food quality is poor, and the fish is much less competitive for the same food resources with others in same environment can lead to poor condition hence edging out of the species from the environment. It can also lead to low fecundity and on the overall the life history of a fish can be negatively impacted (Abedi et al., 2011). Therefore, the variation in condition factor among individual fish seen in this study may be associated with changes in availability of food, the ability to forage, sexual maturity stage and habitat quality (Abdul et al., 2016). Thus, good habitat quality can lead to high condition factor or vice versa. Under stressful environmental conditions where water quality in terms of dissolved oxygen concentration, total dissolved substances, conductivity, and turbidity coupled with the presence of toxins, the condition factor and general fitness of the fish is reduced leading to low recruitment into a fishery (Akongyuure and Alhassan, 2021). Finally, when the environmental quality is good, the condition factor is high, reproduction potential of the fish ensures that recruitment into the fishery becomes good and the fish can be said to realize optimal strategy in its life history.

In this study, the condition factors for males were lower than those of females in both *L. victorianus* and *L. altianalis*. This was because the mean size of females was higher than those of males of both species in samples that were obtained. This can be attributed to the fact that the weight of females was compensated more by growth in gonad sizes as the fish grows into maturity compared to the compensation of the weight of males with the increase of the male gonads. This means that female gonads grow to a bigger size than male gonads of same ages or sizes of fish. This further suggests that females invest more energy resources in the development of their gonads (ovaries) than males which invest lower energy resources in gonadal development.

The observation that the condition factor for both males and females of *L. altianalis* was higher than both sexes of *L. victorianus* can be attributed to the fact that egg sizes of *L. altianalis* were bigger than those of *L. victorianus.* This implies that the female gonads *L. altianalis* grow to a much bigger size compared to those of female *L. victorianus*. Similarly, the condition factor of male *L. altianalis* was slightly higher than males of *L. victorianus* due to the same reasons. Hence the condition factor is closely related to gonadosomatic index. It can also be attributed to the fact that *L. altianalis* is more successful in competition for food and other habitat resources, the reason it was the most dominant fish species in River Kuja - Migori. Rutaisire (2003) studied the breeding biology of *L. victorianus* in river Kagera and found that the eviscerated condition factor showed temporal variation with peak values obtained during the period May – July and September - October. Further significant differences in mean condition factor were observed by Rutaisire (2003) in river Kagera and river Sio in the Lake Victoria basin of Uganda. These findings are more or less similar to observations in this study despite differences in the geographical zones between the River Kuja - Migori in south west Kenya and river Kagera and river Sio in Uganda.

5.6 Sex ratio

The sex ratio of male to female *L. victorianus* and *L. altianalis* did not show significant difference from the expected ratio of 1:1. In many cases, sex ratio deviation is rarely observed in most fishes, although some freshwater fish may be strongly biased in this ratio especially where sex ratios are usually skewed within and between cohorts and spawning aggregations (Hossain et al., 2011; Domínguez-Petit et al., 2017). In other studies, on fish species such as Tilapia, skewed sex ratio was attributed to differential migration of sexes whereby tilapia males established nesting places in shallow waters and aggregated there during spawning, while gravid females visited the nests to spawn but left there quickly after spawning (Njiru et al., 2006). The fertilization success depends largely on sex ratio and bias in either sex may lead to, biological, behavioral, and physiological changes in fish, which may ultimately have a profound effect on reproduction success (Manal et al., 2017; Maskill et al., 2017). In addition, fish behavior which include competition for food resources, mate selection during breeding season, and aggression are influenced by the ratio of female to male fish (Weir, 2013; Hossain et al., 2011).

Competition and aggressive behavior in fishes is predicted to positively correlate with abundance of either sex (Grant et al., 2000). For instance, a study on Japanese medaka (*Oryzias latipes*), aggression of males was shown to increase with increase in their relative abundance (Clark & Grant, 2010) while in two-spotted gobie (*Gobiusculus flavescens*) and sand gobies (*Pomatoschistus minutus*) intrasexual competition in females was seen to decrease with increase in relative abundance of the males (Domínguez-Petit et al., 2017). A high ratio of male to female in fish may lead to stress as a result of competition during the time of courtship preventing spawning activities from taking place and reduced success in fertilization of eggs (Maskill et al., 2017; Rahman et al., 2013). For example, success of fertilization of cod was found to rely on the abundance of males where the number of fertilized eggs decreased with the decrease in the number of spawning males per female (Rowe et al., 2004). Biased sex ratios may lead to a phenomenon known as “Allee effects”, where the growth of a population of fish reduces when the size of the population falls below a threshold whereby regeneration might be affected by reduction in abundance of either sex (Domínguez-Petit et al., 2017; Grant et al., 2000). Sex ratio may greatly be biased due to time of spawning, the type of fishing gear used and the location of the gear during fishing activity. For instance, when spawning fish are sampled it may represent a biased sex ratio in fish populations that are caught at the breeding grounds during spawning migrations (Jakobsen & Ajiad, 1999). The differences in the body size of fish or behaviour, where individuals of one sex are more active than the other sex, may lead to sex ratio estimates that are skewed, due to variation in susceptibility to capture by the fishing gear employed (Rowe et al., 2004). For instance, males of cod (*Gadus morhua*) have been found to be more vulnerable to fishing mortality due to their greater aggression activities (Côté, 2003; Rowe et al., 2004).

5.7 Egg size and fecundity of female *L. victorianus* and *L. altianalis*

Egg size of a fish is an important parameter since its indicative of the number of resources a fish invests to its reproduction. The females of *L. victorianus* had small eggs as observed during this study which shows that this fish species has low investment in egg production. This trend is commonly seen in fish which do not show parental care. The size of the eggs is directly related to the number of eggs produced by fish, fertilization success, the size of larvae and the development duration (Nunes et al., 2011). When the eggs are larger, they take a short period to mature and act as a suitable target for sperms enhancing success during the process of fertilization. Furthermore, when the eggs are larger in size, they produce bigger offsprings which in turn improve the chances of survival of fish larvae during their early days of development. Conversely, the larvae that hatch from small eggs are tiny because of low amount of nutrients stored for the development and growth of offsprings. Reduced size of fish eggs slows down the rate of development of larvae leading to an overall extension of the duration of larval growth (Rahman et al., 2013). In this study, there was a weak relationship of egg size and the weight of fish. However, the size of eggs has been found to increase with fish size in other species of fish.

All the eggs of *L. victorianus* were observed to be of similar sizes with a narrow range in diameter. They were mostly at the same stage of development that is the ripe stage while those of *L. altianalis* were large with their egg diameter having a wider range and were at different developmental stages. The bigger eggs of *L. altianalis* compared to those of *L. victorianus* indicate that *L. altianalis* invests most of its energy resources to reproductive processes than *L. victorianus.* The bigger eggs ensures that there are enough food resources for embryonated stages of the species to consume. Thus, ensuring prolonged periods of survival compared to *L. victorianus* which invest less energy to reproductive processes (Singh et al., 2006). This could be one of the factors that makes *L. altianalis* much more successful in habiting the riverine habitat while *L. victorianus* is considered threatened for extinction within the Lake Victoria basin. Another factor which could make the survivorship of *L. victorianus* less successful in the river could be that it is highly vulnerable to fishing gear particularly gill nets.

Fecundity of *L. victorianus* and *L. altianalis* showed a significant positive correlation with total body length. This was in agreement with the findings of Rutaisire & Booth, (2005) while studying *L. victorianus* of river Kagera and river Sio in Uganda. Increase of fecundity with increase in fish size indicates that bigger individuals possess more eggs as compared to smaller individuals (Lone & Hussain, 2009). The mean fecundity for female *L. victorianus* in the present study was higher than that obtained by Orina et al., (2014) in *L. victorianus* from Kenyan rivers; Yala, Mara, Migori and Nyando. Fecundity in the present study was also higher than that obtained by Kembenya et al., (2016) in *L. victorianus* from river Mara. The differences in fecundity of female *L. victorianus* from various rivers may be attributed to the fact that the number of eggs spawned by a fish differs with the size, age of the individual fish and its adaptations to aquatic environment (Nazek et al., 2018; Yongo et al., 2019). The high fecundity of *L. victorianus* could be attributed to the fact that this fish species does not show parental care. Therefore, it produces high number of eggs as a strategy to increase chances of reproduction success and survival of offsprings (Njiru et al., 2008; Yongo et al., 2019).

Observations on fecundity of *L. victorianus* and *L. altianalis* indicate that the former is more fecund but with smaller egg sizes than the latter with bigger egg sizes. Therefore, it could appear that even though the fecundity of *L. altianalis* is lower than that of *L. victorianus* to some extent it compensates for this deficit with its big sized eggs compared to those of *L. victorianus.* The low fecundity of *L. altianalis* is compensated by extended longevity leading to high reproduction output during its lifetime of 9 years against a longevity of 6 years of *L. victorianus.* Since *L. victorianus* has a much higher fecundity than *L. altianalis* why then is it not more successful in colonizing the riverine environment than *L. altianalis*? This could be probably due to the temporary nature of its breeding habitats which dry sooner after the floods suggesting that both egg and juvenile mortality are high for the species. This can be supported by the observations during this study that larval stage specimen of this species was not caught in the river. *L. victorianus* were caught where the environmental conditions were harsher for *L.*

victorianus. The lack of fingerling stages of *L. victorianus* in the river could mean that they leave the spawning grounds outside the river at a much bigger size and a later stage in life. Further, these stages could be subjected to natural mortality and predation mortality thereby reducing the recruitment potential of the species. The observation that April and October are the months when fish had the highest fecundities could be explained in terms of presence of optimal conditions for reproduction in the river. This is the time when fish food items are abundant and the fish take advantage of investing energy resources in production of eggs and sperms to ensure successful fertilization and recruitment (Abedi et al., 2011). This is an adaptation of the fish in its life history strategy which ensures that spawning begins immediately at the onset of the rain season.

5.8 Gonadosomatic index

High values of GSI were observed in the present study and were comparable to those of Sindhe and Kulkarni, (2004) who indicated that GSI greater than two is a sign that fish are ready to spawn. GSI obtained in this study were similar to those of *L. victorianus* from River Kagera but less than those of *L. victorianus* from River Sio in Uganda (Rutaisire, 2004). This difference can be attributed to differences in the geographical locations of the rivers and the various maximum sizes attained by fish in these regions. For example, the size of *L. victorianus* attained in upper Mara River were larger than those obtained in River Kuja – Migori (Orina et al., 2014). The GSI of females had a positive significant correlation with total body length and was higher than that of males in all stages of gonad maturation. This could be attributed to the fact that the presence of ovaries alters the weight of female fish at the time of breeding (Lederoun et al., 2020). The observation that GSI was higher in older fish than in younger fish can be attributed to the fact that some fish species invest most of their energy resources for growth during the immature phase, after which they divert the energy to reproduction purposes during the mature phase. This is a common phenomenon observed in fishes with *r* - selected life history strategy. In this study, the two species have life histories tending more to *r* - selection. More investment of energy resources into growth of sexual gonads increases the weight of the fish as well as the condition factor. The drop observed in the GSI of older fish can be explained by the shedding of the reproduction products that is eggs and sperms. The shedding reduces the weight of the gonads which in turn reduces the body weight of the fish thus lowering the GSI. Rutaisire (2003) found that both males and females of *L. victorianus* were present throughout the year in the Sio River and that there was an increase in the male GSI before females, together with the predominance of "maturing" and "late maturing" stages. And that there was significantly higher male female sex ratio in the months of February and August in the Kagera river which were attributed to a sex specific migration upstream of males before the females prior to spawning. No similar observations were made by Rutaisire (2003) in the Sio River suggesting that this could be due to sex specific upstream migration. Rutaisire (2003), further noted that there was a decline in the mesenteric fat deposits in female *L. victorianus* therefore, concluding that the mesenteric fat deposits were the major source of energy for migration and reproduction. This supports the observation that in the *r* - selected fish, energy resources are invested in reproductive processes. In this study spawning patterns in River Kuja - Migori were synchronized with peak annual rainfall seasons. This observation concurred with that of Rutaisire (2003) in the spawning of *L. victorianus.* Further, observations during this study in River Kuja - Migori show that, whereas spawning occurred during the rainy season, some fishes were spawning in small numbers even in the dry season. Mills (1991) explains that reproductive strategy of a fish comprises a suite of traits that enable it to produce the highest possible number of off-springs. The suite of traits includes longevity, age, and size at first maturity, specific schedules of fecundity, the timing of spawning and reproductive effort (Abrehouch et al., 2010).

5.9 Growth parameters

The maximum mean sizes of fish were consistently observed in the month of April 2018 and 2019. This consistency suggests that climatic conditions during the 18 months of sampling did not vary significantly. Hence the assumption of dynamic equilibrium or steady- state equilibrium made in this study justifies the use of methodologies in the FiSAT package. During the sampling period of 18 months, April was the month at the beginning of the long rain season and it's at the onset of the long rain season that mature fish congregate at the river mouth to commence their migration to spawning grounds (Ochumba & Manyala, 1992). Another mean maxima were observed during the month of October 2018. This was also at the beginning of the second rainy season (shorter rains) being the reason fish congregate at river mouths before migrating upstream. Therefore, this explains why bigger fish were caught during the rainy season. During the dry season the fish might have probably migrated back to the lake which may be the reason mean lengths were lower during the dry season. Therefore, fish caught in dry season were smaller (immature fish) migrating back to the lake. The changes in rainfall patterns within the Kuja - Migori basin are related to movement of both species into the river and back to Lake Victoria. The changes in rainfall bring about changes in the physical and chemical characteristics in the river as well as in the lake. The maximum lengths attained by both *L. victorianus* and *L. altianalis* during this study were relatively small at 36.89 and 44.94 cm TL respectively suggesting that the fishes are small bodied. However, earlier studies indicate that *L. victorianus* could attain a maximum length of 60 cm TL while *L. altianalis* attains a maximum length of 90 cm TL. The growth constant of both species can be regarded as slow, them being 0.31 for *L. victorianus* and 0.15 for *L. altianalis.* Both species have short lifespan of 6.0 and 9.0 years for *L. victorianus* and *L. altianalis* respectively. The fact that *L. altianalis* has a slower growth constant k may be because it grows to a bigger size than *L. victorianus* resulting to a low growth constant. However, its growth performance index is higher than that of *L. victorianus* for indices based on asymptotic length it being 3.03 against 2.86 and 1.54 and 1.74 for *L. victorianus* and *L. altianalis* respectively. This implies that *L. altianalis* grows much slowly but attains much bigger size than *L. victorianus.* The results indicated that on overall *L. altianalis* which matures earlier than *L. victorianus* exceeds the life expectancy of *L. victorianus* by 3 years. This show that it has a more extended period of reproduction than *L. victorianus* leading to higher populations in River Kuja -Migori compared to *L. victorianus.*

The results of the present study compare well with other studies on African cyprinids (Table 17). It is clear from the table that most African cyprinids especially those in the genus *Labeo* do not grow beyond 45 cm TL and that the longevity does not exceed 10 years (Winker et al., 2012; Montchowui et al., 2009; Weyl & Booth, 1999). Also, the length-based performance index is approximately 2.5 for *L. capensis, L. parvus* and *L. victorianus* (Winker et al., 2012; Montchowui et al., 2009). Only *L. altianalis* has a growth performance of 1.54 and this suggests that African cyprinids tend to exhibit similar growth parameters.

Table 17. Comparison of population parameters of different African cyprinids

Species name	Locality	L_∞	K	Longevity	Ø'	Reference
Labeo capensis	Lake Gariep	38.8 cm FL	0.25 yr^{-1}	9 years	2.58	Winker et al., 2012
Labeo parvus	Ouémé River	30.5 cm TL	0.4 yr^{-1}	2 years	2.57	Montchowui et al., 2009
Labeo cylindricus	Lake Chicamba	22.4 cm FL	0.66 yr^{-1}	-	-	Weyl & Booth, 1999
Labeo victorianus	River Kuja-Migori	36.89 cm TL	0.31 yr^{-1}	6 years	2.10	This study
Labeobarbus altianalis	River Kuja-Migori	44.94 cm TL	0.16 yr^{-1}	9 years	1.54	This study

L_∞- asymptotic length, K- growth constant, Ø'**-** length based growth performance index; TL- Total length; FL-Fork length

5.10 Recruitment patterns

Studies in North America by Winemiller (2005) showed a strong correlation between recruitment and fecundity. This is true for *L. victorianus* and not *L. altianalis* in this study, which despite high batch fecundity had a low recruitment that is very few numbers of young recruits in the river. Further, Winemiller, (2005) notes that among North America freshwater perciforms, periodic strategists tend to have higher inter annual recruitment variation than equilibrium strategists. In this study data is not available for inter annual variation of recruitment, however climate change and unpredictable flooding regimes in the Lake Victoria catchment can easily result to such annual variations in recruitment. Because it creates numerous breeding habitats along most of the river flood plains and back waters. The intensity of rainfall within the Lake Victoria basin has been in the recent past showing significant inter annual variations which are sometimes too low and in other times too high. Results from this study reveals that recruitment of the two fish species is higher during the longer and heavier rain season between March and August while it is much lower during the shorter rain season between September and November. The recruitment pattern of both species depicts an extended period in which most fish in the river were mature that is from March to August. The findings of this study on breeding seasons for the two species agree with those of Manyala et al., (2005) who found that *L. altianalis* breed in the months of March - April, August - September and October - November in River Sondu - Miriu while *L. victorianus* breeds in the months of January - April and September - November in the same river every year. It was also observed that during this time some fish specimens were repeating the sexual maturity stages. The success in fish reproduction activity relies on the match between breeding season and favourable conditions for survival of the off-spring (Lowerre-Barbieri et al., 2011). This therefore suggest that the fish breeds at a given number of times which is not established to date. This is because breeding season in fish is a temporal activity, whereby most fishes exhibit one or more spawning seasons per year (Trindade-Santos & Freire, 2015). Further, the recruitment pattern is thought to occur from two major habitats or populations. The one which is well documented is from Lake Victoria itself through the deltaic wetlands into the river while the other which is suggested in this study could be from the proposed refugia or habitat of riverine resident populations into the breeding ground of the river. Does it mean that recruitment from the lake into the river has got returnees back into the lake after breeding? This could be true however, emigration and immigration of the suggested riverine resident populations for breeding purposes has not been established.

The cause of the two breeding patterns observed is the yearly rainfall cycle. The extended recruitment period corresponds to the prolonged precipitation period commencing between March and August every year. The shorter recruitment period happening between October and December is due to shorter rain period falling later every year. It also must be demonstrated that its only for breeding reasons that the fish recruit into the river during rain seasons and not for feeding or any other purpose. Whereas the recruitment of the two species follows the specific pattern observed (twice a year), there are high chances that, this is being affected by human activities in the catchments of the river such as direct disposal of organic and inorganic wastes especially from agriculture and development activities and gold mining. For example, it has already been discussed that there is a reduction of fish habitats and in particular breeding zones due to encroachment of agricultural activities in the deltaic and riverine wetlands to plant horticultural and cereal crops (Orwa et al., 2012; Raburu et al., 2009). These activities have expanded since 1960s and could have contributed in one way or another to the decline of the once major riverine fisheries consisting of the two species and other species.

It's believed that climate change also contributes to recruitment patterns of fish. This is because the amount of rainfall which was demonstrated in the results of this study influence the recruitment of both species which sometimes changes in a drastic manner. The amount of rainfall could be affecting the intensity of flooding which in turn can affect the area of riparian land to the river which is flooded. When the flooding is reduced its expected that breeding grounds of both species shrinks leading to a reduction in the number of resources required to support breeding of the fish, a factor that can lead to reduction in recruitment. Similarly, expansion of agricultural activities in the breeding areas of both species is expected to result in the decline of the two fish species in future.

Early in the 1980s there were plans to enhance stocks of riverine fish species in the Lake Victoria basin. It's for this very reason that the Kenya Marine and Fisheries Research Institute established the Sangoro Station then referred to as a riverine and aquaculture research laboratory back in the year 1984. The debate that followed on this matter led to the proposal that there was no need to enhance riverine fish because the Nile perch could wipe out most of the introductions hence the plan was abandoned. However, the populations of Nile perch in the lake have continually experienced a steady decline to date and seemingly might not pose any threat to future stock enhancement of the riverine fish species. Its therefore suggested that plans to start captive breeding and enhancement of riverine stocks of indigenous fish species be undertaken. During this study there were no Nile perch found beyond 5 km from the estuary or the delta of River Kuja - Migori. Therefore, an introduction conducted upstream may lead to some of the fish finding refugia in parts of the river which can result to stock enhancement.

5.11 Food and feeding habits

The role of food intake for growth, reduced natural mortality, high fecundity, high juvenile survival, and improved breeding success has been well studied (Bithy et al., 2012; Brooks et al., 1997). Therefore, availability of food resources is a crucial factor which determine where fishes occur and their movement direction (Forsythe et al., 2012). This study demonstrated that *L. victorianus* and *L. altianalis* feed predominantly on detritus and plant material in River Kuja - Migori. The supply of the two items into River Kuja - Migori from the catchment continues over a long period during the heavy rains from March to September and during the short rain between September and November. The biogeographical area in which River Kuja - Migori is found receives rainfall throughout the year. The catchment has evergreen vegetation comprising of woodland grassland and bush land which provides a continuous supply of allochthonous, material into the river. The two fish species can digest detrital and plant material which is more difficult to digest (Njiru et al., 2004), than animal food sources implying that they have evolved digestible capabilities that enables them to digest detritus and plant material. The numbers of other fish that feed on detritus and plant material such as cichlids and catfish were extremely low in River Kuja - Migori. Implying that there are few fierce competitors for detritus and plant material food resource. Therefore, the two fish species could be the only ones competing between themselves for the food resources. Further, the population of *L. victorianus* are very low to an extent that the fish species is considered endangered. Hence *L. altianalis* can be regarded as having a sufficient food energy resource within River Kuja - Migori. It was observed that the food types, detritus, plant material, algal material and chironomids were fed on in much lower proportions during the dry season compared to the wet season. This may be attributed to the fact that during the dry season, there is a decline in the runoff from the river catchment. This implies that allochthonous plant material brought down into the river could be reduced. Another reason may be that the water depth in the river become reduced exposing much of the river bottom which is a rich source of detrital matter and plant material. The reduction in the quantities of these two food sources could have led to lower proportions picked by fish during the dry season. Also, during the same period most of the food material brought into the river during the rainy season could have been exhausted due to feeding by the fish. With respect to lower proportions of algae consumed, the amount of these food items in the riverine environment was low as primary productivity in the river reduced due to siltation and due to instream cover in some sections of the river. The dwindling food supplies in the river during the dry season could be one of the reasons fish migrate into the lake in search of rich food sources. There was evidently little intake of food items ephemeroptera, diptera hemipteran, and coleoptera in both wet and dry seasons in the river. This can be attributed to the way fish select their food items. In other words, the four items may not be more preferred as food by fish than other food items in the river. The abundance of all these food items could be low since their preferred habitats could be few in the river and therefore cannot inhabit areas of the river with a fast flow regime.

There was an observed shift of diet as fish grew from young to adult sizes. It is hypothesized that since juvenile fish have higher demand for protein due to higher specific growth rate and much greater mass specific metabolism, they may not be able to satisfy their demand by consuming plant-based food items. Younger fish are forced to consume animal-based prey, with high protein content and energy per unit of weight (Njiru et al., 2004). This is a common feeding strategy of most fishes during their lifetime at the initial early life stages (Uthayakumar et al., 2013). Fish with this strategy use food energy resources to maximize growth. When the fish become sexually mature food energy resources are diverted to maximization of reproduction processes to ensure that the fish can reproduce to perpetuate its kind (Brown-Peterson et al., 2011; Godinho et al., 2010). Examples of such species include *L. victorianus* and *L. altianalis* which were studied here among others. Hence the difference between the two species is that *L.*

altianalis optimizes resources for growth much earlier than *L. victorianus*, making it attain a smaller size at first maturity than that of *L. victorianus*. Therefore, optimization of energy resources for reproduction starts at a much earlier age and this could be the reason the populations of *L. altianalis* appear to be more successful in colonizing River Kuja - Migori than *L. victorianus*. The change in the diet implies that the predominant diet taken by juvenile fish contain a source of protein which is much needed for growth while the plant material consumed by mature fish contributes a much more suitable form of feed that enhances reproductive process. For example, the presence of plant polyunsaturated fatty acids (PUFAs) constituting omega 3 and omega 6 fatty acids is essential for promoting oogenesis particularly colleogenesis and vitellogenesis which are very important for survival of embryonated or larval stages of fish. The plant PUFAs are more plentiful in the river than the animal source. Further, the two fish species are capable of easily digesting the plant to obtain these critical nutrients including those other than PUFAs. The two fish species therefore could have evolved mechanisms that enable them to easily process omega 3 and omega 6 PUFAs from algae and from aquatic macrophyte source food items which other animals have no ability to process. Besides the dominant food types in juveniles and adults it was observed in common that both consume ephemeroptera, chironomids, coleoptera, and hemipteran. The only reason for this can be that these food items remain to be the source of protein implying that fish require protein sources albeit in different proportions. Protein is essential for growth and repair of body tissues in adult fish. In the dry season the presence of mature fish in the river declined and this could be due to the decline in preferred food items that are essential for promoting reproductive processes. Hence egg production is much more reduced in dry season than the wet season meaning that the number produced are low. Lack of food could also lead to mortality especially for juveniles which may lead to low survival rates. Hence this could be the reason fish have synchronized breeding cycle with wet season when essential food items that is insects, detritus and plant material are in plenty and when survival of young ones is assured. Analysis of the number of food items consumed by both *L. victorianus* and *L. altianalis* in both wet and dry season was the same that is eight food items. However, these food items were taken in different proportions by the two fish species during the wet season and dry season. The fact that the fish could take all items could imply presence of low proportions of most of the food items particularly those of animal sources. Secondly, that the distribution of food items in the riverine habitat could be discrete thus enabling the fish to take what it gets first. The implicit scarcity of the food items affects survivorship of both species particularly the early stages. The availability of food items could put a limit to the carrying capacity of the riverine environment on the population and type of fish it can support. The occurrence of different food items was found to be at variance in guts of *L. victorianus* and those of *L. altianalis*. This can be attributed to the fact that selectivity of different food items by fish may not be the same and that the concentration of different food items may not be evenly distributed in the riverine environment. Some food items could be absent from certain riverine habitats. Either of the two fish species could be outcompeting the other in feeding on a variety of food items and this competition could vary from one food item to another. This could be due to differential selectivity of the food items by the fish as influenced by the abundance of the food items in the riverine environment. The diet of *L. victorianus* was dominated by detritus which may be attributed to the ventral position of the mouth of this fish which encourages detritivore mode of feeding. This finding concurs with (Owori-Wadunde, 2004) who found that the main food items for fish of the genus *Labeo* were detritus and epilithic algae. However, it is also probable that detritus was the major food item at the disposal of the fish in the river.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- This study did not find significant relationship between physico-chemical parameters and abundance of *L. victorianus* and *L. altianalis*. Only pH and hardness had a significant positive correlation with abundance of *L. victorianus* and *L. altianalis* respectively.

- Both *L. victorianus* and *L. altianalis* concentrated in the rivers with peak abundance during the long and short rain seasons. *Labeobarbus altianalis* was more abundant than *L. victorianus* in River Kuja-Migori during the period of the study.

- In terms of growth, *L. victorianus* and *L. altianalis* have become smaller in size with a short lifespan, faster growing and early maturation. They have growth performance indices which suggests that their life history strategy tend more to *r* - selection rather than *k* - selection.

- The average condition factor of both species was above 1.0 indicating that the two fish were in good condition during the extended and short rain seasons which were also the breeding seasons for both species showing that these fishes invest sufficient resources for reproduction.

- The length - weight relationships of *L. victorianus* and *L. altianalis* were allometric whereby growth in length was proportionate to growth in body weight.

- The GSI of females of *L. victorianus* and *L. altianalis* were high during the extended long and protracted short rains, these are also the periods when both fishes breed in the river. This supports the observation that both species deployed sufficient resources for reproductive activities.

- Fecundity of *L. victorianus* was higher than *L. altianalis* but the eggs of *L. altianalis* were bigger than those of *L. victorianus* by a factor of more than two times.

- Some ripe fish of both species were present in the river throughout the year, but peak numbers occurred during the protracted rain seasons. This further supports the observation that the two species deploy most of their resources for reproductive activities. There was evidence of fish which were indicating repeat spawning implying that the fish lay eggs in spawning grounds more than once in a year.

- There were two recruitment periods for both *L. victorianus* and *L. altianalis.* The first recruitment occured over extended periods coinciding with long rains. The second recruitment period occured over a shorter period of the year around October to November coinciding with short rains. There are possibly two sources of recruitment of both *L. victorianus* and *L. altianalis.* The first one is a well-established source that is the main lake (Lake Victoria) while the second appears to be riverine refugia where purely riverine populations exist.

- Studies on food and feeding habits indicated that there were ontogenic shifts in the diets of both species. The young ones of *L. victorianus* and *L. altianalis* fed predominantly on ephemeroptera, chironomids, coleoptera hemiptera and diptera while adults of both species fed on plant material and detritus.

6.2 Recommendations

- To conserve both species and ensure an increase in their stock sizes by imposing a ban on fishing in the river mouths (deltas/estuaries) which constitutes their gateway to the spawning grounds in the riverine environment during their lacustrine – riverine migration. Further, there should be no fishing in the riverine wetlands which are thought to provide refuge and breeding grounds for both species.

- Regulatory authorities should enforce the conservation of the riverine riparian zone to prevent any agricultural activities from taking place. In addition, enforce regulations on pollutants entering from urban and agricultural activities as well as mining wastes that are commonly discharged into the river.
- Since there are no bigger fish species in riverine habitat such as Nile perch and lung fish there is need to review fishing in the riverine environment and recommend the suitable fishing regime for the two fish species.
- Carry out research on egg and larval stages to aid in identifying and delineating the breeding grounds.
- Conduct research to identify habitats in which riverine populations of both species are found. The understanding on the connectivity of essential aquatic habitas utilized by migratory fishes and their characteristics throughout their life histories is essential to their effective conservation. This knowledge can be directed towards effective conservation of critical habitats for various life stages of fish.
- Identify through research specific localities in the riverine environment where embryonated larvae and juveniles of both species are found. Data on the ecological characteristics of this habitat is needed as well as the abundance and distribution of egg and larval stages.
- Conduct research to ascertain the frequency of spawning of individual fish particularly during the major extended recruitment period.

- Fish behavioral studies on both lacustrine and riverine environments will help in understanding the interaction and relatedness of different populations residing in these habitats.

REFERENCES

Abd El-Hack, M. E., El-Saadony, M. T. & Nader, M. M. (2022). Effect of environmental factors on growth performance of Nile tilapia (*Oreochromis niloticus*). International Journal of Biometeorology https://doi.org/10.1007/s00484-022-02347-6

Abdul, W. O., Omoniyi, I. T., Adekoya, E. O., Adeosun, F. I., Odulate, O. O., Idowu, A. A., Olajide, A. E. & Olowe, O. S. (2016). Length-weight relationship and condition factor of some commercial fish species in Ogun State Coastal Estuary, Nigeria. Ife Journal of Agriculture 28 (1):1–9.

Abedi, M., Shiva, A. H., Mohammadi, H. & Malekpour R. (2011). Reproductive biology and age determination of *Garra rufa* Heckel, 1843 (Actinopterygii: Cyprinidae) in central Iran. Turkish Journal of Zoology 35 (3): 317-323.

Abobi, S. M. (2015). Weight-length models and relative condition factors of nine (9) freshwater fish species from the Yapei stretch of the White Volta, Ghana. Elixir Applied Zoology 79: 30427–31.

Abrehouch, A., Ali, A. A., Chebbaki, K., Akharbach, H. & Idaomar, M. (2010). Effect of diet (fatty acid and protein) content during spawning season on fertility, eggs and larvae quality of common porgy (*Pagrus pagrus*, Linnaeus 1758). Agriculture and Biology Journal of North America 1(3): 175-184.

Achieng, A. O., Masese, F. O, Coffey, T. J., Raburu, P. O., Agembe, S. W., Febria, C. M. & Kaunda-Arara B. (2021). Assessment of the Ecological Health of Afrotropical Rivers Using Fish Assemblages: A Case Study of Selected Rivers in the Lake Victoria Basin. Kenya. Frontiers in Water 2:620704. doi: 10.3389/frwa.2020.620704.

Achieng, A. O., Masese, F. O. & Kaunda-Arara, B. (2020). Fish assemblages and size-spectra variation among rivers of Lake Victoria Basin, Kenya. Ecological Indicators 118:106745. doi: 10.1016/j.ecolind.2020.106745.

Adams, P. B. (1980). Life history patterns in marine fishes and their consequences for fisheries management. Fishery Bulletin 78: 1–12.

Akongyuure, D. N. & Alhassan, E. H. (2021). Variation of water quality parameters and correlation among them and fish catch per unit effort of the Tono Reservoir in Northern Ghana. Journal of Freshwater Ecology 36 (1): 253-269. DOI: 10.1080/02705060.2021.1969295.

Anteneh, W., Getahun, A., Dejen, E., Sibbing, F. A., Nagelkerke, L. A. J., De Graaf, M., Wudneh, T., Vijverberg, J. & Palstra, A. P. (2012). Spawning migrations of the endemic *Labeobarbus* (Cyprinidae, Teleostei) species of Lake Tana, Ethiopia: status and threats. Journal of Fish Biology 81: 750–765. DOI: 10.1111/j.1095-8649.2012. 03362.x

APHA, (2000). Standard Methods for the examination of water and wastewater. 20th ed. New York: American Public Health Association, American Water Works Association, Water Environment Federation.

Aruho, C., Walakira, J. K. & Rutaisire, J. (2018). An overview of domestication potential of *Barbus altianalis* (Boulenger, 1900) in Uganda. Aquaculture Reports 11: 31 – 37.

Aura, C. M., Odoli, C., Nyamweya, C. S., Njiru, J. M. Musa, S. Miruka, J. B. Owili, M. O. & Mbaru, E. K. (2020). Application of phytoplankton community structure for ranking the major riverine catchments influencing the pollution status of a lake basin. Lakes & Reservoirs 25: 3 –17. https ://doi.org/10.1111/lre.12307.

Bagenal, T. B. & Braum, E. (1978). Eggs and early life history. In: Bagenal, T., Ed., Methods of Assessment of Fish Production in Fresh Waters, IBP Handbook 3, Blackwell

Scientific, Oxford 165-201.

Bagenal, T. B. & Tesch, F. W. (1978). Methods for assessment of Fish Production in Freshwaters. T.B. Bagenal ed.) I. B. P. Handbook No. Edn 33. Oxford Blackwell Publications 365.

Balirwa, J. S. & Bugenyi, F. B. B. (1990). Notes on the fisheries of the River Nzoia, Kenya. Biological Conservation 18: 53-58.

Balirwa, J. S. (1979). A contribution to the study of the food of six cyprinid fishes in three areas of the Lake Victoria basin, East Africa. Hydrobiologia 66 (1): 65-72.

Balirwa, J. S., Chapman, C. A., Chapman, L. J., Cowx, I. G., Geheb, K., Kaufman, L. & Witte, F. (2003). Biodiversity and Fishery Sustainability in the Lake Victoria Basin: An Unexpected Marriage? BioScience 53 (8): 534–532.

Bayona, J. D. R. (2006). *Labeo victorianus*. The IUCN Red List of Threatened Species. Version 2015.2. <www.iucnredlist.org>. Accessed on 12 June 2021.

Beverton, R. J. H. & Holt, S. J. (1956). A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapports et Procès-Verbaux des RèunI ons Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée 140: 67-83.

Bithy, K., Miah, M. I., Haques, M. S., Hasan, K. R. & Islam, M. F. (2012). Estimation of the Fecundity of Jat Puti, *Puntius Sophore* (Hamilton). Journal of Environmental Sciences & Natural Resources 5 (2): 295- 300.

Brooks, S., Tyler, C. R. & Sumpter, J. P. (1997). Egg quality in fish: what makes a good egg? Reviews in Fish Biology and Fisheries 7: 387 – 416.

Brown-Peterson, N. J., Wyanski, D. M., Saborido- Rey, F., Macewicz, B. J. & Lowerre-Barbieri, S. K. (2011). A standardized terminology for describing reproductive development in fishes. Marine and Coastal Fisheries 3 (1): 52-70.

Cadwalladr, D. A. (1965). The decline in the *Labeo victorianus* (Boulenger) (Pisces: Cyprinidae) fishery of Lake Victoria and an associated deterioration in some indigenous fishing methods in the Nzoia river, Kenya. East Africa Agricultural and Forestry Journal 30: 249 – 256.

Chemoiwa, E. J., Abila, R., Njenga, E. W. & Barasa, J. (2017). Morphological Characterization and Relationship between Morphometric Parameters and Standard Length of *Barbus altianalis* (Boulenger, 1904) Populations in Lake Victoria Drainage Basin, Kenya. Annual Research and Review in Biology 14 (5): 1-11.

Clark, L. & Grant, J.W. A. (2010). Intrasexual competition and courtship in female and male Japanese medaka, Oryzias latipes: effects of operational sex ratio and density. Animal Behaviour 80: 707-712.

Côté, I. M. (2003). Knowledge of reproductive behavior contributes to conservation programs. In: Festa- Bianchet, M., Apollonio, M. (ed.) Animal Behavior and Wildlife Conservation. Island Press. 77-92.

Dadebo, E., Ahlgren, E. & Ahlgren, I. (2011). Aspects of reproductive biology of *Labeo horie* Heckel (Pisces: Cyprinidae) in Lake Chamo Ethiopia. African Journal of Ecology 41: 31–38.

Deepak, S., & Singh, N. U. (2014). The Relationship between Physico-chemical Characteristics and Fish Production of Mod sagar Reservoir of Jhabua District, MP, India. Research Journal of Recent Sciences 3, 82-86.

Dingle, H. (1996). Migration: The Biology of Life on the Move. Oxford University Press.

Domínguez-Petit, R., Anastasopoulou, A., Cubillos, L., Gerritsen, H. D., Gonçalves, P., Hidalgo M., Kennedy, J., Korta M., Marteinsdottir, G., Morgado, C., Muñoz, M., Quincoces, I., Saínza, M., Thorsen, A. & Vitale, F. (2017). Chapter 3: Maturity. In Handbook of applied fisheries reproductive biology for stock assessment and management, ed. R. Domínguez-Petit, H. Murua, F. Saborido-Rey and E. Trippel. Vigo, Spain. Digital CSIC. http://hdl.handle.net/10261/87787.

FAO, (1988). Fisheries Report No. 389. Rome, Italy.

FAO, (2005). State of the world fisheries and aquaculture. FAO. Rome, Italy.

Forsythe, P. S., Crossman, J. A., Bello, N. M., Baker, E. A. & Scribner, K. T. (2012). Individual-based analyses reveal high repeatability in timing and location of reproduction in lake sturgeon (*Acipenser fulvescens*). Canadian Journal of Fisheries and Aquatic Science 68:1-13.

Froese, R. & Pauly, D. Editors. (2022). FishBase. World Wide Web electronic publication. www.fishbase.org, (06/2022).

Froese, R., J. Thorson, R. B. & Reyes, J. (2013). A Bayesian approach for estimating length-weight relationships in fishes. Journal of Applied Ichthyology 1-7.

Ganias, K., Murua, H., Claramunt, G., Dominguez-Petit, R., Gonçalves, P. & Yoneda, M. (2014). Chapter 4: Egg production, 109 pp. In Handbook of applied fisheries reproductive biology for stock assessment and management, ed. R. Domínguez-Petit, H. Murua, F. Saborido-Rey & E. Trippel. Vigo, Spain. Digital CSIC. http://hdl.handle.net/10261/87768.

Gayanilo, J. F. C. & Pauly, D. (1997). FAO-ICLARM fish stock assessment (FiSAT) reference manual. FAO Computerized Information Series (Fisheries), 8, 2.

Gebremedhin, S., Bruneel, S., Getahun, A., Anteneh, W., & Goethals, P. (2019). The Endemic Species Flock of *Labeobarbus* spp. in Lake Tana (Ethiopia) Threatened by Extinction: Implications for Conservation Management of Water 11 (12), 2560.

http://dx.doi.org/10.3390/w11122560.

Gibson-Reinemer, D. K., Stewart, D. R., Fritts, M. W., DeBoer, J. A. & Casper, A. F. (2016). Estimating the effects of environmental variables and gear type on the detection and occupancy of large-river fishes in a standardized sampling program using multiseason Bayesian mixture models 36 (6): 1445–1456. doi:10.1080/02755947.2016.1206642.

Gichuki, J., Guebas, D. F., Mugo, J., Rabuor, C. O., Triest, L. & Deahairs, F. (2001). Species Inventory and the Local Uses of the Plants and Fishes of the Lower Sondu Miriu Wetland of Lake Victoria, Kenya.

Godinho, A. L., Lamas, I. R. & Godinho, H. P. (2010). Reproductive ecology of Brazilian freshwater fishes. Environmental Biology of Fishes, 87 (2): 143-162. http://dx.doi.org/10.1007/s10641-009- 9574-4.

Goldstein, R. M. & Meador, M. R. (2005). Multilevel assessment of fish species traits to evaluate habitat degradation in streams of the Upper Midwest. North American. Journal of Fisheries Management 25: 180 –194.

Gonçalves, C. S., Souza, U. P, Ferreira, F. C, Peressin, A. & Braga, F. M. S. (2013). Life-history strategies associated to reproduction of three Hyphessobrycon species (Characidae) in lentic environments of upper Paraná River basin. Acta Limnologica Brasiliensia 25 (4): 398-405.

Gordon, D. M. (2003). Technological change and economies of scale in the history of Mweru Luapula's fishery (Zambia and Democratic Republic of the Congo). In Management, Co-management or No-management? Major Dilemmas in Southern African Freshwater Fisheries (Jul-Larsen, E., Kolding, J., Over, R., Raakjær Nielsen, J. & van Zwieten, P. A. M., eds), pp. 164–178. FAO Fisheries Technical

Paper 426.

Grant, J. W., Gaboury, C. L. & Levitt, H. L. (2000). Competitor-to-resource ratio, a general formulation of operational sex ratio, as a predictor of competitive aggression in Japanese medaka (Pisces: Oryziidae). Behavioral Ecology 11 (6): 670-675.

Greboval, D. & Mannini, P. (1992). The Fisheries of Lake Victoria: Review of Basic Data. UNDP/FAO Regional Project. Inland Fisheries Planning. RAF/87/099/WP/16/92. FAO, Rome.

Gupta, M., Pandey, N. N., Tiwari, V. K., Singh, R., Prakash C. & Chaturvedi, C. S. (2013). Study of Gonadosomatic Index and fecundity of pond raised *Labeo dyocheilus* in cold water conditions. International Journal of Advanced Research 1 (7): 137-140.

Hitt, N. P., Rogers, K. M., Kelly, Z. A., Henesy, J. & Mullican J. E. (2020). Fish life history trends indicate increasing flow stochasticity in an unregulated river. Ecosphere 11(2): e03026. 10.1002/ecs2.3026.

Hossain, M. Y., Rahman, M. M., Fulanda, B., Jewel, M. A. S., Ahamed, F. & Ohtomi, J. (2011). Length- weight and length-length relationships of five threatened fish species from the Jamuna (Brahmaputra River tributary) River, northern Bangladesh. Journal of Applied Ichthyology p.1-3.

Jakobsen, T. & Ajiad, A. (1999). Management Implications of Sexual Differences in Maturation and Spawning Mortality of Northeast Arctic Cod. Journal of Northwest Atlantic Fishery Science 25: 125–131.

Kembenya, E. M., Marcial, H. S., Outa, N. O., Sakakura, Y. & Hagiwara, A. (2016). Captive Breeding of Threatened African Carp, *Labeo victorianus*, of Lake Victoria. Journal of the World Aquaculture Society doi: 10.1111/jwas.12328.

Kibaara, D. (1981). Endangered fish species of Kenya's inland waters with emphasis on Labeo spp. Aquatic Resources of Kenya, July 13–19, 13–19.

King, J. R. & McFarlane, G. A. (2003). Marine fish life history strategies: applications to fishery management. Fisheries Management and Ecology 10:249–264.

Kizza, M., Rodhe, A., Xu, C., Ntale, H. K. & Halldin, S. (2009). Temporal rainfall variability in the Lake Victoria Basin in East Africa during the twentieth century. Theoretical and Applied Climatology 98: 119-135.https://doi.org/10.1007/s00704-008-0093-6.

Kominoski, J. S., Ruh, A., Hagler, M. M., Petersen, K., Sabo, J. L., Sinha, T., Sankarasubramanian, A. & Olden, J. D. (2018). Patterns and drivers of fish extirpations in rivers of the American Southwest and Southeast. Global Change Biology 24:1175–1185.

Larsen, S., Brunoa, M. C., Vaughan, I. P. & Zolezzia, G. (2019). Testing the River Continuum Concept with geostatistical stream-network models. Ecological Complexity 39. 100773.

Lawson, E. O. (2011). Physico-Chemical Parameters and Heavy Metal Contents of Water from the Mangrove Swamps of Lagos Lagoon, Lagos, Nigeria. Advances in Biological Research 5: 8-21.

Lederoun, D., Vandewalle, D. & Lalèyè. P. A. (2020). Reproductive Biology of the African Lungfish *Protopterus annectens annectens* (Owen, 1839) in the Mono River Basin of Benin, West Africa. Journal of fisheries and environment 44 (3).

Livingston, R. J., X. Niu., Lewis F. H. & Oodsum, G. C. W. (1997). Freshwater input to a gulf estuary: Long-term control of trophic organization. Ecological Applications 7: 277–299.

Lone, K. P & Hussain, A. (2009). Seasonal and Age-related variations in the ovaries of *Labeo rohita* (Hamilton, 1822): A Detailed Gross and Histological Study of

Gametogenesis, Maturation and Fecundity. Pakistan Journal of Zoology 41 (3): 217-239.

Lowerre-Barbieri, S. K., Ganias, K., Saborido-Rey, F., Murua, H. & Hunter, J. R. (2011). Reproductive timing in marine fishes: variability, temporal scales, and methods. Marine and Coastal Fisheries 3: 71–97.doi:10.1080/19425120.2011.556932.

Lytle, D. A. & Poff, N. L. (2004). Adaptation to natural flow regimes. Trends in Ecology & Evolution 19: 94–100.

Manal, M. S., Rasha, A. H. Magdy, E. A. & Mohammed, I. (2017). Sexual maturity, spawning activity, sex ratio and fecundity of two Mullidae species dwelling the Gulf of Suez, Red Sea. Egyptian Journal of Aquatic Research 43: 83–91, http://dx.doi.org/10.1016/j.ejar.2016.04.007.

Manyala, J. O., Bolo, J. Z., Onyang'o, S. & Rambiri, P. O. (2005). Indigenous knowledge and baseline data survey on fish breeding areas and seasons in Lake Victoria, Kenya. In: Knowledge and Experiences gained from Managing the Lake Victoria Ecosystem, Mallya, G. A, Katagira F. F, Kang'oha, G., Mbwana, S. B., Katunzi, E. F., Wambede, J. T., Azza, N., Wakwabi, E., Njoka, S. W., Kusewa, M., Busulwa, H. (eds). Regional Secretariat, Lake Victoria Environmental Management Project (LVEMP): Dar es Salaam; 529-551 pp.

Masese, F. O., Achieng, A. O., Raburu, P. O., Lawrence, T., Ives, J. T., Nyamweya, C. & Kaunda-Arara B. (2020). Distribution patterns and diversity of riverine fishes of the Lake Victoria Basin, Kenya. International Review of Hydrobiology 105: 171–184.doi: 10.1002/iroh.202002039.

Maskill, P. A. C., Miller, I. R., Halvorson, L. J., Treanor, H. B. Fraser, C.W. & Webb, M. A. H. (2017). Role of sex ratio and density on fertilization success of intensively cultured endangered woundfin. Journal of Fish and Wildlife Management 8 (1): 249–254; e1944-687X. doi: 10.3996/062016-JFWM-048.

Mbalassa, M., Bagalwa, J. J. M., Nshombo, M. & Kateyo, M. E. (2014). Assessment of physicochemical parameters in relation with fish ecology in Ishasha River and Lake Edward, Albertine Rift Valley, East Africa. International Journal of Current Microbiolology and Applied Science 3(6): 230-244.

Mills, C. A. (1991). Reproduction and life history. In: Winfield I. J. & Nelson J. S. (eds.) Cyprinids Fishes: Systematics, Biology and exploration. pp. 483-488 Chapman & Hall, London.

Mims, M. C, Olden, J. D, Shattuck, Z. R. & Poff, N. L. (2010). Life history trait diversity of native freshwater fishes in North America. Ecology of Freshwater Fish 19: 390–400.

Miranda, R., Galicia, D., Monks, S. & Pulido-Flores, G. (2009). Weight-length relationships of some native freshwater fishes of Hidalgo State, Mexico. Journal of Applied Ichthyology 25: 620–621.

Mishra, S. & Saksena, D. N. (2012). Gonadosomatic Index and Fecundity of an Indian Major Carp *Labeo Calbasu* in Gohad Reservoir. The Bioscan 7 (1): 43-46.

Mohammad, A. & Pathak, J. K. (2011). Assessment of Fecundity and Gonadosomatic Index of Commercially Important Fish, *Labeo Rohita* from Ramganga River. International Journal of Pharma and Bio Sciences 1 (3).

Montchowui, E., Laleye, P., Moreau, J., Philippart, J. C. & Poncin, P. (2009). Population parameters of African carp: *Labeo parvus* Boulenger, 1902 (Pisces: Cyprinidae) in the Ouémé River in Bénin (West Africa). North-Western Journal of Zoology 5 (1): 26-33

Moradinasab, G. H. Daliri, M. Ghorbani, R. Paighambari, S.Y. & Davoodi, R. (2012). Length-weight and length-length relationships, Relative condition factor and Fulton's condition factor of Five Cyprinid species in Anzali wetland, southwest of the Caspian Sea. Caspian Journal of Environmental Sciences 10 (1): 25-31.

Morgan M.J. (2008). Integrating reproductive biology into scientific advice for fisheries management. Journal of Northwest Atlantic Fishery Science 41: 37–51. https://doi.org/10.2960/J.v41.m615.

Mugo, J. & Tweddle, D. (1999). Preliminary surveys of the fish and fisheries of the Nzoia, Nyando and Sondu/Miriu rivers, Kenya. Part I. In Report of Third FIDAWOG Workshop (Tweddle, D. & Cowx, I. G., eds), LVFRP Technical Report 99/06. pp. 106–125.

Muli, J. & Ojwang, W. (1996). Growth and mortality rates of an endangered species, *Synodontis victoriae*, in Sondu Miriu river, Kenya. In: I.G. Cowx (ed.) Stock assessment in inland fisheries. Oxford, Fishing News Books, Blackwell Science 409-416.

Murua, H., Kraus, G., Saborido, F. R., Witthames, P. R., Thorsen, A. & Junquera, S. (2003). Procedures to Estimate Fecundity of Marine Fish Species in Relation to their Reproductive Strategy Journal of Northwest Atlantic Fishery Science 33: 33-54.

Mwangi, B. M., Ombogo, M. A., Amadi, J., Baker, N. & Mugalu, D. (2012). Fish Species Composition and Diversity of Small Riverine Ecosystems in the Lake Victoria Basin, Kenya. International Journal of Science and Technology 2 (9): 675-680.

Nabi, G., Amin, M., Ullah, N. & Ahmed N. (2014). An overview on the causes, types and role of hormones in fish migration. International Journal of Scientific & Engineering Research 5 (8) 404-412.

Nazek, J., Ghassan, Y., Carol, S. & Mohammad, H. E. (2018). Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon. Egyptian Journal of Aquatic Research 44: 299 - 305.

Neebling, T. E. & Quist, M. C. (2011). Comparison of boat electrofishing, trawling, and seining for sampling fish assemblages in Iowa's non wadeable rivers. North American Journal of Fisheries Management 44: 299–305. doi:10.1080/02755947.2011.576198.

Njiru, M., Getabu, A., Jembe, T., Ngugi, C., Owili, M. & van Knaap, M. (2008). Management of the Nile tilapia (*Oreochromis niloticus* (L.) fishery in the Kenyan portion of Lake Victoria, in light of changes in its life history and ecology. Lakes & Reservoirs: Research and Management 13: 117–124.

Njiru, M., Ojuok, J. E., Okeyo-Owuor, J. B., Muchiri, M., Ntiba, M. J. & Cowx, I. G. (2006). Some biological aspects and life history strategies of Nile tilapia *Oreochromis niloticus* (L.) in Lake Victoria, Kenya. East African Wildlife Society, African Journal of Ecology 44: 30 – 37.

Njiru, M., Okeyo-Owuor, J. B. Muchiri, M. & Cowx, I. G. (2004). Shifts in the food of Nile tilapia, *Oreochromis niloticus* (L.) in Lake Victoria, Kenya. African Journal of Ecology 42:163–170.

Njiru, M., Waithaka, E., Muchiri, M., Knaap, V. M. & Cowx I. G. (2005). Exotic introductions to the fishery of Lake Victoria: What are the management options? Lakes & Reservoirs: Research and Management 10: 147–155.

Northcote, T. G. (1978). Migratory strategies and production in freshwater fishes. pp. 326-359. *In:* Gerking SD (ed.). Ecology of Freshwater Fish Production. Blackwell Scientific Publications, Oxford, UK.

Northcote, T. G. (1984) Mechanisms of fish migration in rivers. pp. 317-355. In: McCleve J.D, Amold G P, Dodson J. J and Neill W. H (eds.). Mechanisms of Migration in Fishes. Plenum Press, New York.

Northcote, T. G. (1997). Potamodromy in Salmonidae living and moving in the fast lane. North American Journal of Fisheries Management 17: 1029-1045.

Nunes, C, Silva, A., Soares, E. & Ganias K (2011) The use of hepatic and somatic indices and histological information to characterize the reproductive dynamics of Atlantic sardine sardina pilchardus from the Portuguese coast. Marine and Coastal Fisheries 3(1), 127–144. https://doi.org/10.1080/19425120.2011.556911.

Nunez, J. & Duponchelle, F. (2009). Towards a universal scale to assess sexual maturation and related life history traits in oviparous teleost fishes. Fish Physiology and Biochemistry 35 (1): 167–180. doi: 10.1007/s10695-008-9241-2.

Nyaundi, J., Getabu, A., Onchieku, J., Kinaro, Z., Bassa, S., Nyamweya, C., Hilda, N. & Getenga Z. (2019). Occurrence and distribution of Organochlorine Pesticide Residues in Water and Sediments of Earthen Fish Ponds in South Western Kenya. Uganda Journal of Agricultural Sciences 19 (2): 47 – 60. DOI: http://dx.doi.org/10.4314/ujas.v19i2.5.

Ochumba, P. B. O. & Manyala, J. O. (1992). Distribution of fishes along the Sondu-Miriu River of Lake Victoria, Kenya with special reference to upstream migration, biology and yield. Aquaculture and Fish Management 23: 701-719.

Odada, E. O., Olago, D.O., Kulindwa, K., Ntiba, M. & Wandiga, S. (2004). Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy option analyses. Ambio 33: 617–627.

Ogamba, E. N., Abowei, J. F. N. & Onugu, A. (2014). Length-weight relationship and condition factor of selected finfish species from Odi River, Niger Delta, Nigeria. Journal of Aquatic Science 29: 1–12.

Ogutu-Ohwayo, R. (1990). The reduction in fish species diversity in Lake Victoria and Kyoga (East Africa) following human exploitation and introduction of nonnative fishes. Journal of Fish Biology 37 (Suppl. A): 207-208.

Ojutiku, R. O., Kolo, R. & Ogunseye, J. (2012). A Fecundity and Length-Weight Relationship of Two Commercially Important Fish Species in Minna, Niger State. Journal of Agriculture, Forestry and the Social Sciences (9) 2.

Ojwang, W. O., Kaufman, L., Soule, E. & Asila, A. A. (2007). Evidence of stenotopy and anthropogenic influence on carbon source for two major riverine fishes of the Lake Victoria watershed. Journal of Fish Biology 70 (5): 1430-1446. https://doi.org/10.1111/j.1095-8649.2007.01421.x.

Okito, G. M., Kasigwa, D. D. C., Micha, J. C., Muderhwa, V. N., Ribakare, O. R., Nzibonera, P. B. & Kaluba, P. M. (2017). Food ecology of *L. victorianus* (Boulenger, 1900) in the Basin Luhoho River, in Kalehe territory (South Kivu, DR Congo). International Journal of Biological and Chemical Sciences 11 (1): 208-227.

Olaka, L. A., Ogutu, J. O., Said, M. Y., & Oludhe, C. (2019). Projected climatic and hydrologic changes to LakeVictoria Basin Rivers under three RCP emission scenarios for 2015–2100 and impacts on the water sector. Water 11:1449. doi: 10.3390/w11071449

Olden, J. D. & Kennard M. J. (2010). Intercontinental Comparison of Fish Life History Strategies along a Gradient of Hydrologic Variability. America Fisheries Society Symposium 73: 83–107

Oliveira, M. S. B.; Silva, L. M. A.; Prestes, L. & Tavares-Dias, M. (2020). Length-weight relationship and condition factor for twelve fish species from the Igarapé Fortaleza basin, a small tributary of the Amazonas River estuary. Acta Amazonica 50: 8-11.

Omondi, R., Kembenya, E., Nyamweya, C., Ouma, H., Machua, S.K. & Ogari, Z. (2014). Recent limnological changes and their implication on fisheries in Lake Baringo, Kenya. Journal of Ecology and The Natural Environment, 6(5): 154-163.

Omwoma, S., Owuor, P., Ongeri, D. M. K., Umani, M., Lalah, J. O. & Schramm, K. W. (2014). Declining commercial fish catches in Lake Victoria's Winam Gulf: The importance of restructuring Kenya's aquaculture programme. Lakes and Reservoirs: Research and Management 19: 206–210.

Ondhoro, C. C, Masembe, C., Maes, G. E, Nkalubo, N. W., Walakira, J. K., Naluwairo, J., Mwanja, M. T. & Efitre, J. (2016). Condition factor, length–weight relationship, and the fishery of *Barbus altianalis* (Boulenger 1900) in lakes upper Victoria and Edward basins of Uganda. Environmental Biology of Fishes 1–12. https://doi.org/10.1007/s10641-016-0540-7.

Orina, P. S., Rasowo, J., Gichana, E., Maranga, B. & Karisa, H. C. (2014). Artificial Breeding Protocol and Optimal Breeding Environment for *Labeo victorianus* (Boulenger, 1901). International Journal of Fisheries and Aquatic Studies 1 (6): 138-143.

Orwa, P. O., Raburu, P., Njiru, J. & Okeyo-Owuor, J. B. (2012). Human Influence on macroinvertebrate community structure within Nyando wetlands, Kenya. International Journal of Aquatic Science 3 (2): 28-48.

Outa, N. O., Yongo, E. O., Keyombe, J. L. A., Ogello, E. O. & Namwaya Wanjala, D. (2020). A review on the status of some major fish species in Lake Victoria and possible conservation strategies. Lakes & Reservoirs: Research & Management, 25(1): 105-111.

Owori-Wadunde, A. (2004). The feeding habits and development of digestive system of *Labeo victorianus* Blgr (pisces: Cyprinidae), http://repository.eac.int/handle/11671/814 accessed 10th October 2021.

Oyoo-Okoth, E. O, Cherop, L., Ngugi, C. C., Boit, C. V., Lusega, M. M., Sabwa, J. A. & Karisa C. H. (2011). Survival and physiological response of *Labeo victorianus* (Pisces: Cyprinidae, Boulenger 1901) juveniles to transport stress under a salinity gradient. Aquaculture 319: 226–231.

Pérez-Palafox, X. A., Morales-Bojórquez, E., Aguirre-Villaseñor, H. & Cruz-Escalona, V. H. (2022). Length at Maturity, Sex Ratio, and Proportions of Maturity of the Giant Electric Ray, Narcine entemedor, in Its Septentrional Distribution. Animals 12, 120. https://doi.org/10.3390/ ani12010120.

Peter, R. E. & Yu, K. L. (1997). Neuroendocrine regulation of ovulation in fishes: basic and applied aspects. Reviews in Fish Biology and Fisheries 7: 173-197.

Peters, N., Bricker, O. & Kennedy, M. (1997**).** Water quality trends and geochemical mass balance, John Willy & Sons.p. 139-170.

Pfauserova, N., Brabec, M., Slavík, O., Horký, P., Žlábek, V. & Hladík M. (2022). Effects of physical parameters on fish migration between a reservoir and its tributaries. Scientific reports 12: 8612. doi.org/10.1038/s41598-022-12231-3.

Poff, N. L-R., Brown, C. N., Grantham, T. E., Matthews, J. H., Palmer, M. A., Spence, C. M., Wilby, R. & Baeza, A. (2015). 'Sustainable water management under future uncertainty with eco-engineering decision scaling. Nature Climate Change 6: 25–34.

Raburu, P. O., Masese F. O. & Mulanda, C. A. (2009). Macroinvertebrate Index of Biotic Integrity (M-IBI) for monitoring rivers in the upper catchment of Lake Victoria

Basin, Kenya. Aquatic Ecosystem Health and Management 12: 197-205.

Rahman, M. A., Yusoff, F. M., Arshad, A., Amin, S. M. N. & Shamsudin, M. N. (2013). Population Characteristics and Fecundity Estimates of Short-spined White Sea Urchin, *Salmacis sphaeroides (*Linnaeus, 1758) from the Coastal Waters of Johor. Malaysia Asian Journal of Animal and Veterinary Advances 8: 301-308.

Romano, N., Egnew N., Quintero H., Kelly A. & Sinha A. K. (2020). The effects of water hardness on the growth, metabolic indicators and stress resistance of largemouth bass Micropterus salmoides. Aquaculture 12:735469. doi: 10.1016/j.aquaculture.2020.735469.

Rose, K. A. (2000). Why are quantitative relationships between environmental quality and fish populations so elusive? Ecological Applications 10: 367–385.

Rowe, S., Hutchings, J. A., Bekkevold, D. & Rakitin, A. (2004). Depensation, probability of fertilization, and the mating system of Atlantic cod (*Gadus morhua* L.). ICES Journal of Marine Science 61(7): 1144-1150.

Rutaisire, J. & Booth, A. (2005). Reproductive Biology of Ningu, *Labeo victorianus* (Pisces: Cyprinidae), in the Kagera and Sio Rivers, Uganda. Environmental Biology of Fishes, 73:153–162.

Rutaisire, J. (2003). The reproductive biology and artificial breeding of ningu *Labeo vicroriunus.* Doctoral thesis. Rhodes University, Grahams town, South Africa.

Rutaisire, J. (2004). Induced Ovulation, Spawning, Egg Incubation, and Hatching of the Cyprinid Fish *Labeo victorianus* in Captivity. Journal of the World Aquaculture Society 35, 3.

Sarkar, U. K., Khan, G. E., Dabas, A., Pathak, A. K., Mir, J. I., Rebello, S. C., Pal, A. & Singh S. P. (2006). Length - weight relationship and condition factor of selected freshwater species found in River Ganga, Gomti and Rapti India”. Journal of Environmental biology 34: 951 – 956.

Sayer, C. A., Máiz-Tomé, L., Akwany, L. O., Kishe-Machumu, M. A., Natugonza, V., & Whitney, C. W. (2018). “The importance of freshwater species to livelihoods in the Lake Victoria basin,” in Freshwater Biodiversity in the Lake Victoria Basin: Guidance for Species Conservation, Site Protection, Climate Resilience and Sustainable Livelihoods (Gland: International Union for Conservation of Nature), 136-151.

Schill, D., Thurow, R. & Kline P. (1994). Seasonal movement and spawning mortality of fluvial bull trout in Rapid River, Idaho. Progress Report. Project: F-73-R-15, Job2. Idaho Department of Fish and Game. Boise.

Schlosser, I. J. (1991). Stream fish ecology: a landscape perspective. BioScience 41: 704 -712.

Shabir, A. D., Najar, A. M., Balkhi, Mohd, A. R. & Sharma, R. (2012). Length - weight relationship and relative condition factor of Schizopyge. International Journal of Aquatic Science 3 (1): 29-36.

Shinkafi, B. A, Ipinjolu, J. K & Hassan, W. A. (2011). Gonad maturation stages of *Auchenoglanis occidentalis* (Valenciennes 1840). Journal of Fisheries and Aquatic Science 6 (3): 236-246. doi 10.3923/jfas.2011.236.246.

Shoko, A. P., Limbu, S. M., Mrosso, H. D. J. & Mgaya, Y. D. (2015). Reproductive biology of female Nile tilapia, *Oreochromis niloticus* (Linnaeus) reared in monoculture and polyculture with African sharptooth catfish *Clarias gariepinus* (Burchell). SpringerPlus 4:275 doi:10.1186/s40064-015-1027-2.

Sindhe, V. R & Kulkarni, R. S. (2004). Gonadosomatic and hepatosomatic indices of freshwater fish *Notopterus notopterus* (pallas) in response to some heavy metal exposure, Journal of Environmental Biology 25(3): 365-68.

Singh, R. K., Khandagale, P. A., Chavan, S. L. & Sapkale, P. H. (2006). The relationship of ova diameter to Fertilization Rates, Hatching Rates, Survival percentage and Specific Growth Rates in the common carp and Indian major carps. Asian Fish Science 19: 257-269.

Skelton, P. H., Tweddle, D. & Jackson, P. (1991). Cyprinids of Africa. In: Winfield, I. J., Nelson, J. S. (Eds.), Cyprinid Fishes, Systematics, Biology and Exploitation. Chapman & Hall, London, UK pp. 211–239.

Snoeks, J., Kaningini, B., Masilya, P., Nyina-Wamwiza, L. & Guillard, J. (2012). Fishes in Lake Kivu: diversity and fisheries. Lake Kivu. Springer, Netherlands. https://doi.org/10.1007/978-94-007-4243-7_8. pp. 127–152.

Snyder, D. E. (1983). Fish eggs and larvae. In Nielsen, L. A. & D. L. Johnson (eds., Fisheries techniques, American Fisheries Society, Bethesda p. 165-197.

Stearns, S. C. (1992). The evolution of life histories. Oxford University Press, Oxford.

Stergiou, K. I. (2000). Life-history patterns of fishes in the Hellenic Seas. Web Ecology 1: 1–10.

Thorstad, E. B., Økland, F. & Aarestrup, K. (2008). Factors affecting the within-river spawning migration of Atlantic salmon, with emphasis on human impacts. Reviews in Fish Biology and Fisheries 18, 345–371. https://doi.org/10.1007/s11160-007-9076-4.

Thurow, R. F. (2016). Life histories of potamodromous fishes [Chapter 4]. In: Morais, Pedro; Daverat, Franchise, eds. An introduction to fish migration. Boca Raton, FL: CRC Press. p. 29-54.

Trindade-Santos, I. & Freire, K. M. F. (2015). Analysis of reproductive patterns of fishes from three Large Marine Ecosystems. Frontiers in Marine Science 2:38. doi:

10.3389/fmars.2015.00038.

UNDPI (United Nations Department of Public Information) (2010). General facts regarding world fisher. Resumed review conference on the agreement relating on the conservation and management of straddling fish stock and highly migratory fish stocks. New York.

Uthayakumar, V., Sreedevi, P., Senthi, D., Munirasu, K. S., Kiruba, A. & Ramasubramanian, V. (2013). Impact of seasonal variation and feeding on reproductive behavior of freshwater spiny eel *Mastacembelus armatus* from Cauvery River. Asian Pacific Journal of Reproduction 2(3): 189-195.

Vannote, R. L., G. W. Minshall, K. W., Cummins, J. R., Sedell, & Cushing, C. E. (1980). The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

Volff, J. H. (2004). Genome evolution and biodiversity in teleosts fish. Heredity 94: 280-2941.

Weir, L. K. (2013). Male–male competition and alternative male mating tactics influence female behavior and fertility in Japanese Medaka (*Oryzias latipes*). Behavioral Ecology and Sociobiology 67:193–203.

Welcomme, R. L., Winemiller, K. O. & Cowx, I. G. (2006). Fish environmental guilds as a tool for assessment of ecological condition of rivers. River Research and Applications 22: 377–396.

Wenjia, H., Guanqiong, Y., Zhenbin, L., Jianguo, D., Mingru, C., Loke, M. C. & Shengyun, Y. (2015). Study on fish life history traits and variation in the Taiwan Strait and its adjacent waters. Acta Oceanologica Sinica 34 (2): 45-54.

Wetherall, J. A. (1986). A new method for estimating growth and mortality parameters from length-frequency data. Fishbyte 4 (1): 12-14.

Weyl, O. L. F. & Booth, A. J. (1999). On the life-history of a cyprinid fish, *Labeo cylindricus*. Environmental Biology of Fishes 55: 215-225.

Williams, S. C. (2011). Life history characteristics of three obligate riverine species and drift patterns of lower Brazos River fishes. PhD Thesis, San Marcos, Texas.

Winemiller, K. O. (2005). Life history strategies, population regulation, and implications for fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 62: 872–885, https://doi.org/10.1139/f05-040.

Winemiller, K. O., & Rose, K. A. (1992). Patterns of life-history diversification in North American fishes: implications for population regulation. Canadian Journal of Fisheries and Aquatic Sciences 49: 2196–2218.

Winker, H., Weyl, O. L. F., Booth, A. J. & Ellender, B. R. (2012). Life history strategy and population characteristics of an unexploited riverine cyprinid, *Labeo capensis*, in the largest impoundment in the Orange River Basin. African Zoology 47 (1): 85–99.

Witte, F., Kishe-Machumu, M. A., Mkumbo, O. C., Wanink, J. H., Goudswaard, P. C., Van Rijssel, J. C. & van Oijen, M. J. P. (2008). The fish fauna of Lake Victoria during a century of human induced perturbations. In Snoeks J. & Getahun A. (eds), Proceedings of the Fourth International Conference on African Fish and Fisheries, Addis Ababa, Ethiopia, 22-26 September 2008. Tervuren: Royal Museum for Central Africa, 'Zoological Documentation Online Series', pp. 49-66.

Wootton, R. J. (1984). Introduction: Tactics and strategies in fish reproduction. In: Potts, G.W. & Wootton, R. J., eds. Fish reproduction: strategies and tactics. London: Academic Press, pp. 1–12.

Xiang, M., Rypel, A. L., Cheng, F., Qin, J., Zhang, L., Chen, Y. & Xie, S. (2021). Shift towards

Opportunistic Life-History of Sleeper in Response to Multi-Decadal Overfishing. Water, 13, 2582. https://doi.org/ 10.3390/w13182582.

Yongo, E., Olukoye, J., Makame, A., & Chebon, B. (2019). Changes in some biological parameters of the silver cyprinid, *Rastrineobola argentea* (Pellegrin, 1904) in the Nyanza Gulf of Lake Victoria, Kenya. Lakes & Reservoirs 1–4. doi.org/10.1111/lre.12281.

Zhang, P., Qiao, Y., Jin, Y., Lek, S., Yan, T., He, Z., Chang, J. & Cai, L. (2020). Upstream migration of fishes downstream of an under-construction hydroelectric dam and implications for the operation of fish passage facilities, Global Ecology and Conservation 23: 1-13.

Zhou, G., Gao, H., & Cuo, L. (2016). Effects of urbanization and climate change on peak flows over the San Antonio River basin, Texas. Journal of Hydrometeorology 17:2371–2389.

LIST OF APPENDICES

Appendix 1: Research License from the National Commission for Science, Technology, and Innovation

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 542762

Date of Issue: 12/July/2021

RESEARCH LICENSE

This is to Certify that Mr.. Elijah Migiro Kembenya of Kisii University, has been licensed to conduct research in Migori, Narok on the topic: LIFE HISTORY STRATEGY PATTERNS OF SELECTED FISH SPECIES OF THE KUJA- MIGORI RIVER BASIN IN SOUTH WEST KENYA for the period ending : 12/July/2022.

License No: **NACOSTI/P/21/11656**

542762

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

Appendix 2: Electrofishing equipment used during collection of fish samples from River Kuja – Migori from January 2018 to June 2019

Appendix 3: Electrofishing in River Kuja – Migori

Appendix 4: Sorting and preservation of fish samples for further laboratory examination

Appendix 5: Samples of *Labeo victorianus* collected from River Kuja Migori

Appendix 6: Samples of *Labeobarbus altianalis* collected from River Kuja -Migori

Appendix 7: Fish gut content samples used to analyze food items

Appendix 8: Female fish with ovaries dissected for estimation of fecundity

Appendix 9: Plagiarism report

STUDIES ON LIFE HISTORY STRATEGIES OF Labeobarbus altianalis (BOULENGER 1900) AND Labeo victorianus (BOULENGER 1901) IN RIVER KUJA -MIGORI, KENYA

ORIGINALITY REPORT

17%	13%	10%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	journal.bdfish.org Internet Source	2%
2	banglajol.info Internet Source	2%
3	erepository.uoeld.ac.ke Internet Source	1%
4	etd.aau.edu.et Internet Source	1%
5	library.kisiiuniversity.ac.ke:8080 Internet Source	1%
6	projectbluearchive.blob.core.windows.net Internet Source	1%
7	Elijah Kembenya, Albert Getabu, James Njiru, Reuben Omondi. "Reproductive Biology of Ripon Barbel (Labeobarbus Altianalis) In River Kuja-Migori Basin, Kenya", Research in Agriculture Livestock and Fisheries, 2022 Publication	1%