SCHOOL OF NATURAL SCIENCES
DEPARTMENT OF BIOLOGICAL SCIENCES

# Growth and Abundance of the Introduced Crayfish, *Cherax quadricarinatus* (Von Martens, 1868) in the Kafue Flood-plain and Lake Kariba, Zambia

By

Chibwe Katapa, B.Sc. (Unza),

Degree of Master of Science in Tropical Ecology and Biodiversity

Department of Biological Sciences

University of Zambia

Lusaka.

December, 2024

## TABLE OF CONTENTS

## AUTHOR'S DECLARATION

I, Chibwe Katapa, declare that the work contained in this dissertation is my own work and that it has not been previously submitted for any award at this University or any other institution. All published work or material from other source incorporated in this report have been specifically acknowledged and adequate reference thereby given.

Student's Signature: ___________________________

Date: _______________________________________

## COPYRIGHT DECLARATION

## APPROVAL

This study by Chibwe Katapa is approved as partial fulfilment of the requirement for the award of the Master of Science in Tropical Ecology and Biodiversity of the University of Zambia.

Examiners:

1. Examiner: ____________________________________ Signature: ________________

   Date: ___________________

2. Examiner: ______________________________________ Signature: _________________

   Date: ___________________

3. Examiner: ______________________________________ Signature: _________________

   Date: ___________________

## DEDICATION

To my beloved Husband,

Mwale Elias Mbiliyawo

and

Children;

Elias, Lubuto, Chiyamiko, Zoe and Charisa.

## ACKNOWLEDGEMENTS

This dissertation was made possible by the generous support of the American people provided by the Feed the Future Innovation Laboratory for Fish through the United States Agency for International Development (USAID). The contents are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government. The Feed the Future Innovation Laboratory for Fish is managed by Mississippi State University through an award from USAID (Award No.7200AA18CA00030; Mark Lawrence, PI) and provides support to this project (Subaward No.193900.312455.04E to the University of Rhode Island; Michael A. Rice, PI).

It was also partly made possible by the Zambian Ministry of Technology and Science.

I am grateful to God for bringing people along my way to help me throughout the research period. Without God I can do nothing. I say thank you to my supervisors, Dr. Chabwela H. N. and Mr. Mudenda H. G. for offering me valuable mentorship, guidance and direction. It was a great honour and privilege to have been part of the Zambia crayfish project team; Professor Michael A. Rice, Dr. Marjatta Eilitta, Mrs. Eva Nambeye Kaonga, Dr. Bernadette Chimai and Mr. Gordon H. Mudenda. A big THANK YOU to each one of them for accommodating me. I would also want to express gratitude to my colleagues Elvis Nonde and Chanda Ngoma for their moral support and availability to help me with any matter at hand. I am thankful to my husband Mwale Elias Mbiliyawo for his tireless encouragements throughout my research period. Last but not least I sincerely appreciate Mr. Robert Nkhata, former technician from the Zambian Department of Fisheries for accompanying me in the field and assisting with data collection.

## LIST OF FIGURES

**LIST OF TABLES**

## LIST OF APPENDICES

## ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| b | Regression coefficient in length-weight relationship |
| E | Exponent |
| Φ' | Growth Performance Index |
| Kg | Kilogram |
| mm | Millimetre |
| K | Fulton's Condition Factor |
| k | Intrinsic Growth Rate |
| Log10 | Logarithm (Raised to base 10) |
| L∞ | Asymptotic Length or Length at Infinity |
| $t_0$ | Age when Fish has zero length (t-zero) |
| % | Percent |
| yr -1 | per year |
| $r^2$ | Coefficient of determination |
| $t_{max}$ | Longevity |
| In | natural logarithm |
| Log | logarithm |
| ANOVA | Analysis of Variance |
| E | exponential (antilogarithm) |
| FAO | Food and Agriculture Organization of the United Nations |
| KRB | Kafue Road Bridge |
| CPUE | Catch per unit effort |
| FiSAT | Fish stock assessment tools |
| ELEFAN | Electronic length- frequency analysis |
| VBGF | von Bertalanffy growth formula |
| CBD | Central Business District |

**ABSTRACT**

*Cherax quadricarinatus* is an Alien Invasive Species (AIS) native to Australia and Papua New Guinea, which has been introduced into Lake Kariba and the Kafue Floodplain and has since established its populations. Continued population growth and spread of *C. quadricarinatus* threatens the integrity of the two freshwater ecosystems. However, not much work has been done on its population dynamics. Comparative information on growth and relative abundance from this current study is cardinal to the long-term biodiversity management solutions of the two ecosystems. von Bertalanffy growth parameters asymptotic length ($L\infty$) growth coefficient (k) was obtained in Elefan I of FiSAT II software and were used to compute growth performance index ($\Phi'$). Relative abundance was estimated using catch per unit effort (CPUE) and conduciveness of Lake Kariba and the Kafue floodplain for the growth of *C. quadricarinatus* was assessed by length-weight relationships ($W=aL^b$) and the condition factor, K ($K= 100W/L^3$). Analysis was done monthly and by sex. The class size-frequency analysis and CPUE revealed that the two study areas were lightly exploited. Kafue Road Bridge, a site near the central business district (CBD), experienced higher fishing pressure than Chanyanya a site located further from the CBD. Significant differences ($P > 0.05$) in carapace mean lengths on the Kafue Floodplain were due to differences in fishing pressure between sites. No dissimilarities were observed in growth performance between sites and there were no significant differences in the conduciveness of the two sites at Lake Kariba and the two sites at Kafue Floodplain fishery for the growth of *C. quadricarinatus* ($P > 0.05$). *Cherax quadricarinatus* is well adapted to Lake Kariba and Kafue Floodplain ecosystems. Future research could focus on formulating management strategies that would reduce negative impacts in areas where it has been introduced.

**KEY WORDS**: Relative abundance, *Cherax quadricarinatus*, condition factor, growth, Kafue Flood plain, Lake Kariba

# CHAPTER 1: INTRODUCTION

## 1.1 Background

Lake Kariba is a man-made lake shared between Zambia and Zimbabwe with a catchment area measuring 66300 $km^2$. It ranks 3rd in fisheries importance in Zambia after Lake Tanganyika and Lake Bangweulu (Zengeya and Marshall, 2007). It drains five riparian states namely Zambia, Zimbabwe, Angola, Namibia and Botswana (Tumbare, 2008). Lake Kariba consists of five basins namely; Sanyati, Bumi, Senguwa, Binga and Mlibizi (Marufu *et al.*, 2014).

The Kafue flats are an extensive area of wetlands and floodplains along the Kafue River (Welcome, 1979). The Kafue flood plain lies between Itezhi-tezhi dam upstream and the Kafue Gorge dam downstream of the Kafue River occupying a total of 4, 340 $km^2$ in the wet season. It ranks $4^{th}$ in fishery importance after Lake Tanganyika, Lake Bangweulu and Lake Kariba among the Zambian fisheries (Makeche, 2020).

Lake Kariba and the Kafue Floodplain have been invaded by an alien Redclaw crayfish, *Cherax quadricarinatus* (von Martens, 1868) native to Australia and Papua New Guinea. The Redclaw crayfish has since established its populations in the two ecosystems (Nakayama *et al.,* 2010; Marufu *et al.,* 2014; Douthwaite *et al*., 2018)

Intentional introductions of crayfish in Africa have been through aquaculture while unintentional introductions are due to interconnected waterways (Lodge *et al.,* 2012).

The first species of crayfish to be reported in Zambia is *Procambarus clarkii* in 1979 at a farm in Livingstone introduced from lake Naivasha, Kenya and it has since been established in Maramba River Livingstone. Out of the four species of crayfish imported into Zambia for aquaculture namely; *Procambarus clarkii*, *Cherax cainii*, *Cherax destructor* and *Cherax quadricarinatus*, only C. *quadricarinatus* has successfully been established in the wild (Douthwaite *et al* 2018).

*Cherax quadricarinatus* is known by several other names including; Australian red claw crayfish, Queensland red claw, R ed claw, Tropical blue crayfish and Freshwater blue crayfish among others. It appears blue-green to green in colour, with red and maroon highlights and its epithet is the presence of four carinae on the dorsal carapace (Coughran and Leckie, 1997).

According to Douthwaite *et al* (2018), introduction of *C. quadricarinatus* on the Kafue flats came from Miengwe farm on the upper Kafue River and from a fish farm at the eastern end of the Kafue flats and its presence in the Kafue River was first documented in 2001.

Another batch of *C. quadricarinatus* imported from Swaziland were relocated to aquaculture cages at Siavonga in Lake Kariba. They escaped into the lake in 2002 (Nakayama *et al* 2010; Douthwaite *et al*

2018). The red claw crayfish is now present in high abundance in the Sanyati Basin of Lake Kariba and a new population has also been reported on Upper Zambezi at Mongu (Nunes *et al.*, 2017).

*Cherax quadricarinatus* is tolerant of a wide variety of habitats from coastal streams to fresh water environments preferably slower moving upper reaches of rivers, lakes and lagoons (Wingfield, 2002). It is non-burrowing and tolerant of high temperatures and low dissolved oxygen. It is an omnivorous detritivore and breeds all year round. It reaches sexual maturity before 1 year and can have three to five broods during a breeding season, laying 300 to 800 eggs per brood. The eggs remain attached to the abdominal limbs (pleopods) in each case yielding a high number of offspring with low mortality rate and a very high growth rate (Masser and Rouse 1997). *Cherax quadricarinatus* exhibits both r and K selection traits (Beatty, 2005).

In captivity they can grow to a length of 250mm and weigh up to 600g while in the wild and natural populations a typical individual weighs less than 100g and 200g can be considered to be very large (Kouba *et al.*, 2014).

Studies done by Marufu *et al* (2018) on the population dynamics of *C. quadricarinatus* in the Sanyati Basin of Lake Kariba show that naturalization-invasion continues and is spreading in the lake. High fecundity and omnivorous trophic position have enabled the spread and establishment of *C. quadricarinatus* in Lake Kariba and the Kafue Floodplain (Hobbs and Lodge 2010). As an invasive species they usually exert negative ecological impact on native biodiversity and reduce abundance of macrophytes, aquatic invertebrates, amphibians and fishes (Twardochleb *et al* 2013)

Negative ecological impacts of *C. quadricarinatus* affect ecosystems at different trophic levels. Their omnivorous, detritus and invasive nature may change the trophic structure of the invaded environment and destroy habitats which may lead to extinction of some animals (Hobbs and Lodge 2010). However, *C. quadricarinatus* is still plentiful in the wild and therefore it is a species of least concern (Haubrock *et al.*, 2021).

Most crustaceans are affected by factors of the environment in which they live as these factors determine the physiological processes that enhance their survival rate, growth and reproduction (Gonzalez *et al.*, 2010).

Environmental stressors including nutrient effluents such as nitrates influence survival of freshwater species in anthropogenically disturbed habitats. Nitrates and low pH affect energy allocation by increasing maintenance costs and disruption of oxygen uptake resulting in negative impacts upon the performance of many crustaceans inclusive of their growth and abundance (Isaza *et al.,* 2018).

This study investigated the growth and abundance of *C. quadricarinatus* in the Kafue Floodplain and Lake Kariba fisheries and the conduciveness of the two ecosystems for its growth.

## 1.2 Statement of the Problem

The Kafue flood plain and Lake Kariba fisheries have numerous fish biodiversity, support tourism, agriculture and fishing activities (Makwelele, 2019). However, the integrity of the two ecosystems is threatened with the invasion of a non-native species *C. quadricarinatus*. Since Kafue Flood plain is already an over exploited fishery, invasion of *C. quadricarinatus* may lead to a further reduction in the biodiversity and catches of traditional fin fishes (Makwelele, 2019). According to Tumbare (2008) threats facing Lake Kariba include *C. quadricarinatus* (which seem to be causing considerable negative impacts on the fish habitats and ecology of the lake). Invasive species have been known to cause extinction of exotic flora and fauna in areas where they have been introduced (Pysek and Richardson, 2010).

In Zambia *C. quadricarinatus* entangles itself in the fishers' nets causing considerable damage to the fishers' nets. It also feeds on the fish caught in the nets which result in the fishermen incurring losses (Nakayama *et al.*, 2010).

Information on population dynamics and some growth aspects such as condition factor and length-weight relationships which are relevant in the formulation of policies that may reduce adverse ecological impacts are insufficient or lacking for this invasive species.

Past works on the distribution and growth of *C. quadricarinatus* on the Kafue Floodplain and Lake Kariba (Madzivanzira *et al.,* 2021; Nunes *et al.*, 2017; Makwelele, 2019; Marufu, 2018) lack comparative information on some population and growth aspects or how they vary with changing environmental factors and sex within different locations of lake Kariba and the Kafue floodplain. According to Madzivanzira (2021) failure to eradicate or control alien invasive species such as *C. quadricarinatus* could be attributed to insufficient information on their abundance.

## 1.3 Study Objectives

### 1.3.1. General objective

To investigate growth and relative abundance of *Cherax quadricarinatus* in Kafue Floodplain and Lake Kariba fisheries.

### 1.3.2. Specific objectives

1. To determine growth parameters of *Cherax quadricarinatus* in Kafue Floodplain and Lake Kariba fisheries.
2. To determine relative abundance of *Cherax quadricarinatus* in the Kafue Flood plain and Lake Kariba fisheries.

3. To determine conduciveness of the Kafue flood plain and Lake Kariba ecosystems for the growth of the introduced crayfish *Cherax quadricarinatus.*

### 1.4. Hypotheses of the study

1. There are no significant differences in the growth parameters of *Cherax quadricarinatus* in the Kafue Flood plain and Lake Kariba fisheries.
2. There are no significant differences in the relative abundance of *Cherax quadricarinatus* in the Kafue Flood plain and Lake Kariba fisheries.
3. There are no significant differences in the conduciveness of Kafue Floodplain and Lake Kariba ecosystems for the growth of *Cherax quadricarinatus.*

### 1.5. Significance of the study

Among other several social economic and ecological benefits such as tourism and conservation, Lake Kariba and the Kafue Floodplain are also important for their biodiversity, capture fisheries and aquaculture. There are about fifty different fish species in Lake Kariba of which Tiger fish and Cichlids are over exploited. At least fifty-five species are known to be found in the Kafue Floodplain fishery of which eighty percent of the twenty-three economically important fish are Cichlids (Makeche, 2020).

However, *C. quadricarinatus* is also important as a source of protein and has recreational, cultural, ethical, aesthetic, scientific, technological and educational value (Haubrock, 2021). Length-weight relationships are useful in the evaluation of size at sexual maturity while condition factor finds its application in the calculation of weights at certain lengths and comparison of populations from different regions (Talevski *et al.*, 2009)

Investigation of growth and abundance of *C. quadricarinatus,* in different locations of the Kafue Floodplain and Lake Kariba fisheries and assessment of the conduciveness of its growth in the two ecosystems, will provide background information for future research and give insights to policy makers as they develop appropriate and effective management strategies of the two fisheries (Blackburn *et al.*, 2011). The comparative approach taken in this current study, has an advantage of allowing inferences about the growth of *C. quadricarinatus* in future research and policy making (Vejan *et al.*, 2022).

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Growth of *Cherax quadricarinatus*

According to Lawrence (2002), the life cycle of *Cherax quadricarinatus* involves; mating, egg laying, incubation, hatching, juvenile stage and adult stage. Mating takes place in water. The petasma (formed when the first pair of pleopods fuse) is used to deposit spermatophore into the female's reproductive openings called gonopores. They lay eggs in the burrow and the eggs remain attached to the abdominal appendages (pleopods) during the incubation period. Incubation period depend on humidity and temperature and can last two to four weeks. At the end of the incubation period hatchlings are detached, become independent and look like transparent versions of adults measuring about five to six millimetres. Juveniles between six and twelve months undergo a series of moulting (shedding off of the exoskeleton) as they grow. Shedding of exoskeleton is more frequent when they are younger than in subsequent stages, Makwelele (2019). Adults reach maturity at 12 to 24 months at which stage they are ready for mating and the cycle can begin again (Jones and Lawrence, 2002).

Red claw has a rapid growth rate such that it can gain 50g to 90g in eight to twelve months. However, males grow faster than females and may slow down when their weights are approaching 400g (Haubrock, 2021)

Marufu's study of 2018, on the growth of *Cherax quadricarinatus* in lake Kariba found that the growth rate was higher in males than in females. The maximum size recorded for males was 61.1 mm total length (TL), while for females it was 54.8mm TL. Marufu (2014) estimated the growth coefficient (k) to be higher for males (0.42/year) than females (0.36/year), indicating faster growth in males. However, Marufu (2014) did not compare growth parameters between different populations. Differences in the von Bertalanffy growth parameters are possible between different populations because of fluctuations in water quality parameters (Hamidah et al., 2017).

According to Wicaksono et al (2021) exclusive male populations had a much higher growth rate than mixed populations or all female populations and growth regulated both the number of age one crayfish attaining sexual maturity and was directly related to the proportion of mature females.

Nga *et al.*, (2005) investigated chemical communication and growth and established that large red claw males do not inhibit the growth of juveniles, he reports that *C. quadricarinatus* does not occur in large groups and that at high densities, aggression results in injuries, cannibalism, infections and high mortalities.

Makwelele (2019) established that there were no significant differences in the growth rate and growth performance indices of *C. quadricarinatus* in different parts of the Kafue Floodplain. However, he indicates that there is need for more studies to be done on its growth in the Kafue Floodplain (Makwelele, 2019).

### 2.2 Abundance of *Cherax quadricarinatus*

Austin, (1996) investigated the relationship between lake depth and *Cherax quadricarinatus* abundance in Lake Argyle in Western Australia. He found a significant corelation between the abundance of *Cherax quadricarinatus* and lake depth with higher densities found in shallower waters. He also established that the abundance of *C. quadricarinatus* is related to the depth of the lake. Wicaksono *et al.*, (2021) investigated the distribution and abundance of *Cherax quadricarinatus* in Lindu Lake, Indonesia and confirmed Austin (1996) findings. Crayfish was frequently caught at depths ranging from shallow waters of 0.5-1.5 meters, medium depths of 1.5-3.0 meters and deeper waters of 3.0 to 5.0 meters. The depth at which *C. quadricarinatus* was caught was mainly attributed to food availability. Their food includes snails, macrophytes, fruits and detritus matter (Wicaksono *et al.*, 2021).

Marufu's, (2014) study on the abundance of *C. quadricanatus* in Lake Kariba established that the species was more abundant in areas with temperatures below 25 $^{o}$C, dissolved oxygen above 5mg/L and abundance decreased with higher water depth. The species was also more abundant in areas with less water pollution and minimal human disturbance. In another study on abundance of crayfish by Marufu, (2018) the ratio of males to females was found on average to be 1:1. The highest abundance was obtained in the wet season suggesting that the wet season provides suitable conditions for *C. quadricarinatus*. He also states that the number of female crayfish caught decreases when it is mating season because some may be hidden under rocks or crevices laying eggs and others could be incubating the eggs. He further eluded that the abundance of C. quadricarinatus was more in areas with low sedimentation and turbidity and varied spatially across Lake Kariba with highest abundance in the Sanyati basin

Although *C. quadricarinatus* can tolerate extreme extrinsic factors such as low dissolved oxygen levels, high turbidity and low to high alkalinity ranging from pH of 6 to pH of 9, when oxygen levels are extremely low red claw has a tendency of moving to water edges where oxygen levels are mostly higher and, in some instances, may even move on to land (Haubrock (2021).

Munder and Punt (2004) interpret changes in catch per unit effort (CPUE) to mean changes in abundance with the assumption that the number of fish captured is proportional to the amount of fishing effort expended.

Madzivanzira (2021) compared probability of capture, CPUE and population characteristics of new invasions with that of older invasions in Lake Kariba and Kafue River. It was established that increased electrical conductivity decreased CPUE of *C. quadricarinatus* and that length and mass of the new invasions were significantly different from the older invasions. The study suggested that older invasions had more time to adapt and establish themselves, leading to increased growth and biomass. He concluded that investment in population management of *C. quadricarinatus* will give great conservation value and restrict ecological impacts and stresses the need for biosecurity in order to stop the spread of the crayfish which is a threat to the fresh water ecosystems.

Although, comparison information on the abundance of *C. quadricarinatus* between different populations in Lake Kariba is available, the same is insufficient for the Kafue Flood plain. Makwelele, (2019) investigated growth and reproductive biology of *Cherax quadricarinatus* in the Kafue floodplain but did very little work on its abundance.

### 2.3.1 Condition factor

According to Hamidah *et al.*, (2017) condition factor measures the well-being and state of organisms. A condition factor of more than 1 indicates the red claw crayfish has attained a good condition (Weya *et al.*, 2017). It determines present and future population success by the influence it has on the growth, reproduction and survival of the crayfish and reflects the prevailing physical and biological circumstances. It fluctuates among feeding conditions, parasitic infections and physiological factors. Morphometric variation in different locations is influenced by genetic factors and environmental conditions.

### 2.3.2 Length-weight relationships

Analysis of the length-weight relationship is important in the conservation and management of fisheries as well as in the study of a population's structure and evaluation of population status Hamidah *et al.*, (2017). Length-weight relationship values are influenced by several factors, which include sex, season, length ranges and sample sizes (Haimovici and Velasco, 2000).

According to Velasco *et al.*, (2004) sample sizes with N larger than 50 usually give $r^2$ values above 0.95.

Environmental stressors including nutrient effluents such as nitrates influence survival of fresh water species in anthropogenically disturbed habitats. Nitrate and low pH affect energy allocation by increasing maintenance costs and disrupting oxygen uptake which results in impacts upon the whole animal performance (Isaza *et al.*, 2018).

Most crustaceans are affected by factors of the environment in which they inhabit. The factors determine the physiological processes that enhance survival rate, growth and reproduction (Gonzalez *et al.*, 2010). However, information on the assessment of the wellbeing of *C. quadricarinatus* in Lake Kariba and the Kafue Floodplain ecosystems is insufficient.

### 2.3.3 Water quality parameters in Lake Kariba and Kafue Floodplain.

Madzivanzira (2020) reports that the growth period for *C. quadricarinatus* is influenced by temperature and maximum growth rate is attained at 30$^{o}$C. He further states that, thermal tolerance is within 15$^{o}$C to 30$^{o}$C and that in males, temperature affects somatic growth while in females it affects spawning.

Surface temperatures in the Kafue Floodplain range from 17$^{o}$C to 33$^{o}$C with a mean value of 24$^{o}$C and concentration of dissolved solids (phosphates, calcium, sodium and magnesium ions) varies between 68mg/l to 220mg/l (Vanden Bossche and Bernacsek, 1990a)

Lake Kariba is characterized by both the riverine and lacustrine ecosystems and is suggested to be a eutrophic Lake by Calamita *et al.,* (2019). The lacustrine sub-basins of Lake Kariba are stratified in July. Thermal stratification exhibits a temperature range of 20$^{o}$C to 25$^{o}$C in cold and dry season with dissolved oxygen concentration of 9mg/l. Highest temperatures are experienced in February and are about 5$^{o}$C higher than in July with dissolved oxygen of about 7mg/l. However, hypo limnetic temperatures remain at 22.5$^{o}$C.

According to Calamita *et al* (2019) DO in Lake Kariba increases from July to August sharply and increases very little between April and September and then starts falling up to December slowly.

Madzivanzira (2021) and Marufu, (2014;2018) established that water quality parameters such as turbidity, dissolved oxygen, temperature and conductivity had an effect on the abundance and distribution of *Cherax quadricarinatus* in Lake Kariba. However, they did not investigate condition factor and length-weight relationships so as to establish more information on the wellbeing of *Cherax quadricarinatus* and the conduciveness of lake Kariba for the growth of *Cherax quadricarinatus*.

## CHAPTER 3: METHODOLOGY

### 3.1 Study Area

Two sites were sampled on the Kafue Floodplain as shown in figure 3.1; Kafue Road Bridge after the Kafue central business district (CBD) in the eastern part of Kafue and the Chanyanya lagoon before the CBD in the western part of Kafue. The two sites were located at grid references -15.836895 S, 28.237517 E and -15.688956 S, 28.005541E. The study sites had a slow water gradient and the substrate consisting mainly of sand and mud. A lot of hydrophytes consisting of submerged, emergent and floating in still water were also observed.

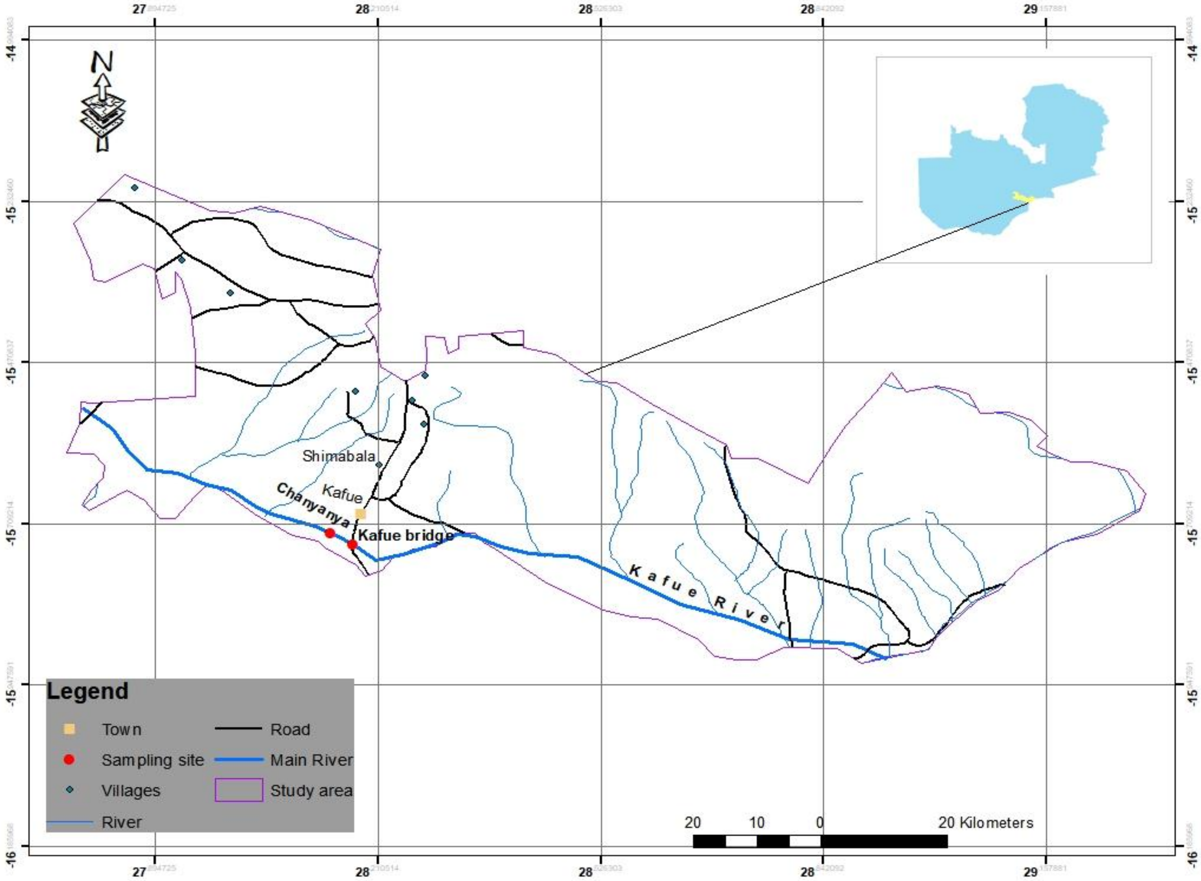



*Figure 3.1. Map showing study sites on the Kafue Floodplain*

On

Lake Kariba, the sampling area lies in the Bumi basin located north east in the lacustrine part of the Lake (figure 3.2). Sampling sites were selected on the basis of vicinity to the central business district (CBD). The first sample site included the benthonic areas near Siavonga CBD at a grid reference of -16.5384436, 28.7064776. It was characterized by a rocky shore. The second sample site (Kabyobyo) was located away from the CBD at a grid reference -16.529682, 28.569225 and had a lacustrine littoral rocky shore with dead submerged trees.

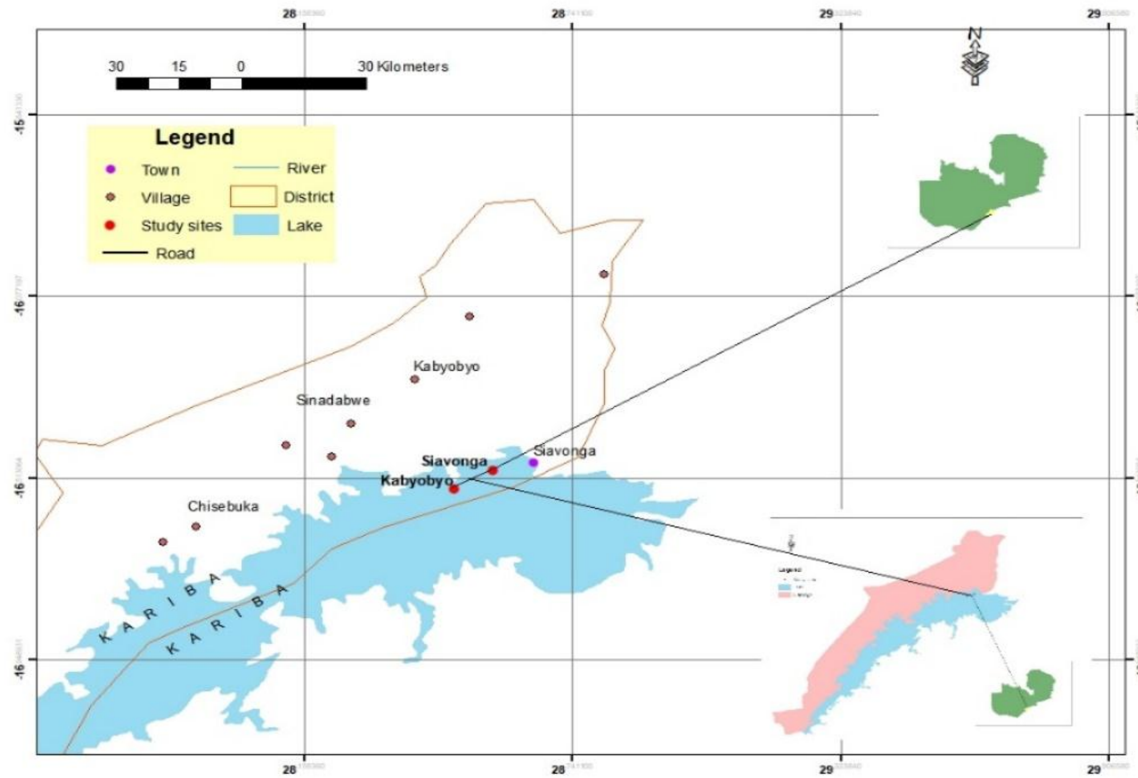



*Figure 3.2: Map showing study sites, Siavonga and Kabyobyo on Lake Kariba*

### 3.2 Sample Collection

For the Kafue Floodplain the sampling period was from July 2022 to November 2022 from two sampling points (Kafue Road Bridge and Chanyanya Lagoon). The study area was sampled once every month for a period of five months. Kafue Road Bridge was a sampling site near the Kafue CBD while Chanyanya was the sampling site away from the CBD. However, only months that had large enough sample sizes and had samples from both sampling sites were considered for a comparative study. On the Kafue Floodplain Five months were included in the comparative study between Kafue Road Bridge and Chanyanya; July, August, September, October and November.

On Lake Kariba the sampling was done between August 2022 and November 2022 from two sampling sites (Siavonga and Kabyobyo). The sampling was done once every month. However, this being a comparative study between two populations of the same ecosystem only those months that had large enough sample sizes from both sampling sites were considered for analysis. On lake Kariba only samples for the months of September and October were analysed, August and November did not have large enough sample sizes from both sample sites for analysis. Siavonga town was the sampling site near the CBD while Kabyobyo was a sampling site away from the CBD.

Chanyanya and Kabyobyo being located further from the CBD were assumed to have fewer anthropogenic activities compared to Kafue Road Bridge and Siavonga which were situated inside the CBD.

*Figure 3.3. photo of collapsing crayfish trap with captured crayfish inside*

For the relative abundance study the crayfish was obtained from the sampling points using collapsing crayfish traps (figure 3.3). Collapsible traps were used to catch crayfish because they are light weight, easy to transport and can be set in a variety of habitats. On both study areas (Lake Kariba and Kafue Flood Plain), 11 trap nets were set per sampling site not so far away from the shore and not deeper than 3 meters. Nshima (maize meal) left overs and rotten fish were used as bait (figure 3.4). Traps were cast overnight and crayfish caught was counted, placed in wet sisal bags and transported to land for measurements.

For growth parameters study, crayfish sampled was collected from crayfish fishermen landings and was placed in wet sisal bags for temporal storage before commencing measurements of length and weight.

The length of crayfish was measured using a fish measuring board and weight was taken using a kitchen scale. Weight was recorded in grams (g) while total length (TL) and carapace length were taken in millimetres (mm). The total length (TL) for each cray fish was measured from the tip of the anterior part of the mouth to the posterior end of the tail. Carapace length was measured from the tip of the anterior part of the mouth to the end of the fourth carinae on the posterior end of the dorsal carapace. In each case sex and state of the gonads were determined and recorded.

Carapace and total length measurements were used to determine asymptotic lengths ($CL\infty$ and $TL\infty$), growth coefficient (k) and construction of length frequency histograms of *C. quadricarinatus*. However, only total length was used to determine length-weight regression coefficient, b and the condition factor K.

*Figure 3.4: Putting bait in a trap at Siavonga*

Temperature and pH were determined on site using a water quality meter (figure 3.5). The probe was dropped to a depth of at least 2 meters because crayfish is usually found within this depth. The meter readings were taken and recorded. Turbidity was determined using a Secchi disk. The Secchi depth gave a measure of water quality by indicating water clarity, turbidity, light penetration and phytoplankton concentration.

*Figure 3.5: Taking water quality measurements at Chanyanya on the Kafue Floodplain with the help of a Local fisherman Mr. Mulenga (paddling the boat)*

### 3.3 Data Analyses

The data that was obtained using the various methods explained, were analysed to determine significant differences, if any. All data analyses were done in GenStat statical package 2016. Male and female crayfish were analysed separately using an independent two-sample t-test. The t-test measured significance of difference between Kabyobyo and Siavonga on Lake Kariba and between Kafue Road bridge and Chanyanya on the Kafue Floodplain.

### 3.3.1 Length frequency data and histograms

Length frequency data was obtained by classifying carapace length frequencies into bin ranges of 5mm using raw counts per month. It was also used to create percentage length frequency histograms with percentage of total catch on the y-axis and size class on the x-axis. This was done for both males and females by; dividing the number of crayfish in each size category by the total number of crayfish caught at that particular site each month. The histograms were then arranged with the earlier date on top and the most recent at the bottom with the x-axis length data on a common scale. Modal lengths were obtained from the length frequency histograms. Monthly mean lengths for each site were also determined.

### 3.3.2 Growth Parameters

Growth parameters of *C. quadricarinatus* were obtained by using the FiSAT II (FAO-ICLARM Stock Assessment Tools), version 1.2.2 (2000-2005) software. Length frequency data was entered into the FiSAT II software in order to generate the von Bertalanffy growth parameters $L\infty$ and k.

### 3.3.3 Growth Performance Index and Longevity

Growth parameters $L\infty$ and k were then used to estimate the Growth Performance Index ($\Phi'$) using the equation by Pauly and Munro of 1984;

$$\Phi' = \log_{10}(k) + 2\log_{10}(L\infty) \text{ ....................(1)}$$

where:

k = von Bertalanffy growth coefficient and

$L\infty$ = von Bertalanffy asymptotic carapace length (mm).

Longevity was estimated using the equation;

$$tmax = (3/k) + t_0 \text{ ....................(2)}$$

Where:

k = von Bertalanffy growth coefficient and

$t_0$ = the theoretical time when the length size of crayfish is zero.

Growth comparison between populations was assessed using the growth performance index ($\Phi'$).

### 3.3.4 Length at age t ($L_t$)

$L_t$ values were used to determine if there were significant differences in the von Bertalanffy growth parameters. The values of $t_0$ and $L_t$ were determined by the empirical formulae;

(I) $\mathbf{Log_{10} -t_0 = -0.3922 - 0.2752\log_{10}L\infty - 1.038\log_{10}k}$ **(Pauly 1979) .................................. (3)**

(ii) $L_t = L_\infty (1-e^{-k (t-t0)})$ **……………………...…………………………………………... (4)**

Where:

$t_0$ = the theoretical time when the length size of crayfish is zero,

k = the growth coefficient which determined how rapidly the growth curve was attaining the early infinity and

$L_\infty$ = the length the fish should attain if it lived infinity years.

### 3.3.5 Relative Abundance

Relative abundance was estimated by counting the number of crayfish caught in the net for one night per sampling site. Catch per unit effort (CPUE) was taken as the average number of crayfish (N) caught per trap per night at each site (N/trap/night). CPUE was then compared between sites for both study areas.

### 3.3.6 Length-weight relationships

The body length and weight of *C. quadricarinatus* are related by the allometric expression:

$W = aL^b$ **......................................................................................................................... (5)**

Where:

W = weight of crayfish in grams (g),

L = total length of the crayfish in centimetres (cm),

a = intercept in the y –axis and

b = regression coefficient (indicates isometric growth when equal to 3)

When $b > 3$ weight is gained faster than increase in length, when $b < 3$ weight is gained less than increase in length and if $b = 3$ the weight increases cubically with length (isometric growth). Log W against log L is a linear regression relationship. If the correlation value between log W and log L approaches -1 or 1 then the relationship between length and weight is strong (Hamidah *et al.*, 2017). An independent two-sample t-test was used to determine the significance of the difference in the regression coefficient, b between two sampling sites.

### 3.3.7 Condition Factor

Fulton's growth condition factor (K) was determined using the equation:

$K = 100W/L^3$ **.......................................................................................................................… (6)**

Where:

W = weight in grams (g) and

L = length of crayfish in centimetres (cm).

Mean values of weight and length were used to calculate the condition factor. Two sample t-test was used to determine the significance of the difference in the condition factors of the sampled sites in the two study areas.

K is an index that reflects interaction between biotic and abiotic factors in the physiological condition of fishes. It varies in different locations and can be used to compare environmental conditions in different locations as well as to monitor feeding intensity, age and growth rates in fish (Naguib *et al.*, 2021). $K>1$ means nutritional level in the crayfish is good (Weya *et al.*, 2017).

# CHAPTER 4: RESULTS

From Lake Kariba, a total of one thousand seven hundred and five (1705) *C. quadricarinatus* were sampled between August 2022 and November 2022 of which 932 (54.66%) were female; 281 from Siavonga town and 651 from Kabyobyo. The number of males sampled was 773 (45.34%) of which 252 were from Siavonga town and 521 from Kabyobyo. There were more females sampled at each sampling site than males.

A total of one thousand one hundred and fifty-three (1153) *C. quadricarinatus* were sampled from the Kafue Floodplain between July 2022 and November 2022 of which 691(59.9%) were female; 174 from Chanyanya and 517 from Kafue Road Bridge (KRB). The number of males sampled was 462 (40.06%) of which 82 were from Chanyanya and 380 from Kafue Road Bridge. There were more females than males sampled at each site.

## 4.1 Growth of *Cherax quadricarinatus*

### 4.1.1 Length frequency distributions

The monthly carapace length–percent frequency distributions (Appendix A) revealed multiple cohorts in both sexes for each month in the two study areas depicting multiple spawns in *C. quadricarinatus* at the two study areas. Peak cohorts were identified as modes (Table 4.1 and table 4.2). As the months progressed the modal cohorts generally shifted to the left.

*Table 4.1: Monthly Modal Carapace Lengths (mm) in Lake Kariba from September 2022 to October 2022*

| | MALES | | FEMALES | |
|---|---|---|---|---|
| MONTH | Siavonga town | Kabyobyo | Siavonga town | Kabyobyo |
| September | 50 | 50 | 55 | 55 |
| October | 55 | 45 | 60 | 45 |

The carapace modal lengths for Siavonga town and Kabyobyo, in both males and females were the same for the month of September but in October, the males and females at Siavonga town had a higher modal length than the males and females at Kabyobyo (Table 4.1).

*Table 4.2: Monthly Modal Carapace Lengths (mm) in the Kafue Floodplain from July 2022 to November 2022*

| MONTH | Male | | Female | |
|---|---|---|---|---|
| | Chanyanya | KRB | Chanyanya | KRB |
| July | 70 | 60 | 60 | 60 |
| August | 70 | 60 | 70 | 60 |
| September | 70 | 60 | 60 | 60 |
| October | 65 | 60 | 60 | 55 |
| November | 55 | 60 | 50 | 55 |

From table 4.2, Chanyanya males and females exhibited slightly higher modal lengths than KRB except for the month of November when KRB males and females had a slightly higher modal length than Chanyanya.

Figure 4.1 shows overall percentage length frequency for Siavonga town, N=533 and Figure 4.2 for Kabyobyo, N=1172 from August 2022 to November 2022 on Lake Kariba. Figure 4.3 shows overall length frequency histograms for KRB, N=897 and figure 4.4 for Chanyanya, N=256 from July to November 2022 on the Kafue Floodplain. Figure 4.3 (KRB) and figure 4.4 (Chanyanya) revealed that KRB was more exploited than Chanyanya.

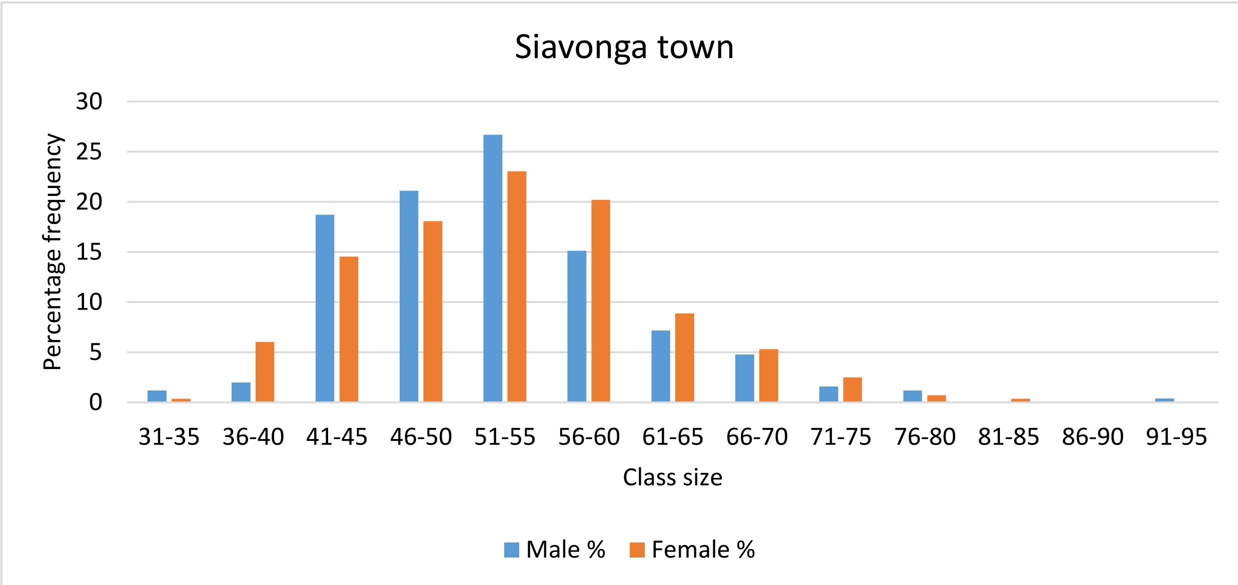



*Figure 4.1. Overall carapace length frequency histogram for Siavonga town from September 2022 to October 2022*

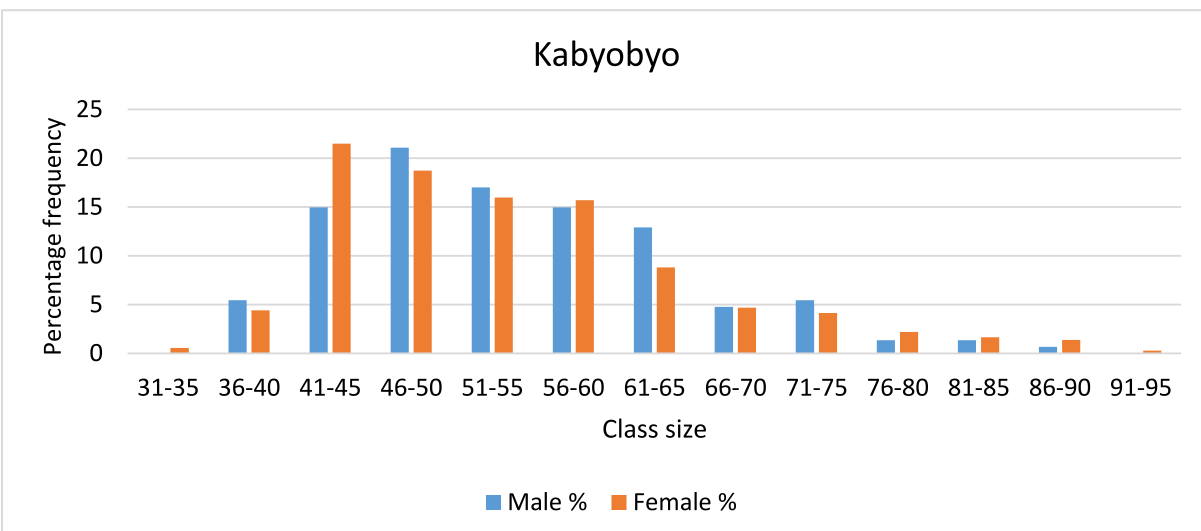



*Figure 4.2. Overall Carapace length frequency histogram for Kabyobyo from September to October 2022 in lake Kariba Fishery*

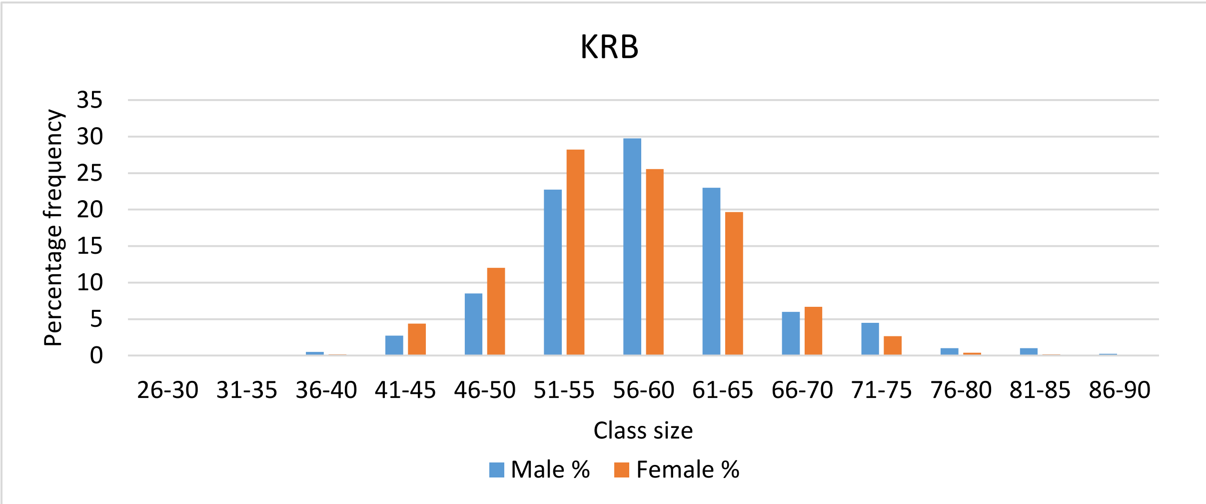



*figure 4.3. Overall carapace length percent frequency histogram for KRB from July 2022 to November 2022 on the Kafue Floodplain fishery.*

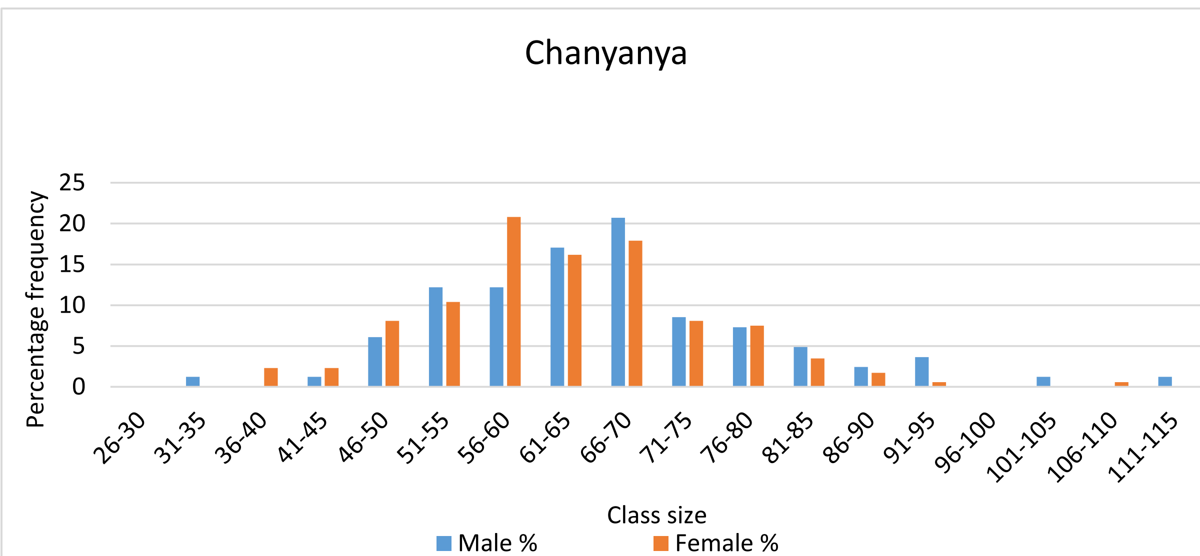



*Figure 4.4: Overall carapace length percent frequency histogram for Chanyanya from July 2022 to November 2022 on the Kafue floodplain fishery.*

### 4.1.2 Mean Carapace Lengths

*Table 4.3: Monthly mean Carapace lengths (mm) for KRB and Chanyanya, males and females, on the Kafue Floodplain between July 2022 and November 2022*

| | Male | | Female | |
|---|---|---|---|---|
| Month | KRB (Mean ± SD) | Chanyanya (Mean ± SD) | KRB (Mean ± SD) | Chanyanya (Mean ± SD) |
| July | 61.34 ± 4.44 | 63.55 ± 7.39 | 60.15 ± 5.05 | 63.41 ± 7.11 |
| Aug | 64.51 ± 6.67 | 71.10 ± 8.67 | 58.95 ± 5.26 | 67.40 ± 7.59 |
| Sept | 58.48 ± 4.71 | 73.67± 6.88 | 58.38 ± 4.69 | 72.25 ± 6.13 |
| Oct | 56.74 ± 5.32 | 67.57± 7.88 | 53.64 ± 4.46 | 61.25 ± 9.92 |
| Nov | 58.40 ± 5.18 | 56.87± 8.38 | 55.94 ± 5.12 | 56.26± 9.70 |

Table 4.3 shows monthly mean carapace lengths for KRB and Chanyanya, males and females on the Kafue Floodplain. An independent two sample t-test performed between KRB and Chanyanya for male mean carapace length revealed significant differences; ($t (433) = 7.616$, $P < 0.05$). Chanyanya females also revealed significant higher mean lengths than KRB females; ($t (567) = 7.588$, $P < 0.05$).

*Table 4.4: Monthly Mean Carapace length (mm)in Lake Kariba between September 2022 and October 2022*

| | Males | | Females | |
|---|---|---|---|---|
| Month | Siavonga town Mean ± SD | Kabyobyo Mean ± SD | Siavonga town Mean± SD | Kabyobyo Mean ± SD |
| September | 51.28 ± 6.34 | 55.02 ± 8.45 | 50.79 ± 6.08 | 55.23 ± 7.68 |
| October | 55.59 ± 6.51 | 52.70 ± 9.57 | 56.67 ± 6.77 | 54.76 ± 10.24 |

Table 4.4 shows monthly mean carapace lengths for Siavonga town and Kabyobyo in Lake Kariba. An independent two sample t-test performed between Siavonga town and Kabyobyo for male carapace mean

length revealed significant differences; (t (489) = 1.475, P > 0.05). Kabyobyo females were equally observed to have no significant higher mean length than Siavonga females (t (550) = 1.819, P > 0.05)

#### 4.1.3 von Bertalanffy Growth Parameters in Lake Kariba and Kafue Floodplain

*Table 4.5a: von Bertalanffy Growth Parameters based on TL (mm) of C. quadricarinatus in Kafue Floodplain (n= 1153) and Lake Kariba (n=1705) collected between July 2022 and November 2022*

| Site | TL∞ | k | Φ′ | $t_0$ | $t_{max}$ |
|---|---|---|---|---|---|
| Kafue Floodplain | 215mm | 0.5/year | 4.4 | -0.2years | 5.7years |
| Lake Kariba | 215mm | 0.9/year | 4.6 | -0.1years | 3.3years |

*Table 4.5b: von Bertalanffy Growth Parameters based on CL (mm) of C. quadricarinatus in Kafue Floodplain (n=1153) and Lake Kariba (n=1705) collected between July 2022 and November 2022*

| Site | CL∞ | *k* | Φ′ | $t_0$ | $t_{max}$ |
|---|---|---|---|---|---|
| Kafue Floodplain | 120.8 | 0.5/year | 3.8 | -0.2years | 6.3years |
| Lake Kariba | 120.8 | 0.7/year | 4.0 | -0.2years | 4.4years |

*Table 4.5c: von Bertalanffy Growth Parameters based on CL (mm) of C. quadricarinatus in Lake Kariba (n: Siavonga=533 and Kabyobyo=510) collected between September 2022 and October 2022.*

| Site | k | | L∞ | | Φ′ | | $t_0$ | | $t_{max}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F | M | F |
| Siavonga T | 1.5 | 1.6 | 94.5 | 94.5 | 4.1 | 4.1 | -0.1 | -0.1 | 1.9 | 1.8 |
| Kabyobyo | 0.6 | 0.7 | 120.8 | 120.8 | 3.9 | 3.9 | -0.2 | -0.2 | 5.2 | 4.4 |
| Mean | 1.0 | 1.1 | 107.6 | 107.6 | 4.0 | 4.1 | -0.1 | -0.1 | 3.5 | 3.1 |
| SD ± | 0.5 | 0.5 | 13.0 | 13.0 | 0.1 | 0.1 | 0.1 | 0.1 | 1.6 | 1.3 |

*Table 4.5d: von Bertalanffy Growth Parameters based on CL (mm) of C. quadricarinatus in Kafue Floodplain (n: KRB=897 and n: Chanyanya=256) collected between July 2022 and November 2022*

| Site | K | | L∞ | | Φ′ | | $t_0$ | | $t_{max}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F | M | F |
| KRB | 1.2 | 1.9 | 94.5 | 84 | 4 | 4.1 | -0.1 | -0.1 | 2.4 | 1.5 |
| Chanyanya | 0.3 | 0.3 | 120.8 | 110.1 | 3.7 | 3.5 | -0.4 | -0.4 | 9.3 | 10.3 |
| Mean | 0.8 | 1.1 | 107.6 | 97.1 | 3.8 | 3.8 | -0.2 | -0.2 | 5.8 | 5.9 |
| SD± | 0.4 | 0.8 | 13.1 | 13.1 | 0.2 | 0.3 | 0.1 | 0.2 | 3.5 | 4.4 |

NB: KRB= Kafue Road Bridge

The derivation of von Bertalanffy growth parameters in tables 4.5a, 4.5b, 4.5c and 4.5d are shown in appendix B. Table 4.5a is based on Total length (TL) measurements while table 4.5b is based on carapace length (CL) measurements. Measurements based on TL yielded von Bertalanffy growth parameters similar to those based on carapace length.

The L∞ and K values were used to estimate the growth performance index. The growth performance indices (Φ′) for the males and females at Siavonga town were similar to the growth performance indices for the males and females at Kabyobyo table 4.5c. From table 4.5d, Kafue Road Bridge (KRB) males and females also had similar growth performance indices with Chanyanya males and females ($t(2) = 4.025$, $P > 0.05$). At all the four sites of the two study areas k and $t_0$ were inversely proportional to L∞ and tmax (longevity).

**4.1.4: Growth rates based on von Bertalanffy growth equation**

The growth rates of *C. quadricarinatus* in Lake Kariba (table 4.6 and table 4.7) and Kafue Floodplain (table 4.8and table 4.9) were obtained using the von Bertalanffy growth equation, $L_t = L_\infty (1-e^{-k(t-t0)})$. An Independent two-sample t-test was then used to determine if there were signifiant differences in the von Bertalanffy growth rates k, based on $t_0$ and the von Bertalanffy growth equation.

*Table 4.6: Growth rates for C. quadricarinatus males at Siavonga and Kabyobyo on Lake Kariba based on von Bertalanffy growth equation*

| Age (years) | $L_t$ (mm) Siavonga town | Growth rates (mm/yr) | $L_t$(mm) Kabyobyo | Growth rates (mm/yr.) |
|---|---|---|---|---|
| 1 | 76 | 0 | 44 | 0 |
| 2 | 90 | 14 | 64 | 20 |
| 3 | 94 | 4 | 76 | 12 |
| 4 | 94 | 0 | 83 | 7 |
| 5 | 95 | 1 | 88 | 5 |

Table 4.6 shows growth rates based on von Bertalanffy growth equation for *C. quadricarinatus* males at Siavonga town and Kabyobyo on Lake Kariba. A two-sample t-test performed on the growth rates revealed no significant differences in the growth rates between males at Siavonga town and Kabyobyo ($t(8) = 2.179$, $P > 0.05$)).

*Table 4.7: Growth rates for C. quadricarinatus females at Siavonga and Kabyobyo on Lake Kariba based on von Bertalanffy growth equation*

| Age (years) | $L_t$ (mm) Siavonga | Growth rate (mm/year) | $L_t$ (mm) Kabyobyo | Growth rate (mm/year) |
|---|---|---|---|---|
| 1 | 77 | 0 | 44 | 0 |
| 2 | 91 | 14 | 64 | 20 |
| 3 | 94 | 3 | 76 | 12 |
| 4 | 94 | 0 | 84 | 8 |
| 5 | 95 | 1 | 88 | 4 |

Table 4.7, shows growth rates based on the von Bertalanffy growth equation for the females at Siavonga and Kabyobyo. An independent two-sample t-test performed on Kabyobyo females and Siavonga females revealed no significant differences in growth rates between the females at the two study sites ($t(8) = 2.203$, $P > 0.05$).

*Table 4.8: Growth rates for C. quadricarinatus males at KRB and Chanyanya in the Kafue Floodplain based on Von Bertalanffy growth equation*

| Age (years) | $L_t$ (mm) at KRB | Growth rate(mm/year) | $L_t$ (mm) at Chanyanya | Growth rate (mm/year) |
|---|---|---|---|---|
| 1 | 69 | 0 | 61 | 0 |
| 2 | 87 | 18 | 85 | 24 |
| 3 | 92 | 5 | 98 | 13 |
| 4 | 94 | 2 | 104 | 6 |
| 5 | 94 | 0 | 107 | 3 |

Table 4.8 shows growth rates for *C. quadricarinatus* males at KRB and Chanyanya based on von Bertalanffy growth equation. An independent two-sample t-test between KRB males and Chanyanya males revealed no significant differences in growth rates for the males at KRB and Chanyanya ($t(8) = -0.349$, $P > 0.05$).

*Table 4.9: Growth rates for C. quadricarinatus females at KRB and Chanyanya based on von Bertalanffy growth equation*

| Age (years) | $L_t$ (mm) at KRB | Growth rate (mm/year) | $L_t$ (mm) at Chanyanya | Growth rate (mm/year) |
|---|---|---|---|---|
| 1 | 73 | 0 | 36 | 0 |
| 2 | 82 | 9 | 54 | 18 |
| 3 | 84 | 2 | 68 | 14 |
| 4 | 84 | 0 | 78 | 10 |
| 5 | 84 | 0 | 86 | 8 |

Table 4.9 shows growth rates for *C. quadricarinatus* males at KRB and Chanyanya based on von Bertalanffy growth equation. A two-sample t-test between KRB females and Chanyanya females revealed no significant differences in growth rates for the females at KRB and Chanyanya ($t(8) = 1.860$, $P > 0.05$).

### 4.2 Relative Abundance

*Table 4.10: Relative Abundance of C. quadricarinatus in Lake Kariba and Kafue Floodplain*

| LAKE KARIBA | | | | | | KAFUE FLOODPLAIN | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Siavonga Town | | | Kabyobyo | | | Chanyanya | | | KRB | | |
| N | Traps | CPUE | N | Traps | CPUE | N | Traps | CPUE | N | Traps | CPUE |
| 12 | 11 | 1.1 | 8 | 11 | 0.7 | 13 | 11 | 1.2 | 1 | 11 | 0.1 |

N= Number of crayfish caught

Catch per unit effort at Chanyanya was 13 times more than catch per unit effort at KRB (table 4.10). Therefore, Chanyanya had a higher relative abundance than KRB. CPUE at Siavonga was slightly higher than at Kabyobyo. However, CPUE disparities between Siavonga and Kabyobyo were minimal compared to CPUE disparities between Chanyanya and Kafue Road Bridge (figure 4.5).

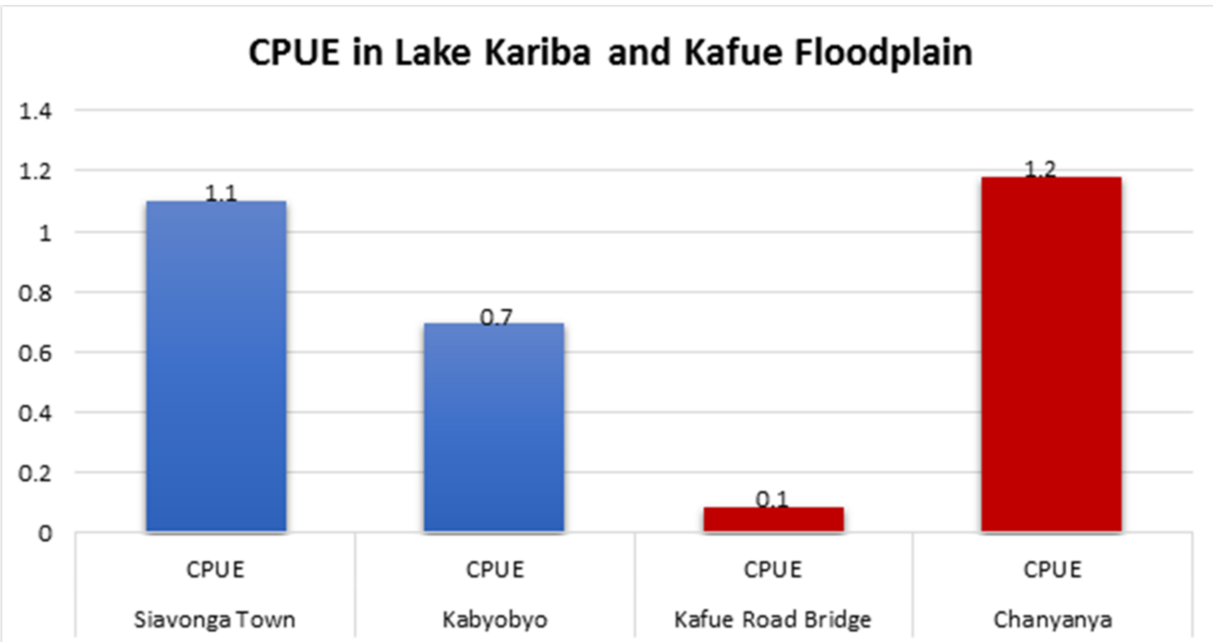



*Figure 4.5. Catch per unit effort (N/trap/day) of C. quadricarinatus at Lake Kariba and Kafue Floodplain. NB: N=number of crayfish.*

## 4.3 Length-Weight Relationships, Condition Factor and Water Quality

### 4.3.1: Length-weight relationships

Values of regression coefficient, b were derived from monthly length-weight relationship graphs shown in appendix D. Table 4.11 shows regression coefficient, b for males on Lake Kariba from the linear regression of the relationship between total length and weight.

*Table 4.11: Length-weight relationships analysis for males at Siavonga town and Kabyobyo in Lake Kariba*

| **MONTH** | Siavonga | | | Kabyobyo | | |
|---|---|---|---|---|---|---|
| | b | a | $r^2$ | b | a | $r^2$ |
| September | 2.43 | -3.52 | 0.78 | 2.97 | -4.61 | 0.95 |
| October | 2.79 | -4.23 | 0.86 | 2.92 | -4.48 | 0.97 |
| **MEAN ± SD** | 2.61 **±0.18** | -3.88 **±0.35** | 0.83 **±0.03** | 2.95 **±0.03** | -4.73 **±0.24** | 0.96 **±0.01** |

Kabyobyo had slightly higher values of regression coefficient, b than Siavonga town. However, both their mean allometric growth was approaching isometric growth (b=3). The independent two sample t-test performed between males at Siavonga town and Kabyobyo revealed no significant differences (t (2) =-1.843416175, P > 0.05).

*Table 4.12: Length-weight relationships for Siavonga town and Kabyobyo females in Lake Kariba*

| **MONTH** | Siavonga town | | | Kabyobyo | | |
|---|---|---|---|---|---|---|
| | b | a | $r^2$ | b | a | $r^2$ |
| September | 2.86 | -4.42 | 0.95 | 2.97 | -4.63 | 0.93 |
| October | 2.69 | -4.03 | 0.82 | 2.90 | -4.46 | 0.97 |
| **MEAN ± SD** | 2.78 **±0.09** | -4.22 **±0.20** | 0.88 **±0.06** | 2.93 **±0.03** | -4.54 **±0.08** | 0.95 **±0.021** |

Table 4.12 shows length-weight relationships for Siavonga town and Kabyobyo females in Lake Kariba. The regression coefficient, b value was approaching isometric growth (b=3). The independent two sample t-test performed between Siavonga town females and Kabyobyo females revealed no significant differences (t (2) = -1.740570538, P > 0.05)

*Table 4.13 Length-weight relationships for the males at KRB and Chanyanya in Kafue Floodplain Fishery.*

| **MONTH** | Chanyanya | | | KRB | | |
|---|---|---|---|---|---|---|
| | b | a | $r^2$ | b | a | $r^2$ |
| July | 2.8 | -4.16 | 0.88 | 2.74 | -4.1942 | 0.9004 |
| August | 2.67 | -3.96 | 0.93 | 3.03 | -4.7504 | 0.907 |
| September | 2.69 | -4.07 | 0.93 | 3.06 | -4.806 | 0.954 |
| October | 3.08 | -4.87 | 0.95 | 3.00 | -4.657 | 0.915 |
| November | 2.23 | -3.15 | 0.79 | 2.9031 | -4.4636 | 0.8829 |
| **MEAN** ± **SD** | 2.69 ±0.19 | -4.04 ±0.39 | 0.90 ±0.05 | 2.9460 ±0.10 | -4.5742 ±0.20 | 0.9119 ±0.02 |

Table 4.13 shows values of regression coefficient, b for the males in Kafue Floodplain between July and November 2022. KRB recorded positive allometric values (3.0262, 3.0641) in August and September while Chanyanya recorded a positive allometric value (3.0977) in October only. The means of regression coefficient, b for both sites were approaching isometric growth (b= 3).

The independent two sample t-test performed between Chanyanya and KRB males revealed no significant differences in the values of regression coefficient, b (t (8) =-1.696692952, P > 0.05).

*Table 4.14: Length-weight relationships for the females at Chanyanya and KRB in Kafue Floodplain Fishery.*

| **MONTH** | Chanyanya | | | KRB | | |
|---|---|---|---|---|---|---|
| | b | a | $r^2$ | b | a | $r^2$ |
| July | 2.53 | -3.10 | 0.84 | 2.58 | -3.81 | 0.85 |
| August | 2.78 | -4.25 | 0.95 | 2.73 | -4.14 | 0.98 |
| September | 3.10 | -4.98 | 0.98 | 3.07 | -4.86 | 0.98 |
| October | 2.97 | -4.64 | 0.97 | 2.90 | -4.51 | 0.92 |
| November | 2.93 | -4.62 | 0.93 | 2.55 | -3.78 | 0.66 |
| Mean ± SD | 2.86 ±0.17 | -4.32 ±0.51 | 0.94 ±0.04 | 2.77 ±0.18 | -4.22 ±0.37 | 0.88 ±0.10 |

Table 4.14 shows length-weight relationships for females in Kafue Floodplain fishery. The regression coefficient, b values for both Chanyanya and KRB females were approaching isometric growth (b=3). The independent two sample t-test performed between Chanyanya and KRB females revealed no significant differences ($t(8) = 0.693905399$, $P > 0.05$).

### 4.3.2 Condition factor (K)

Table 4.15 shows values of condition factor, K in Lake Kariba at the two sampling sites; Siavonga town and Kabyobyo for the months of September and October. Males and females were analysed separately.

*Table 4.15: Condition Factor (K) values at Siavonga and Kabyobyo in Lake Kariba*

| | Males | | Females | |
|---|---|---|---|---|
| Month | Siavonga town | Kabyobyo | Siavonga town | Kabyobyo |
| September | 2.22 | 2.38 | 2.08 | 2.18 |
| October | 2.35 | 2.65 | 2.24 | 2.46 |

| | | | | |
|---|---|---|---|---|
| Mean | 2.29 | 2.52 | 2.16 | 2.32 |
| SD ± | 0.06 | 0.13 | 0.08 | 0.14 |

The males at Kabyobyo had a slightly higher condition factor (K= 2.516) compared to the males at Siavonga town (K= 2.288). The females also revealed slightly higher values of K at Kabyobyo (K= 2.318) than at Siavonga town (K= 2.160). Slightly Higher values of K were observed for the month of October as compared to the month of September for both sites and both sexes.

However, the independent two sample t-test revealed no significant differences in K, between the males at Siavonga town and males at Kabyobyo (t (2) = -1.535039882, P > 0.05). There were equally no significant differences in the condition factor between the females (t (2) = -0.99228, P> 0.05).

Table 4.16 shows condition factor values observed for the males and females at Chanyanya and Kafue Road Bridge in the Kafue floodplain. Males and females were analysed separately. There were minimal differences in the mean condition factor values between Chanyanya females (K= 2.005) and KRB females (K= 2.043) as well as between KRB males (K= 2.173) and Chanyanya males (K= 2.244).

*Table 4.16: Condition Factor values for Kafue Floodplain Fishery*

| | Females | | Males | |
|---|---|---|---|---|
| **MONTH** | Chanyanya | KRB | Chanyanya | KRB |
| July | 2.00 | 1.83 | 2.15 | 1.98 |
| August | 2.01 | 2.23 | 2.94 | 2.16 |
| September | 1.95 | 2.06 | 1.88 | 2.21 |
| October | 2.20 | 2.02 | 2.34 | 2.28 |
| November | 1.87 | 2.08 | 1.91 | 2.24 |
| Mean | 2.01 | 2.04 | 2.24 | 2.17 |
| **SD ±** | 0.08 | 0.09 | 0.32 | 0.08 |

The condition factor values for the males in Kafue Floodplain exhibits negligible differences. This is confirmed by results of the independent two sample t-test which revealed no significant differences between the males Condition factor (t (2) = 0.349729065, P > 0.05). There were equally no significant differences in the condition factor between the females (t (2) =-0.451231317, P> 0.05).

### 4.3.3 Water Quality Parameters

Tables 4.17 shows the water quality parameters taken at Siavonga town and Kabyobyo in Lake Kariba. This was done in August 2022, just after a homogeneity period in July and in January 2023, during stratification of the Lake.

*Table 4.17: Water quality parameters across sampling sites in Lake Kariba*

| | Kabyobyo | | | Siavonga town | | |
|---|---|---|---|---|---|---|
| Month | pH | Temperature ($^{o}C$) | Secchi depth (m) | pH | Temperature ($^{o}C$) | Secchi depth (m) |
| August | 8.1 | 23.7 | 2 | 7.7 | 24.0 | 3.5 |
| January | 8.6 | 27.7 | 2 | 7.3 | 28.8 | 3.5 |
| Mean | 8.3±0.2 | 25.7±2 | 2 | 7.5±0.2 | 26.4±2.4 | 3.5 |

A two-sample independent t-test revealed that there were no significant differences in pH (t (2) = 2.655, P > 0.05) and temperature (t (2) = -0.22406454, P > 0.05) between the two sampling sites. There was a difference of 1.5m in Secchi depth between the two sampling points.

Table 4.18, shows water quality parameters taken at Chanyanya and KRB in the Kafue Floodplain, in August 2022 and January 2023.

| | Chanyanya | | | Kafue Road Bridge (KRB) | | |
|---|---|---|---|---|---|---|
| Month | pH | Temperature (°C) | Secchi depth (m) | pH | Temperature (°C) | Secchi depth (m) |
| August | 8.0 | 22.2 | 2 | 7.5 | 22.2 | 2 |
| January | 8.5 | 26.0 | 2 | 7.6 | 25.6 | 2 |
| Mean | 8.25±0.3 | 24.1±1.9 | 2 | 7.57±0.03 | 23.9±1.7 | 2 |

*Table 4.18: Water quality parameters across sampling sites in Kafue Floodplain*

There were no significant differences in pH ($t(2) = 2.746$, $P > 0.05$) and temperature ($t(2) = 0.0784$, $P > 0.05$) between Chanyanya and KRB. No dissimilarities in Secchi depth values were observed between the two sampling sites.

# CHAPTER 5: DISCUSSION

## 5.1 Growth

Length frequency histograms were constructed in order to determine population length distributions and spawning patterns. Modal lengths revealed that the majority of the catch were between 45mm and 60mm in Lake Kariba and between 50mm and 70mm in the Kafue Floodplain with lightly exploited populations in each case. From the distribution of size classes (appendix A), multiple spawns were observed in *C. quadricarinatus* confirming Makwelele (2019) and Marufu's (2018) findings.

Significance of the difference ($P < 0.05$) in mean carapace length between males and females at Chanyanya and KRB on the Kafue Floodplain were probably due to differences in fishing pressure. The higher mean lengths at Chanyanya compared to KRB were due to less fishing pressure at Chanyanya than KRB. There were no significant differences in the mean carapace sizes between Kabyobyo and Siavonga town. However, significant differences in the mean carapace length between KRB and Chanyanya could have been due to the fact that Chanyanya had fewer samples analysed, (256) than KRB, (897). Therefore, in future research further investigation on the differences in mean lengths between the two sites may be required.

The unisex individuals were isolated and classified as unknown sex. In many cases male to female ratio is 1:1(Douthwaite 2016; Marufu 2018; Marufu 2014; Madzivanzira 2021;) with males being slightly more in number than females as males are assumed to be more probable to be trapped due to them being more active than females. Although Marufu (2018), Madzivanzira (2020) and Douthwaite (2016) numerated unisex *C. quadricarinatus* separately they combined males and females in their analysis. Males have relatively larger body sizes than females (Haubrock, 2021) and it would be more precise to analyse them separately.

Both Lake Kariba and Kafue Floodplain revealed no significant differences in growth parameters between sites. Predicted length ($L_t$) at age t, using the von Bertalanffy model revealed no significant differences ($P > 0.05$) in the growth rates. Therefore, there were no significant differences in von Bertalanffy parameters between Kabyobyo and Siavonga town, at Lake Kariba and between Chanyanya and KRB at Kafue Floodplain in both males and females.

Moreover, *C. quadricarinatus* has the ability to take up both r and K selection life history strategies. Marufu *et al.*, (2018) observed that *C. quadricarinatus* in lake Kariba was following a more 'r' selected life history strategy than in its native range (Western Australia and Papua New Guinea). It also revealed a higher growth rate compared to *C. quadricarinatus* reared under controlled conditions (Beatty *et al.*, 2005). Therefore, *C. quadricarinatus* could be following a more r selection history strategy at KRB than at Chanyanya. However, this requires further investigations. The ability of *C. quadricarinatus* to take up both r and K selection strategies helps it to survive in a wide range of habitats, Beatty *et al.,* (2005).

Slight disparities in the values of growth parameters between sexes at the same site could be explained by the hypothesis of sexual dimorphism where, males relatively increase faster in size than females (Vejan *et al.,* 2022)

The von Bertalanffy growth parameters, $L_\infty$ and k using carapace length (CL) varies considerably between sites than does the growth functionality index; Φ′ (Gayanilo *et al.,* 2005). Therefore, instead of comparing $CL\infty$ and k individually, Φ′ was preferred for comparison of growth between populations and to assess confidence of the estimated growth parameters on Lake Kariba and Kafue Floodplain (Munro and Pauly, 1983; Pauly and Munro, 1984). The growth performance was preferred because it integrates both descriptors of the von Bertalanffy growth curve; $L\infty$ and k (Vejan *et al.*, 2022)

Mean value of Φ′ for combined sexes at Siavonga; 4.1 and for combined sexes at Kabyobyo; 3.9 (table 4.5 c) exhibited negligible differences ($P > 0.05$) and mean values of Φ′ for combined sexes at Chanyanya (3.6) and KRB (4.1) exhibited negligible dissimilarities as well ($t(2) = 4.025$, $P > 0.05$). According to Vejan *et al.*, (2002), it can be assumed that they were no differences in growth performance between Kabyobyo and Siavonga and between Chanyanya and Siavonga.

Marufu (2018) investigated aspects of population ecology for *C. quadricarinatus* in the Sanyati basin of Lake Kariba and sampled from 13 sites on the Zimbabwean side not very distanced from Siavonga and Kabyobyo in the Bumi basin on the Zambian side. The mean value of Φ′ for both sexes at Kabyobyo and Siavonga in Lake Kariba (3.9) is not very different from the 4.0 obtained by Marufu (2018) for combined sexes in Lake Kariba.

A study done by Makwelele (2019) investigated population dynamics of *C. quadricarinatus* at KRB in 2015 and obtained the growth performance index (Φ′) value of 2.8 which is a lower value when compared to 3.8 (table 4.5d) obtained for both males and females for the same sampling site in 2022 by this current study. It is also much less than the 4.0 obtained by Marufu (2018) and the 3.9 (table 4.5c) obtained by this current study for lake Kariba.

A comparison of body sizes of *C. quadricarinatus* in the native Australian waters and that of the invaded Kafue floodplain and Lake Kariba reveals that, there are similarities in some growth measurements. The largest *C. quadricarinatus* in the native ranges of Australian fresh water rivers, streams and lakes in the Northern territory measured 175mm. Condition factor for the males ranged between 1.43-1.63 and females 1.53-1.73. Length-weight relationship regression coefficient, b ranged between 2.85-2.97 with the coefficient of determination between 0.85-0.95 (Morgan *et-al.*, 2017; Kennard et al., 2015).

In this study the largest *C. quadricarinatus* was a male measuring 205mm from lake Kariba and a female measuring 201mm from Kafue Floodplain. The condition factor (K) in Zambian waters had higher values than those of the native Australian waters ranging between 2.17-2.52 in males and 2.01-2.32in females. Length-weight relationship regression coefficient, b ranged between 2.61-2.95 with the coefficient of determination between 0.83-0.94. Therefore, *C. quadricarinatus* is well adapted to Lake Kariba and Kafue Floodplain.

## 5.2 Relative Abundance

Although Siavonga town recorded a slightly higher CPUE compared to Kabyobyo (figure 4.5) the length frequency histogram results revealed that Siavonga town was more exploited than Kabyobyo because the length percentage histogram shifted to the left more at Kabyobyo than at Siavonga town (figure 4.1 and figure 4.2). Wickson *et al,* (2021) described the distribution of crayfish as random between sampling sites and dependent on the availability of food and depth of the lake.

On the Kafue Floodplain, higher abundance was observed at Chanyanya (1.2N/trap/day) compared to KRB (0.1N/trap/day). These differences in CPUE could not be explained by minor dissimilarities in environmental conditions such as pH and temperature ($P > 0.05$). They could not also be associated with changes in the values of, K or b as there were no significant differences in the nutritional status and environmental condition between the compared sites in the Kafue Floodplain and Lake Kariba ($P > 0.05$). However, this could be related to the presence of commercial *C. quadricarinatus* fishermen at KRB exerting fishing pressure on the resource, and the absence of the same at Chanyanya.

## 5.3 Length-weight Relationships, Condition Factor and Water quality parameters

### 1. Length-weight Relationships

Differences in the regression coefficient, b of length-weight relationships, between months and between males and females in Lake Kariba as well as in the Kafue Floodplain could have been influenced by several factors, which include; sex, season, length ranges and sample sizes. However, slight disparities in the regression coefficient, b for all the sites at Lake Kariba and the Kafue Floodplain were insignificant ($P > 0.05$). In order to avoid bias in the determination of regression coefficient, most samples worked on had sample sizes with N larger than 50, because according to Velasco (2007) sample sizes with N larger than 50 gives $r^2$ values above 0.95.

Harlioglu (2019) argues that it is not possible to determine age of crayfish due to moulting, instead length-weight and length-length relationships are considered. Going by this argument, the absence of differences in regression coefficient, b, between Kabyobyo and Siavonga in lake Kariba and between Chanyanya and KRB in Kafue Floodplain could mean that there were no significant differences in the growth of *C. quadricarinatus* between these sampling sites for the period of study.

**2. Condition Factor (K)**

Condition factor K, quantitatively expresses the effect of feeding, since it measures the nutritional capacity and the conditioning factor that gives information about the nutritional level. Condition factor is useful in the comparison of populations of the same species and in determining relative growth (Naguib et al, 2021).

According to Weya et al (2017), a condition factor of more than 1 indicates that *C. quadricarinatus* has attained a good condition. All the condition factor values obtained at all the study sites were above one (table 4.15 and 4.16). Based on this, all the crayfish in Lake Kariba and in the Kafue, floodplain was in good condition. The absence of significant differences in the K value, at the two sites in the Kafue floodplain and the two sites at Lake Kariba could mean that there were no dissimilarities in factors such as, food availability, water level fluctuations and water quality (Acosta and Perry 2000). Crayfish in habitats that were without any anthropogenic influences and with suitable shelters were observed to have higher K values by Anderson and Simon (2015). In this current study Chanyanya and Kabyobyo located further from the Central business District (CBD) were assumed to have fewer anthropogenic activities compared to Kafue Road Bridge and Siavonga which are situated in the CBD. However, there were no observable differences between habitats at all the compared sites.

The slightly higher values of K, at Kabyobyo than Siavonga could also be attributed to Kabyobyo being located near the fish farms. The feed served to fish in the cages could be reaching the crayfish at Kabyobyo and thereby providing it with extra nutrients. Naguib (2021) investigated K values of *C. quadricarinatus* at three sites in Peninsular Malaysia. His study revealed that crayfish sampled in the waters near restaurants where people were throwing left over foods in water, had higher values of K compared to the crayfish that was located at sites away from anthropogenic activities.

**Water quality Parameters**

Temperature and oxygen are significant in the operations of aquatic ecosystems because they directly affect growth and cause acute impact on aquatic ecosystems Cassie (2006). Temperature differences as small as $2^oC$ are sufficient to induce detectable seasonal growth oscillations (Pauly, 1990). Hamidah

(2017) shows that differences in the length and weight of the species is possible because of the influence of factors such as fluctuations in the water quality.

Warmer water is usually associated with lower dissolved oxygen which results in an increase in its demand (Haubrock *et al.,* 2021). The water quality parameter values obtained at the two sites in Lake Kariba (table 4.17) and the two sites in the Kafue floodplains (table 4.18) all fall within optimum ranges for *C. quadricarinatus*. Most preferred temperature range for *C. quadricarinatus* is between 23$^{o}$C and 26$^{o}$C, dissolved oxygen of at least above 6mg/l and pH range between 6 and 9 (Haubrock *et al.*,2021; García-Guerrero 2013). There were no dissimilarities observed in temperature and pH between the sites on Lake Kariba and between the sites on the Kafue Floodplain (P>0.05).

**Limitations**

Limitations of FiSAT which uses ELEFAN protocols to determine von Bertalanffy growth parameters k and L'inf, according to Gayanilo et al (1996) include; the use of K-scan which produces large biases in parameter estimation; the use of non-informative priors that have little effect on the posteriors and the use of the response surface analysis (RSA) which is unable to model seasonal growth. Therefore, Schwamborn et al, (2018) recommends the Bayesian approach which according to him does not use many averages to find peaks and troughs in the length frequency distributions (LFD) but first fits a multi-normal mixture model (MNMM) to LFD to determine the mean length and its variance for each age class in each sample. However, this current study monitored short seasonal growth by analysing data monthly for Length frequency histograms, length weight relationships, and condition factor

Other limitations included challenges in collecting samples from both sites for certain months. On Lake Kariba the month of August and November only had samples for Kabyobyo but not Siavonga. Therefore, only September and October were considered for comparative analysis because they were represented with samples from both Siavonga and Kabyobyo. Dissolved oxygen was only measured on lake Kariba for January, 2023 and obtained as 7.1mg/l and 6.2mg/l for Siavonga town and Kabyobyo respectively.

# CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusion

1. The study found no significant differences in the growth parameters and growth performance index of *Cherax quadricarinatus* between Kabyobyo and Siavonga on Lake Kariba, nor between Chanyanya and Kafue Road Bridge on the Kafue floodplain.
2. There were no notable differences in relative abundance between the two locations on Lake Kariba. However, significant differences in relative abundance were observed between Chanyanya and Kafue Road Bridge, attributed to higher fishing pressure at Kafue Road Bridge.
3. There were no significant differences in conditions conducive to growth of *Cherax quadricarinatus*, such as water quality and other parameters, between the sampling sites.

Overall, *Cherax quadricarinatus* is well adapted to both ecosystems and may spread to other aquatic environments in central and southern Africa

## 6.2 Recommendations

1. Future researchers can also investigate phytoplankton production and fecundity in the Kafue Floodplain and Lake Kariba as there seem to be insufficient information available. Studies on fecundity may help to establish if *Cherax quadricarinatus* is following a more r- selection history strategy at some locations than others.
2. Exploitation of *C. quadricarinatus* in fisheries located away from Central business districts should be encouraged in order to keep its population minimal and reduce possible occurrence of adverse ecological impacts that could result from overpopulation of *C. quadricarinatus* on the invaded ecosystems.
3. It is recommended that the populations and spread of *Cherax quadricarinatus* in Lake Kariba and Kafue Floodplain are monitored on a regular basis. This may guide government to formulate policies that govern exploitation and trade of crayfish in Zambia which in turn can curb its spread to new ecosystems (Marufu, 2018).
4. Education of economic benefits of crayfish and encouragement of its exploitation and consumption especially in remote areas may keep its populations under control. Sensitization on the potential adverse effects of crayfish to the local people can enhance early detection and reporting of new invasions.

## REFERENCES

Acosta, C.A., and Perry, S. A. (2000). Differential growth of crayfish Procambarus alien in relation to hydrological conditions in marl prairie wetlands of Everglades National Park, USA. Aquatic Ecology, 34, 389−395.

Anderson, W.E., and Simon, T.P. (2015). Length-weight Relationship, Body Morphometrics, and Condition Based on Sexual Stage in the Rusty Crayfish, Orconectes rusticus Girard, 1852 (Decapoda, Cambaridae) with Emphasis on Management Implications. Fish Aquatic J 6: 129. doi:10.4172/2150-3508.100012

Austin, C.M. (1996). Systematics of the fresh water crayfish Cherax Ericson (Decapoda: Paracidae) in Western Australia. PhD thesis, University of western Australia.

Beatty, S.J. (2005). Translocations of freshwater crayfish: contributions from life histories, trophic relations and diseases of three species in Western Australia. Unpublished Ph.D. dissertation. Murdoch University, Perth, Western Australia.

Blackburn, T.M., *et al*. (2011). A proposed unified framework for biological invasions. Trends in Ecology and Evolution 26: 333–339.

Caissie, D. (2006). The thermal regime of rivers: a review. Freshwater Biol. 2006; 51: 1389–1406.

Calamita E., *et al*. (2019) Sixty years since the creation of Lake Kariba: Thermal and oxygen dynamics in the riverine and lacustrine sub-basins. PLoS ONE 14(11): e0224679.

Coates, *et al*. (2018). Freshwater Crayfish of Papua New Guinea. Journal of crustacean Biology,38(3), 349-359. DOI: 10.1093/jcbiol/rux092.

Coughran, J., and S. R. Leckie. (1997). Invasion of a New South Wales stream by the tropical crayfish, *Cherax quadricarinatus* (von Martens). Pest or Guest: the zoology of overabundance:40-46.

Douthwaite, R.J., *et al*. (2018). The introduction, spread and ecology of redclaw crayfish *Cherax quadricarinatus* in the Zambezi catchment. *African Journal of Aquatic Science*, *43*(4), pp.353-366

García-Guerrero M., *et al*. (2013). Effect of temperature on weight increase, survival, and thermal preference of juvenile redclaw crayfish *Cherax quadricarinatus*. Hidrobiológica 23 (1): 73-81

Gayanilo, F.C. Jr., Sparre, P. & Pauly. D (1996) “FAO-ICLARM Fish Stock Assessment (FiSAT) User’s Guide”, FAO Computerized Information Series (Fisheries) 7, FAO of the United Nations, Rome, Italy,180 p. Gulland, J.A. (1969), “Manual of methods for fish stock assessment”, Part 1, Fish population analysis, FAO Manuals in Fisheries Science 4,154.

Gayanilo, F.C., Sparre, P. and Pauly, D. (2005) FAO-ICLARM Stock Assessment Tools ll. Revised Version. User’s Guide. Worldfish Centre, Rome.

González, R.A., *et al*. (2010). Thermal preference, tolerance and oxygen consumption of adult white shrimp Litopenaeus vannamei (Boone) exposed to different acclimation temperatures. *Journal of Thermal Biology*, *35*(5), pp.218-224.

Haimovici, M. and Velasco, G. (2000) Length-Weight Relationship of Marine Fishes Southern Brazil. NAGA, 23, 19-23.

Hamidah, H. and Bowolaksono, A. (2017). July. Comparative study of freshwater crayfish, Cherax spp. (crustaceae: decapoda: parastacidae) from Papua, Indonesia based on length-weight analysis. In *AIP Conference Proceedings* (Vol. 1862, No. 1, p. 030101). AIP Publishing LLC.

Harlioglu, A. (2019). Importance of Length-length and Length-weight Relations in Crayfish. *Turkish Journal of Science and Technology* 14(1), 9-13, 2019

Haubrock, P.J., *et al*. (2021). The redclaw crayfish: A prominent aquaculture species with invasive potential in tropical and subtropical biodiversity hotspots. *Reviews in Aquaculture*, *13*(3), pp.1488-1530.

Hobbs, H.H. and Lodge, D.M. (2010). Decapoda. In *Ecology and classification of North American freshwater invertebrates* (pp. 901-967). Academic Press.

Isaza, D.F.G., *et al*. (2018). Negative impacts of elevated nitrate on physiological performance are not exacerbated by low pH. *Aquatic Toxicology*, *200*, pp.217-225.

Jones, C. M. and Austin, C. M. (2001). The biology and ecology of *Cherax quadricarinatus* (Decapoda: Parastacidae) in Lake Argyle, Western Australia. Fresh water crayfish, 13, 349-362.

Jones, C. M. and Lawrence, C. S. (2002). Reproduction and growth in the tropical freshwater crayfish, *Cherax quadricarinatus* (Decapoda: Parastacidae). Fresh water crayfish, 13, 427-436.

Kennard et al. (2015). Distribution, abundance and size structure of *Cherax quadricarinatus* in northern Australia. Marine and fresh water research, 66(9), 831-841.DOI: 10.107/MF14143.

Kouba, A., *et al*. (2014). Continental-wide distribution of crayfish species in Europe: update and maps. *Knowledge and Management of Aquatic Ecosystems*, (413), 05.

Lawrence, C. S. (2002). *Cherax quadricarinatus*. In: Holdich, D. M. (Ed), Biology of Freshwater Cray fish (pp. 645—653). Blackwell Science, Oxford.

Lodge, D.M., *et al*. (2012). Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution, and Systematics*, *43*, pp.449-472.

Madzivanzira, T.C., *et al.* (2021). Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in the Zambezi Basin. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*(11), pp.3156-3168.

Madzivanzira, T.C., *et al*. (2020). A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture*, *29*(2), pp.218-241.

Makeche, M., *et al*. (2020). Growth and Mortality of Mouth Brooding Tilapiines of the Kafue Floodplain Fishery, Zambia. International *Journal of Development Research*, pp.109-118

Makwelele, G. (2019). Reproductive Biology, Growth and Mortality of the Introduced Crayfish, *Cherax quadricarinatus* (Von Martens, 1868) in the Kafue Floodplain Fishery. University of Zambia

Marufu, L., *et al*. (2018). The population dynamics of a recently introduced crayfish, *Cherax quadricarinatus* (von Martens, 1868), in the Sanyati Basin of Lake Kariba, Zimbabwe. *African Zoology*, *53*(1), pp.17-22.

Marufu, L.T., *et al*. (2020) Spatial and temporal distribution of an invasive crayfish (*Cherax quadricarinatus*) in Lake Kariba, Zimbabwe

Marufu, L.T., *et al*. (2014). Invasive Australian crayfish *Cherax quadricarinatus* in the Sanyati Basin of Lake Kariba: a preliminary survey. *African journal of aquatic science*, *39*(2), pp.233

Masser, M.P. and Rouse, D.B. (1997). Australian red claw crayfish. Southern Regional Aquaculture Centre. SRAC Publication No. 244. 8 p.

Maunder, M.N. and Punt, A.E. (2004). Standardizing catch and effort data: a review of recent approaches, Fisheries Research, Volume 70, Issues 2–3,2004, Pages 141-159.

Morgan *et al*. (2017). Freshwater Crayfish in Australia: Diversity, Distribution and Conservation. Journal of Crustacean Biology, 37(4), 439-453.DOI:10.1093/jcbiol/rux045.

Naguib, S., *et al*. (2021). Length-weight relationship and condition factor of Australian red claw crayfish (*Cherax quadricarinatus*) from three locations in Peninsular Malaysia. Bioscience Research. 18. 413-420.

Nakayama, S.M., *et al*. (2010). Heavy metal accumulation in lake sediments, fish (Oreochromis niloticus and Serranochromis thumbergi), and crayfish (*Cherax quadricarinatus*) in Lake Itezhi-tezhi and Lake Kariba, Zambia. *Archives of environmental contamination and toxicology*, *59*(2), pp.291-300.

Ndebele-Murisa, M.R., *et al*. (2014). A decline in the depth of the mixed layer and changes in other physical properties of Lake Kariba's water over the past two decades. Hydrobiologia. 2014; 721: 185–195.

Nga, B.T., *et al*. (2005). Chemical and physical effects of crowding on growth and survival of Penaeus monodon Fabricius post-larvae. *Aquaculture*, *246*(1-4), pp.455-465.

Nunes, A.L., *et al*. (2017). Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. *PeerJ*, *5*, p.e3135.

Pauly, D. (1990). Length converted catch curves and the seasonal growth of fishes. Fishbyte 8: 33– 38.

Pysek, P. and Richardson, D.M. (2010) Invasive species, environmental change and management, and health. ScienceDirect, 35(8), pp.529-538.

Schwamborn, R., *et al*. (2018b). Assessing sources of uncertainty in length-based estimates of body growth in populations of fishes and macroinvertebrates with bootstrapped ELEFAN. Ecological Modelling, 393: 37-51

Talevski, T., *et al*. (2009). Biodiversity of Ichthyofauna from Lake Prespa, Lake Ohrid and Lake Skadar, Biotechnology & Biotechnological Equipment, 23:sup1, 400-404, DOI: 10.1080/13102818.2009.1081844

Tumbare, M.J. (2008). Managing Lake Kariba sustainably: threats and challenges. *Management of environmental quality: An international journal*.

Twardochleb, L.A., *et al*. (2013). A global meta-analysis of the ecological impacts of nonnative crayfish. *Freshwater Science*, *32*(4), pp.1367.

Vanden Bossche**,** J.P. and Bernacsek, G. (1990). Source book on the inland fishery resources of Africa. Vol I. CIFA Tech. Pap., 18/1: 411 pp

Vejan, A., *et al*. (2022) Comparative population dynamics of two sympatric Palaemon shrimps (Palaemon adspersus Rathke, 1836 and Palaemon elegans Rathke, 1836) from the Southeast Caspian Sea. Front. Mar. Sci. 9:928445. doi: 10.3389/fmars.2022.928445

Velasco, G. and Oddone, M. C. (2004). Growth parameters and growth performance indexes for some populations of marine catfishes (actinopterygii, siluriformes, ariidae).

Welcome, R. L. (1979). Fisheries Ecology of Floodplain Rivers. Longman, London and New York.317p

Weya, *et al*., (2017). Length-weight relationship and condition factor of crayfish from South Sorong and Jayawijaya, Papua, Indonesia. Croatian Journal of Fisheries, 75: 18–24. p.

Wicaksono, A., *et al*. (2021). "Distribution and abundance of *Cherax quadricarinatus* in Lindu Lake, Central Sulawesi, Indonesia". Journal of Fisheries and Marine Science, 13(2), 123-132.

Wicaksono, C.W., *et al* (2021). Population Estimation of An Invasive Alien Species, *Cherax quadricarinatus* (von Martens, 1868) in Lido Lake, Indonesia. *Journal of Environmental and Agricultural Studies*, *2*(2), pp.01-10.

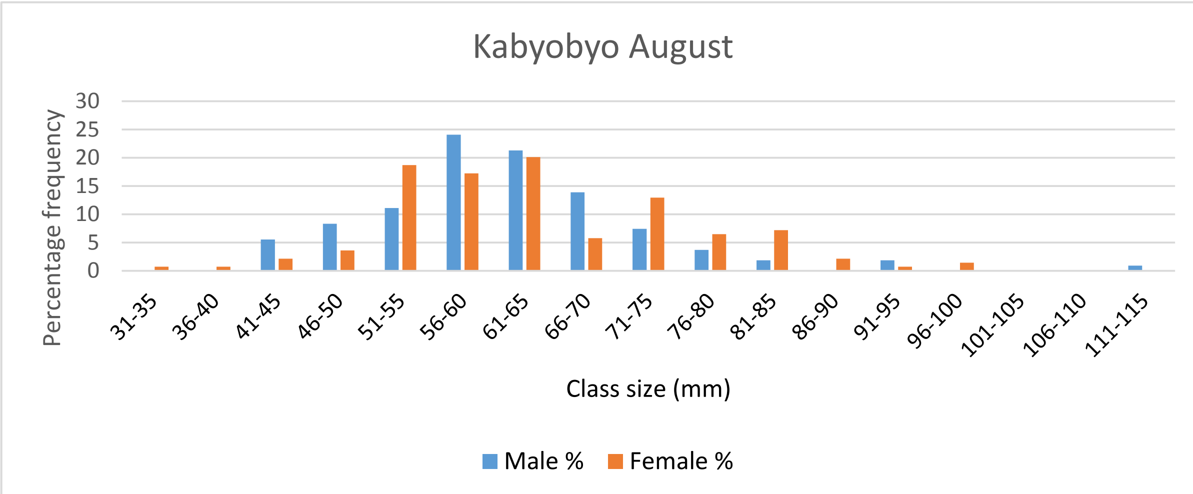
Wingfield, M. (2002). An overview of the Australian freshwater crayfish farming industry. Freshwater Crayfish 13: 177–184. Wood KA, Hayes RB, England J, Grey J (2017) Invasive crayfish impacts on native fish diet and growth vary with fish life stage. Aquatic Sciences 79: 113–125. Xiaxuan C, Edgerton B (2001) Freshwater crayfish culture in China. Aquaculture Magazine 27: 41–44

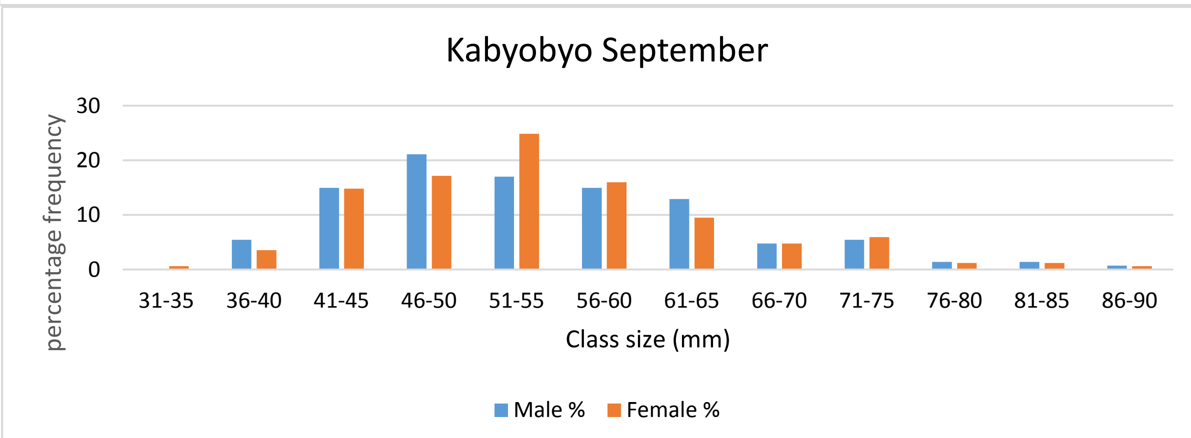
Zengeya, A.T. and Marshall, E.B. (2007). 'Fresh water molluscs of Zimbabwe'. In freshwater molluscs of Africa, edited by K.G. Smith, W.R.T. Darwall, and P.H. Skelton, 147-164. Grahamstown: South African Institute for Aquatic Biodiversity.

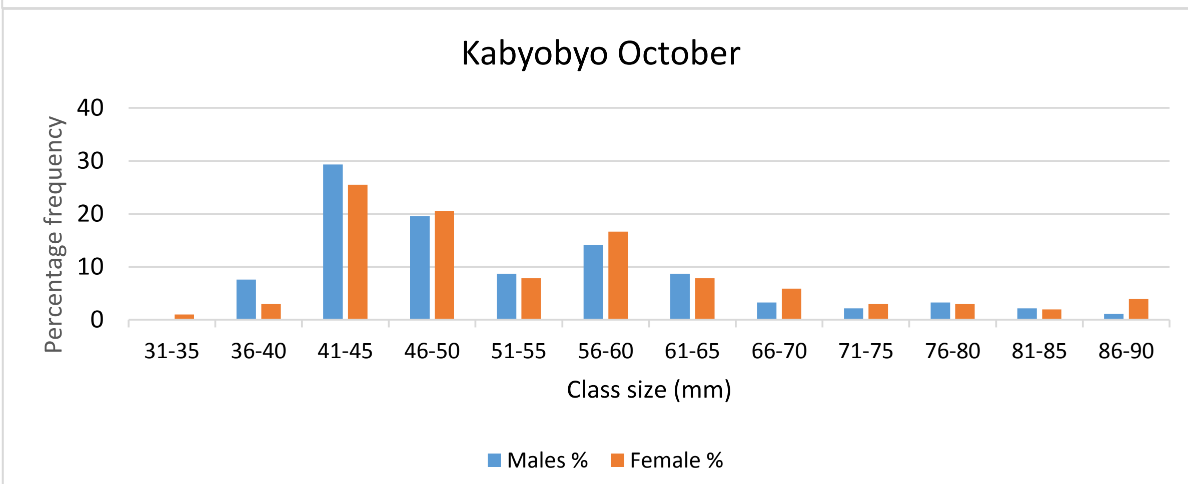
Zengeya A.T. and Marshall E.B. (2008). The inshore fish community of Lake Kariba half a century after its creation: what happened to the Upper Zambezi species invasion? African Journal of Aquatic Science, 33:1, 99-102

## APPENDICES

### Appendix A: Monthly Length Frequency Distributions Graphs



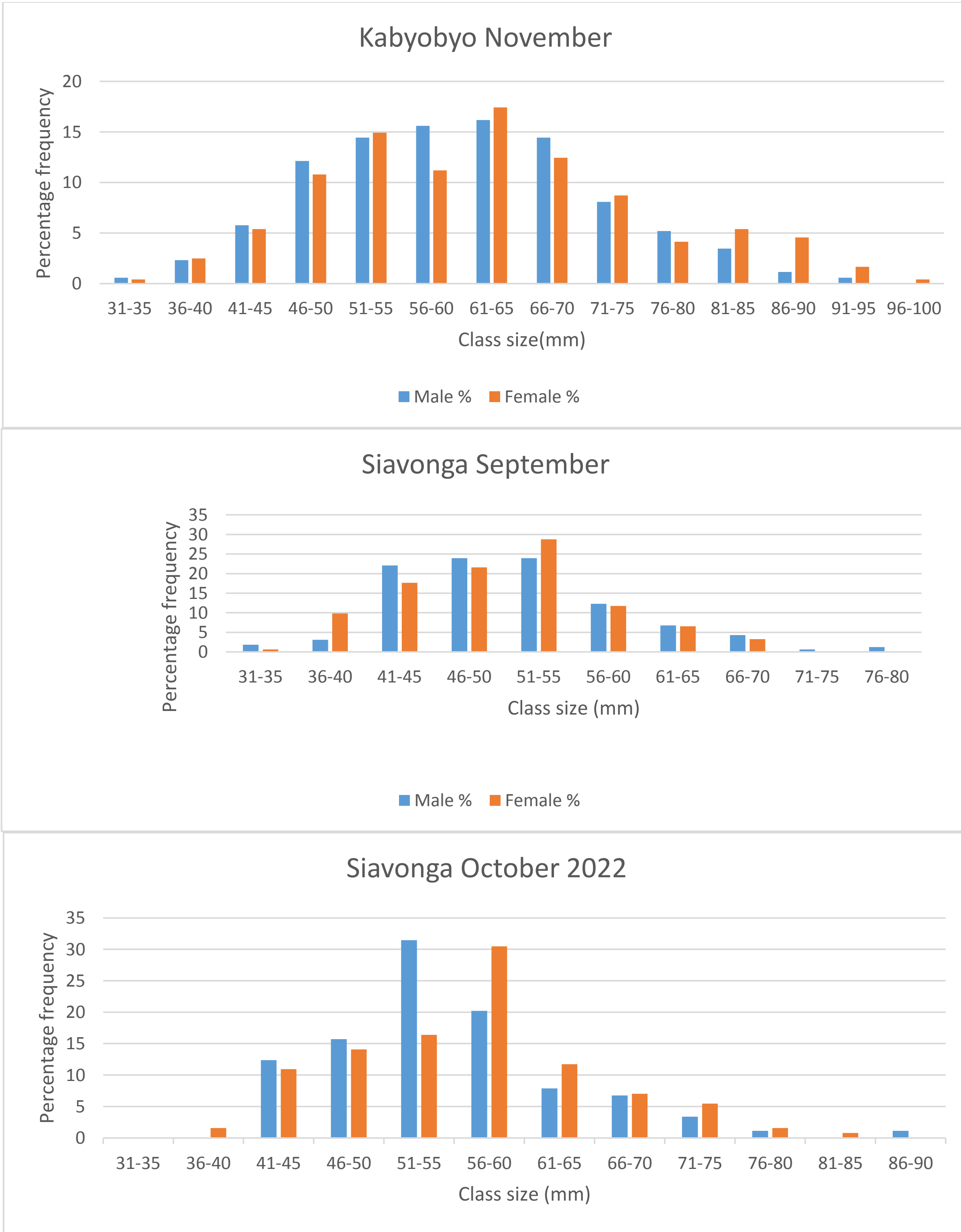
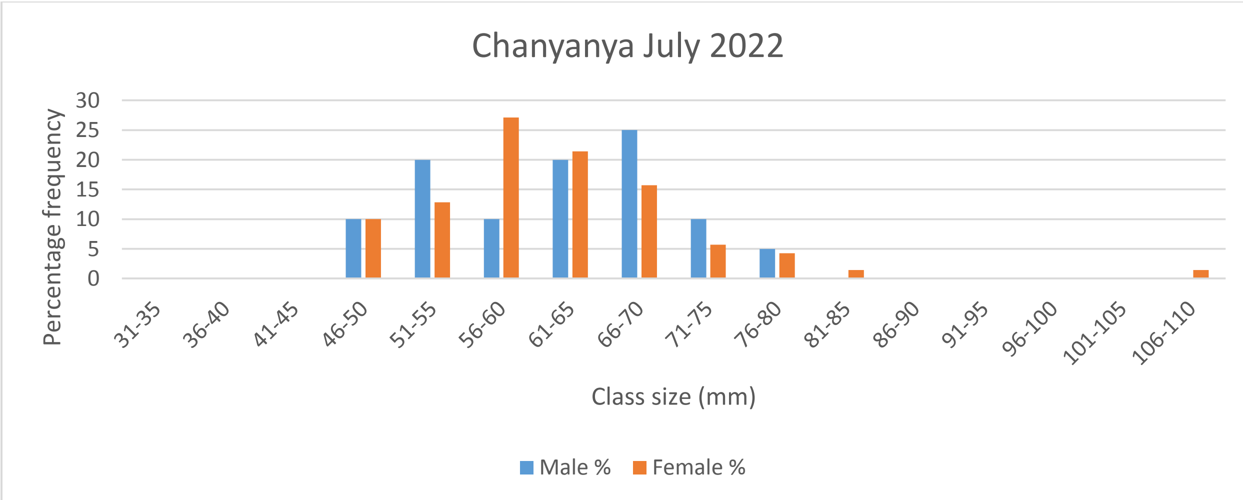
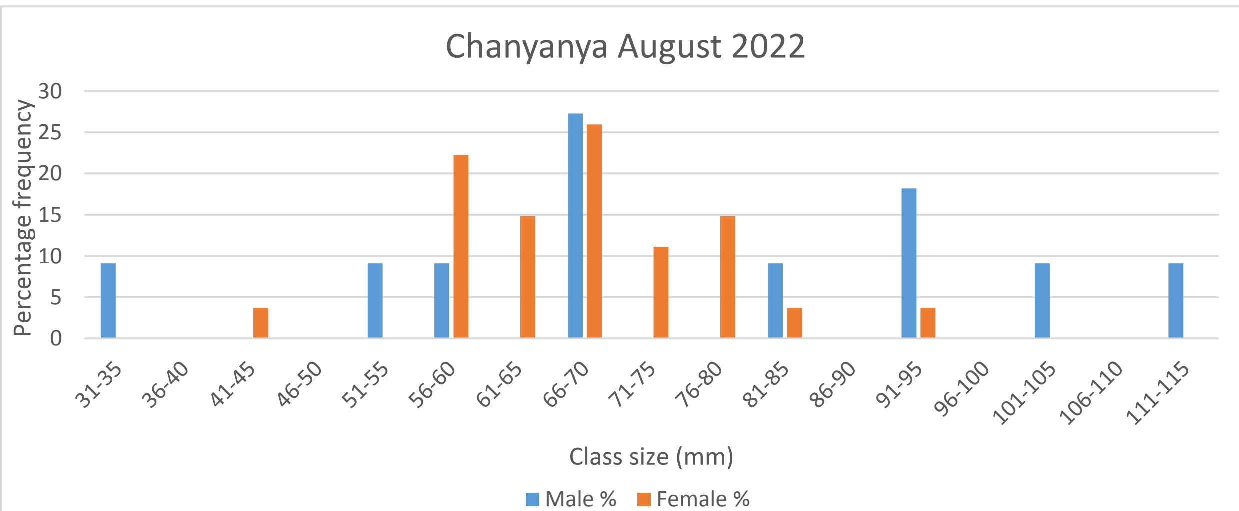
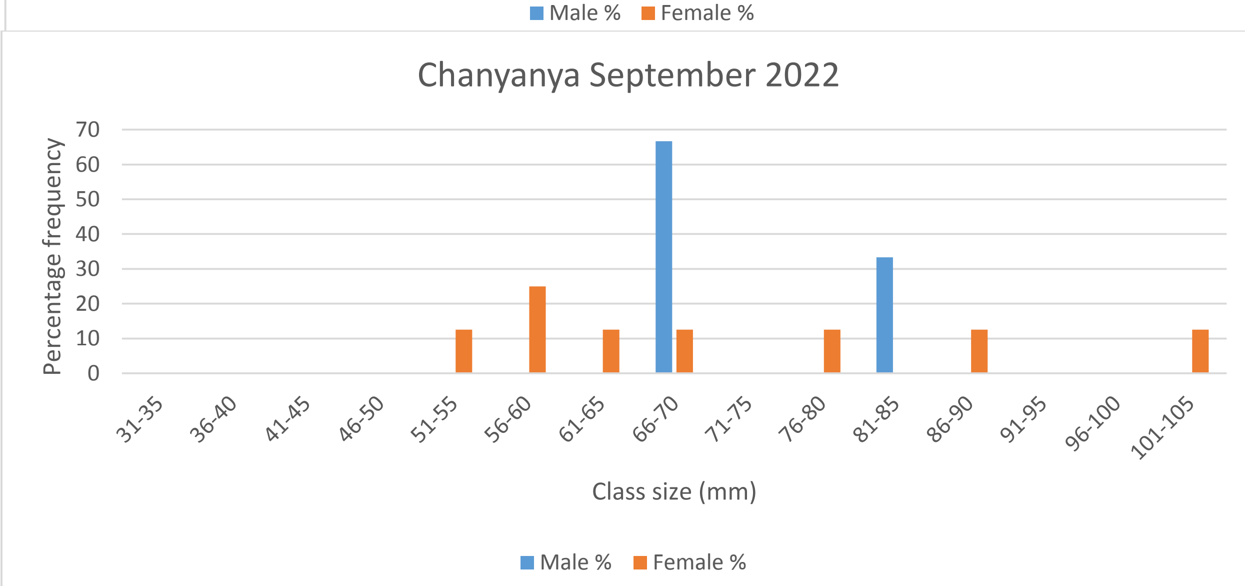
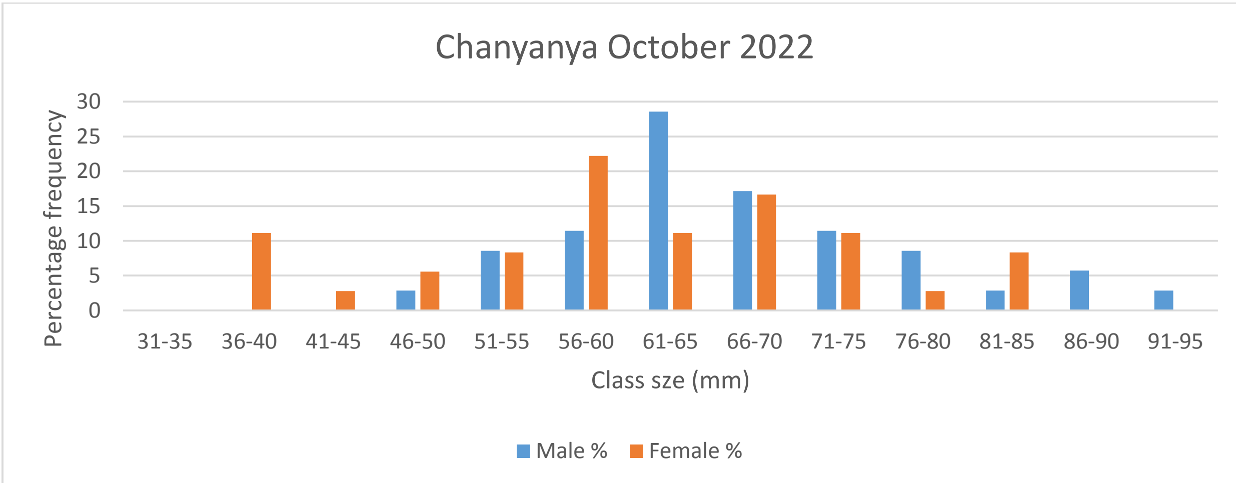


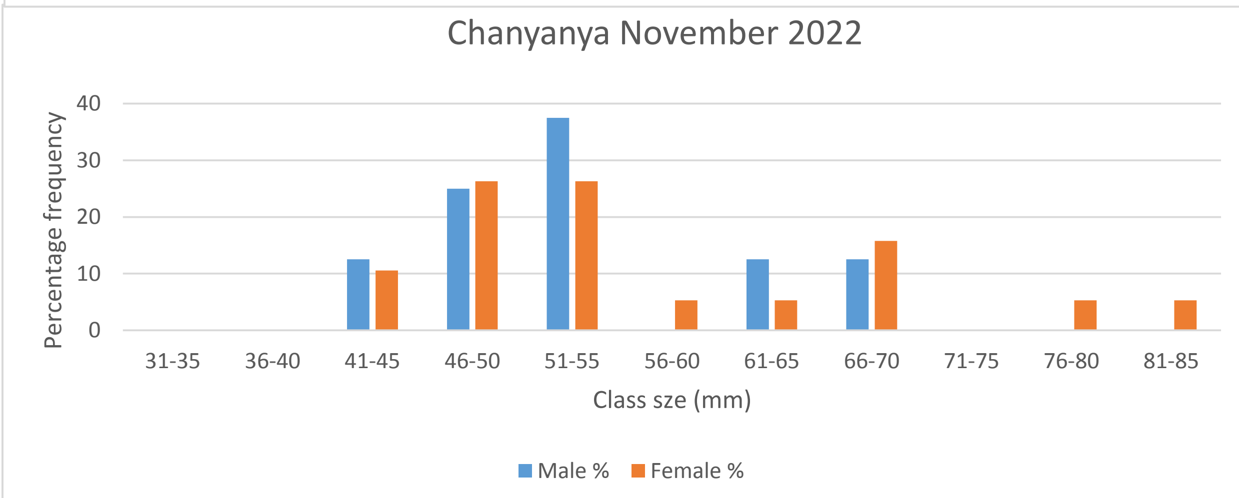

*Figure A1: Monthly Length Frequency Distribution Graphs for Kabyobyo and Siavonga on Lake Kariba between August 2022 and November 2022*

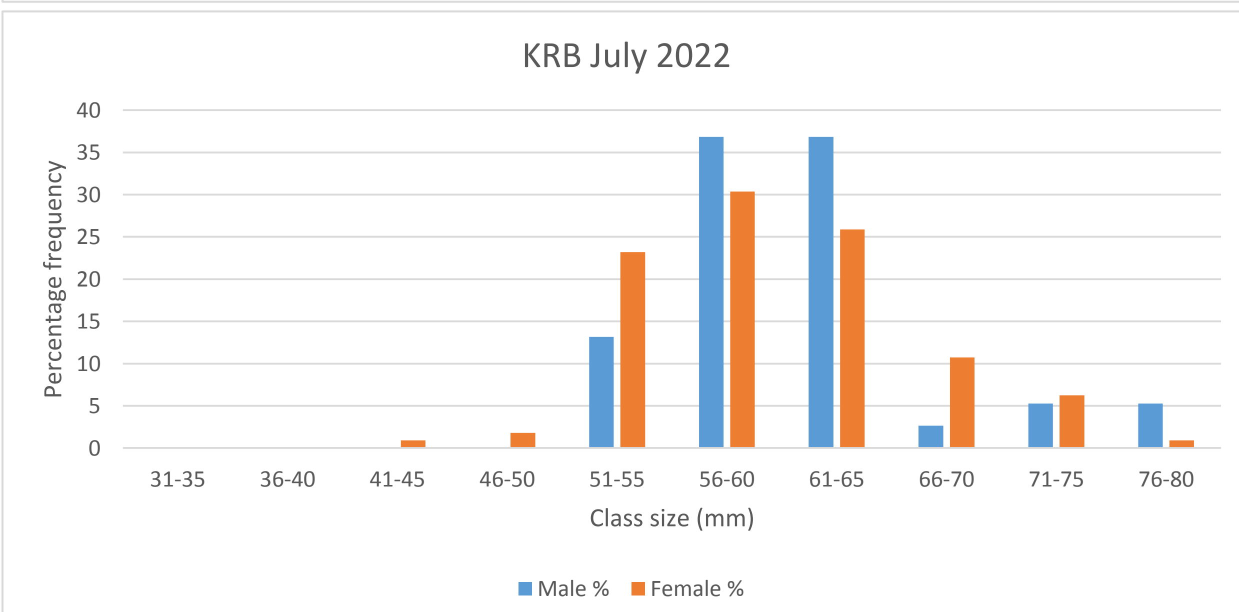

Chanyanya July 2022
Percentage frequency
30
25
20
15
10
5
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
101-105
106-110
Class size (mm)
Male %
Female %

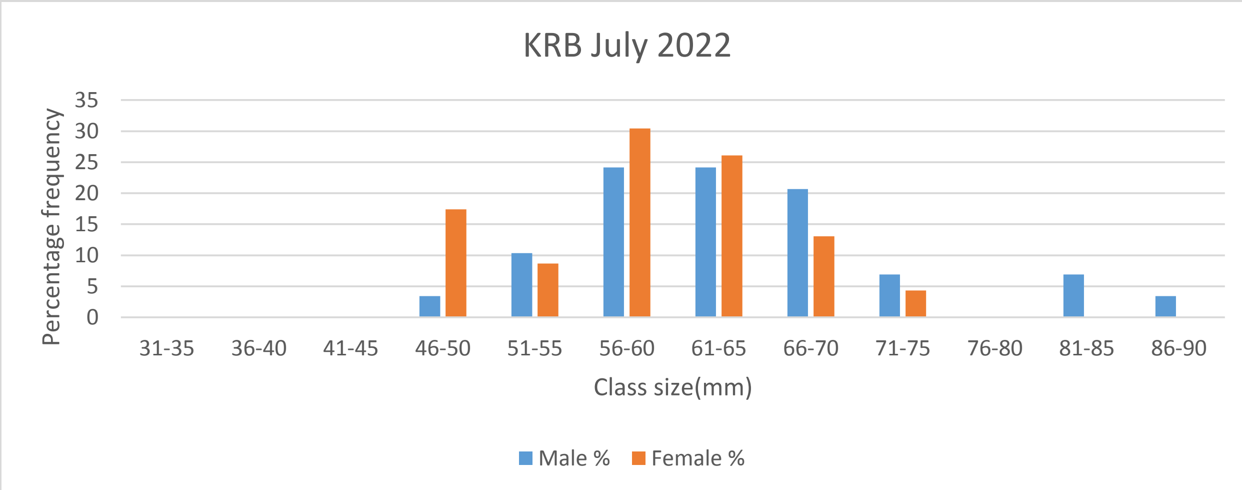

Chanyanya August 2022
Percentage frequency
30
25
20
15
10
5
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
101-105
106-110
111-115
Class size (mm)
Male %
Female %

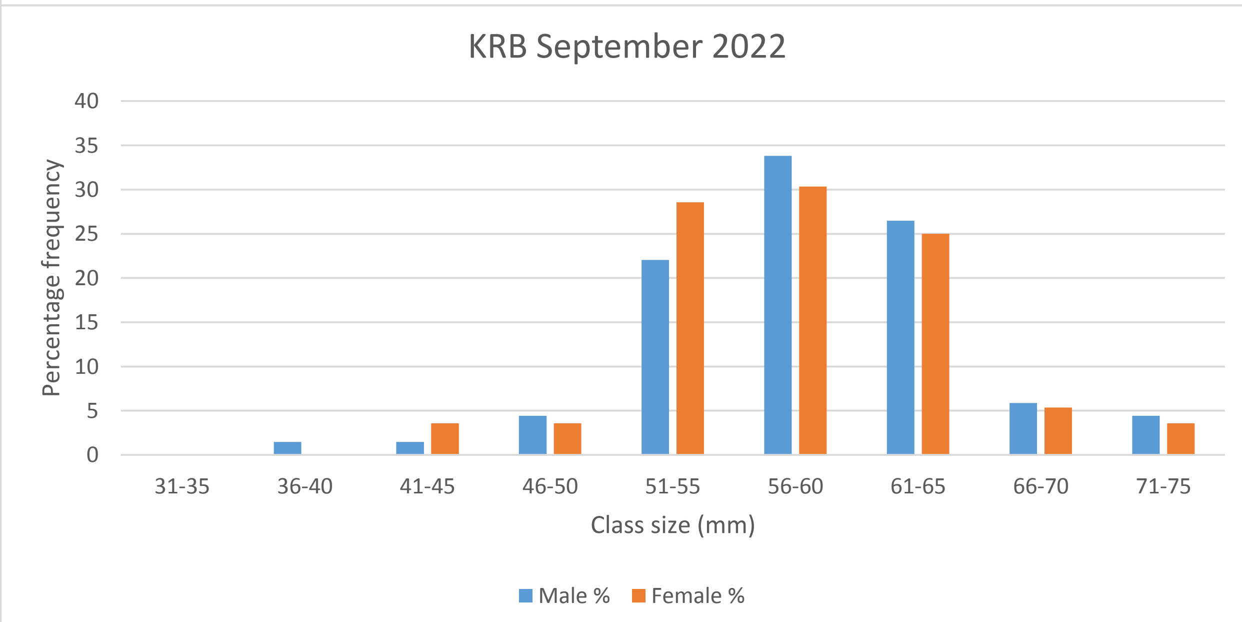

Chanyanya September 2022
Percentage frequency
70
60
50
40
30
20
10
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
101-105
Class size (mm)
Male %
Female %

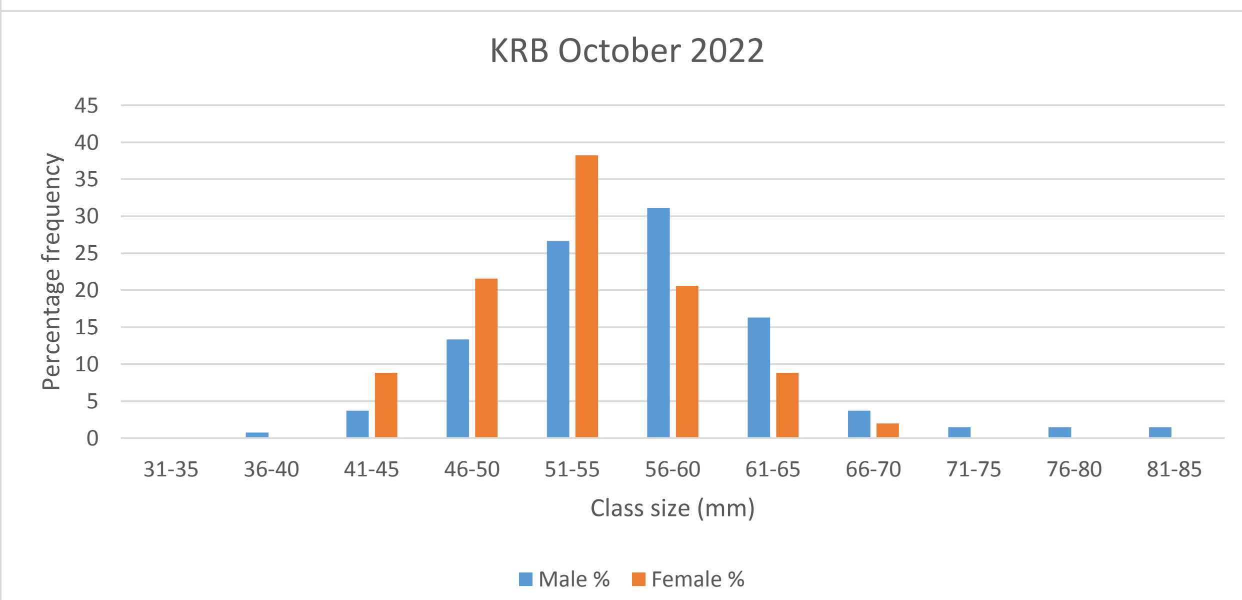

Chanyanya October 2022
Percentage frequency
30
25
20
15
10
5
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
Class sze (mm)
Male %
Female %


Chanyanya November 2022
Percentage frequency
40
30
20
10
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
Class sze (mm)
Male %
Female %


KRB July 2022
Percentage frequency
40
35
30
25
20
15
10
5
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
Class size (mm)
Male %
Female %


KRB July 2022
Percentage frequency
35
30
25
20
15
10
5
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
Class size(mm)
Male %
Female %


KRB September 2022
Percentage frequency
40
35
30
25
20
15
10
5
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
Class size (mm)
Male %
Female %


KRB October 2022
Percentage frequency
45
40
35
30
25
20
15
10
5
0
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
Class size (mm)
Male %
Female %

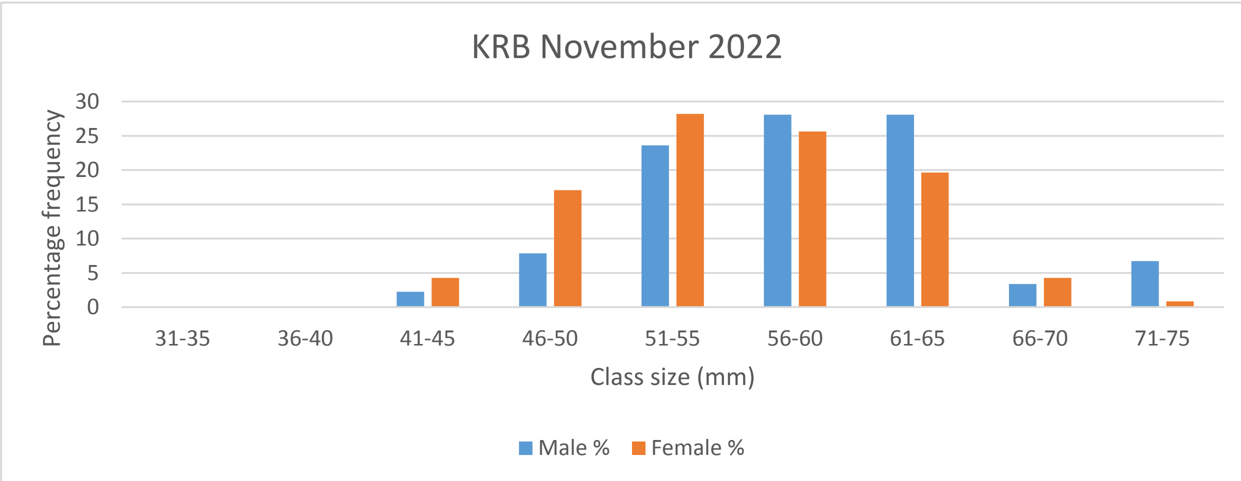
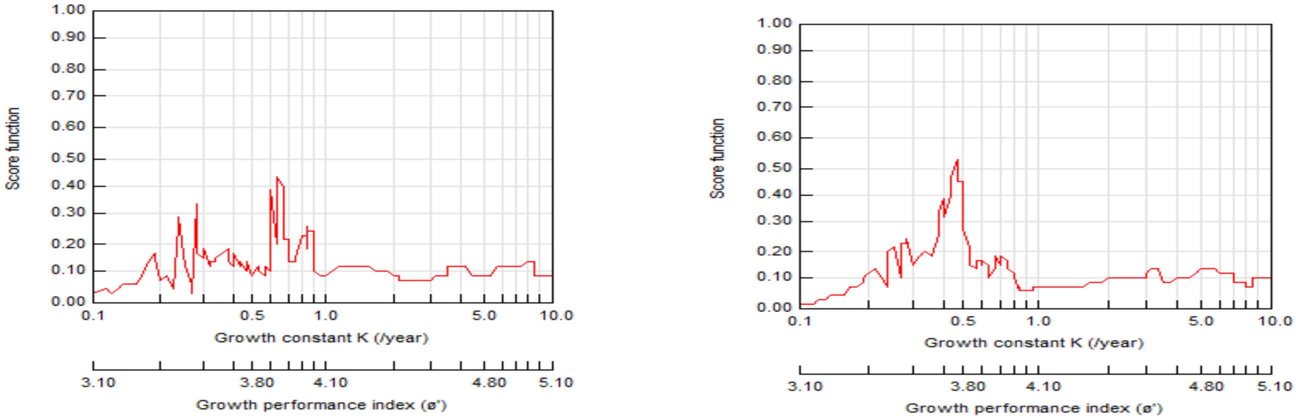



*Figure A2: Monthly Length Frequency Distribution Graphs for Chanyanya and KRB on Kafue Floodplain between July 2022 and November 2022*

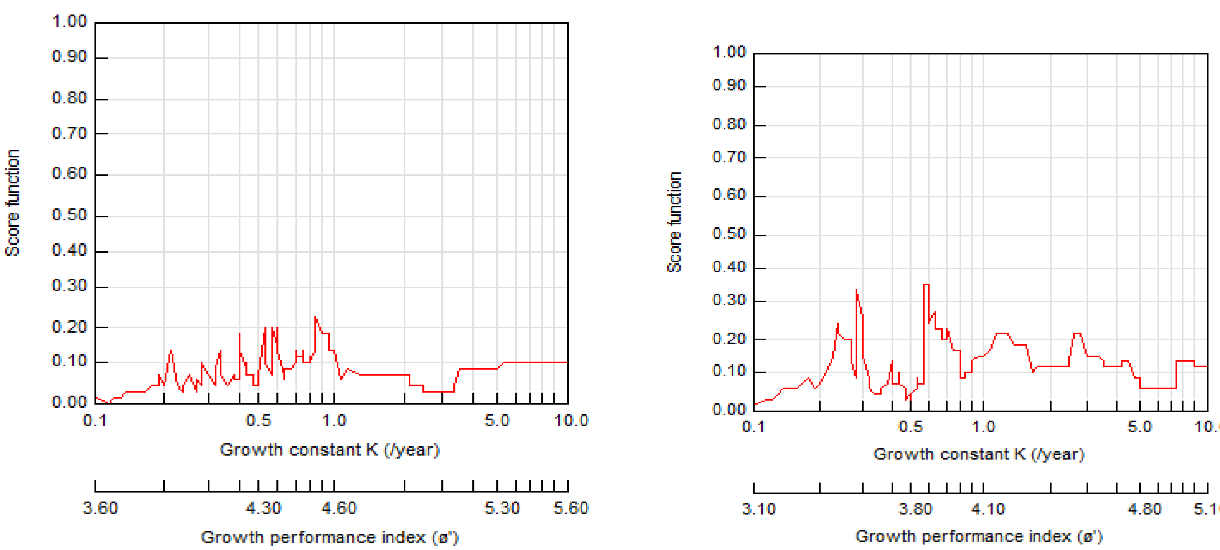
**Appendix B: K- scan routine FiSAT II output: von Bertalanffy Growth Parameters in Lake Kariba and Kafue Floodplain**

**Lake Kariba** **Kafue Floodplain**




**(A)** **(B)**

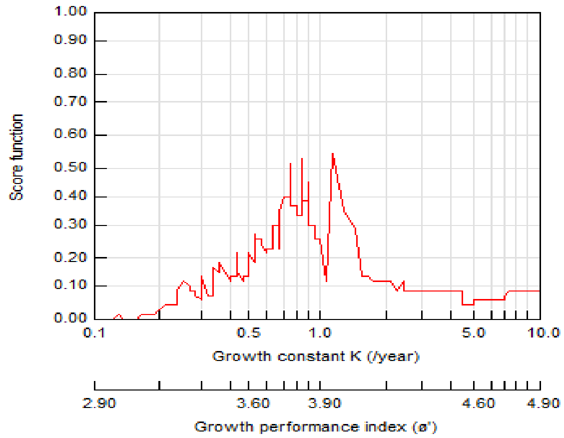
*Figure B1: ELEFAN I K-scan routine FiSAT II output for von Bertalanffy Growth Parameters: (A) Lake Kariba and (B) Kafue Floodplain based on carapace length (July 2022-November 2022).*




*(A)* *(B)*

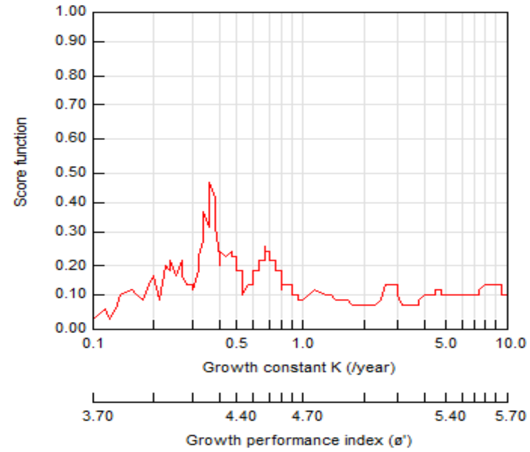
*Figure B2: ELEFAN I K-scan routine FiSAT II output for von Bertalanffy Growth Parameters: (A) Lake Kariba and (B) Kafue Floodplain based on total length (June 2022-November 2022).*

**Chanyanya Males**




**(A)**

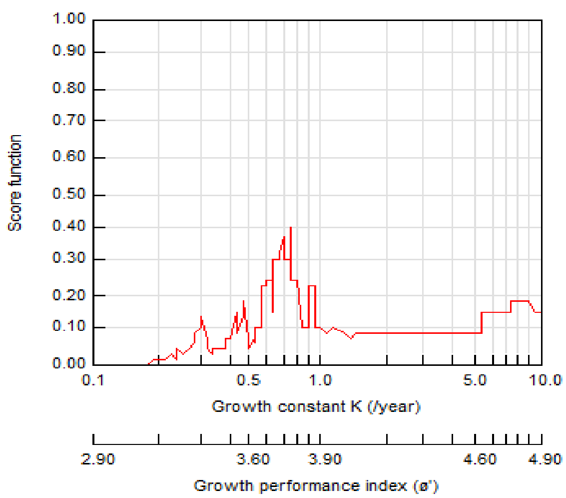
**KRB Males**




**(B)**

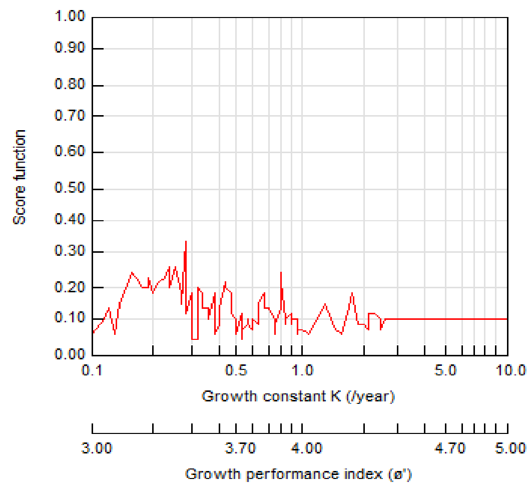
*Figure B3: K- scan routine output FiSAT II output for KRB males (A) and Chanyanya males (B) on the Kafue Floodplain (September 2022- October 2022)*

**KRB Females**




**(A)**

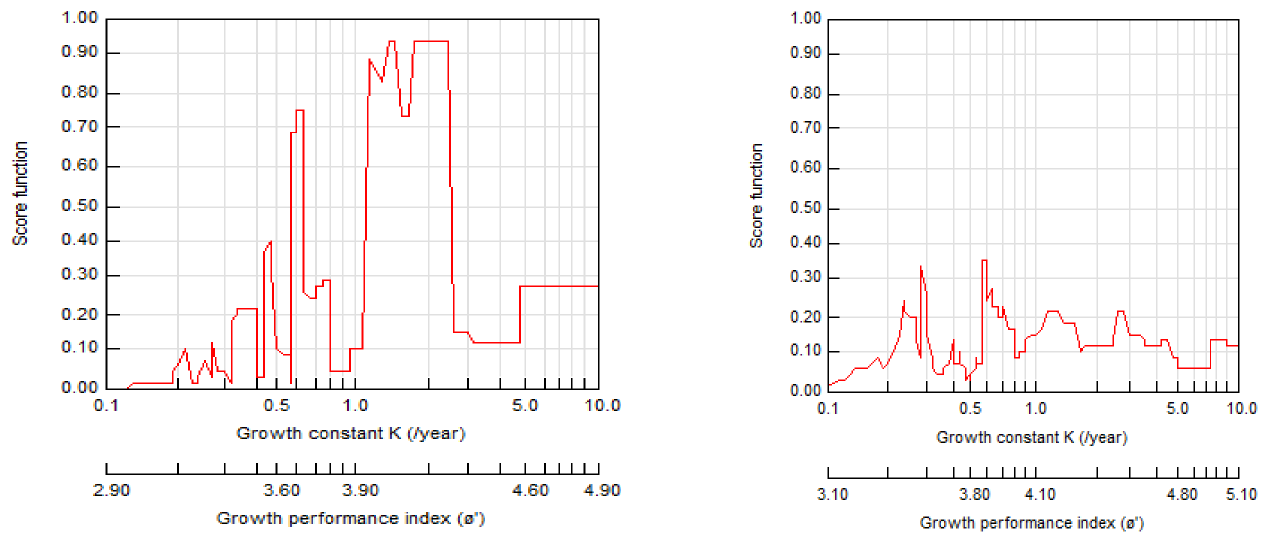
**Chanyanya Females**




**(B)**

*Figure B4: K- scan routine output FiSAT II output for KRB females (A) and Chanyanya females (B) (September 2022- October 2022).*

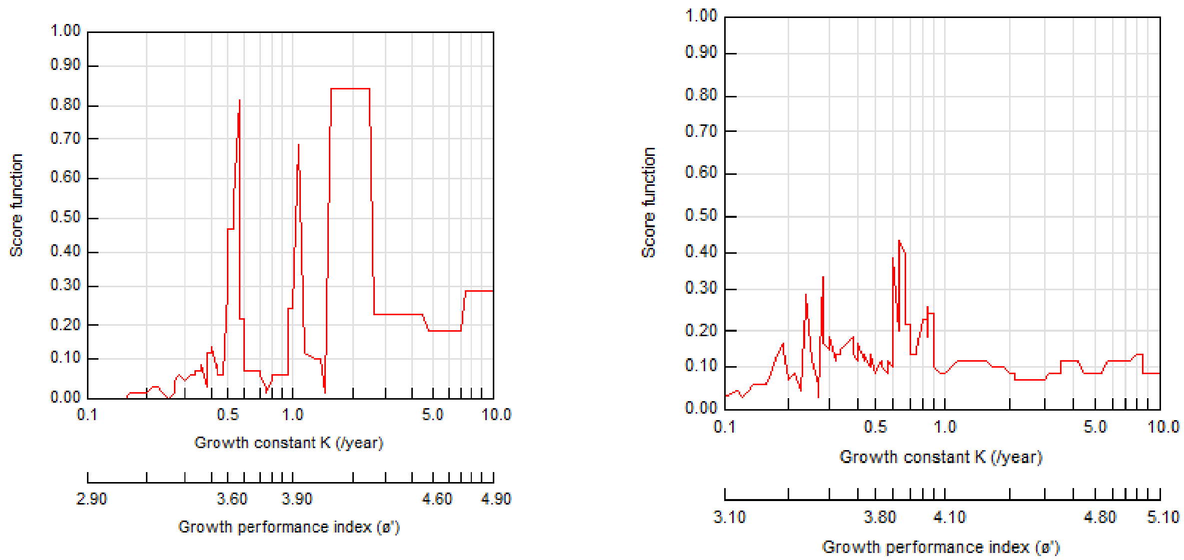
**Siavonga Males** **Kabyobyo Males**




**(A)** **(B)**

*Figure B5: K- scan routine output FiSAT II output for Siavonga males (A) and Kabyobyo males (B) (September 2022- October 2022)*

**Siavonga Females** **Kabyobyo Females**




**(A)** **(B)**

*Figure B6: K- scan routine output FiSAT II output for Siavonga females (A) and Kabyobyo females (B) on the Kafue Floodplain (September 2022- October 2022*

**Appendix C: Length-frequency distribution data and growth curves estimated using ELEFAN protocols in FiSAT II.**

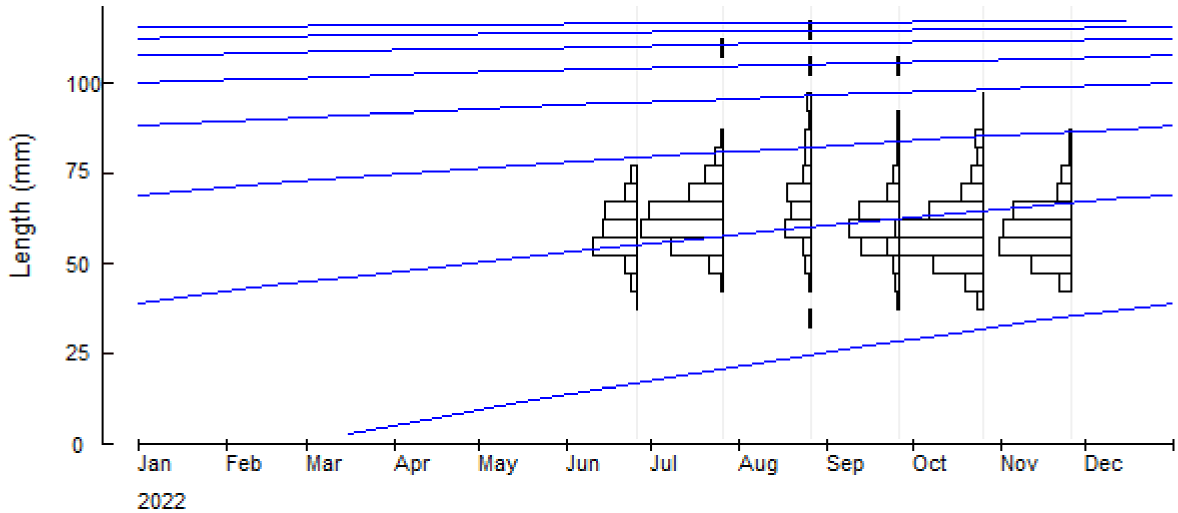



*Figure C1: Length-frequency distribution data and the growth curves estimated using ELEFAN protocols in FiSAT II, for the Kafue Floodplain, between July 2022- November 2022. Figure 7A revealed multiple spawns.*

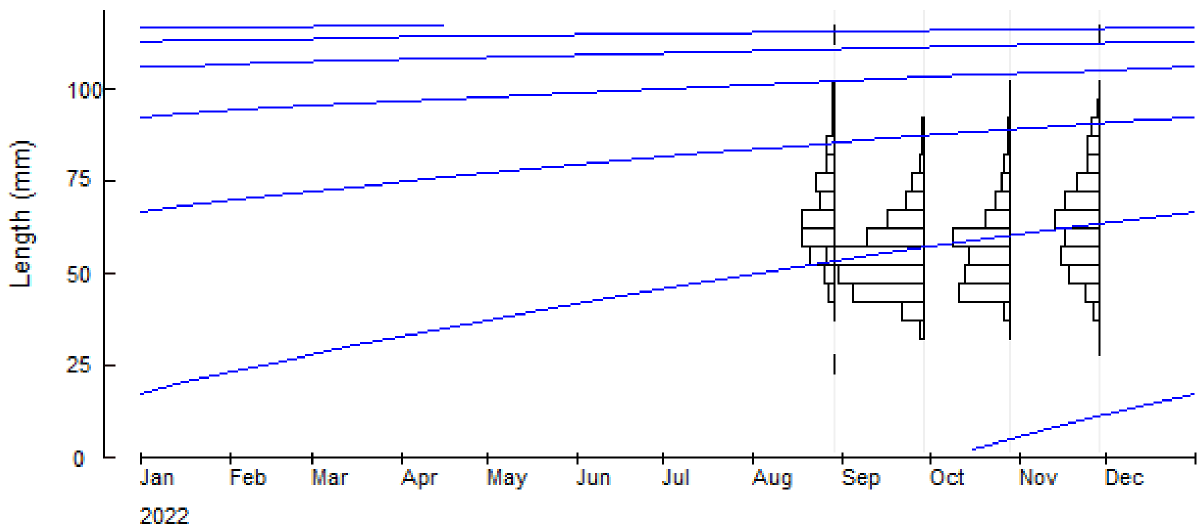



*Figure C2: Length-frequency distribution data and the growth curves estimated using ELEFAN protocols in FiSAT II, for Lake Kariba between August 2022- November 2022. Figure 7B revealed multiple spawns.*

## Appendix D: Monthly Length-weight relationships

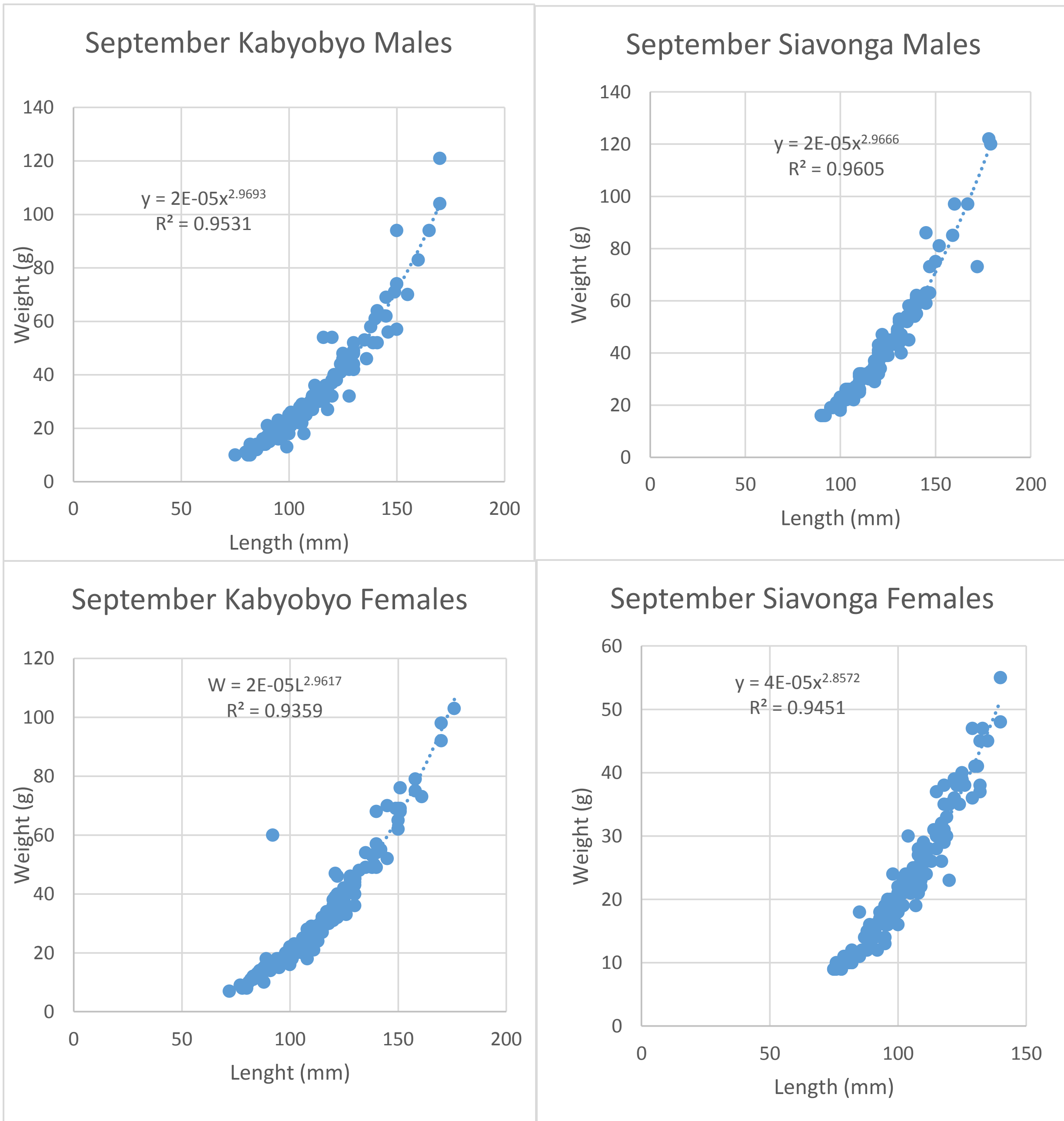



*Figure D1: Length–weight relationship curves for Kabyobyo and Siavonga in Lake Kariba for September 2022. No dissimilarities observed in the value of regression coefficient, b between Kabyobyo and Siavonga.*

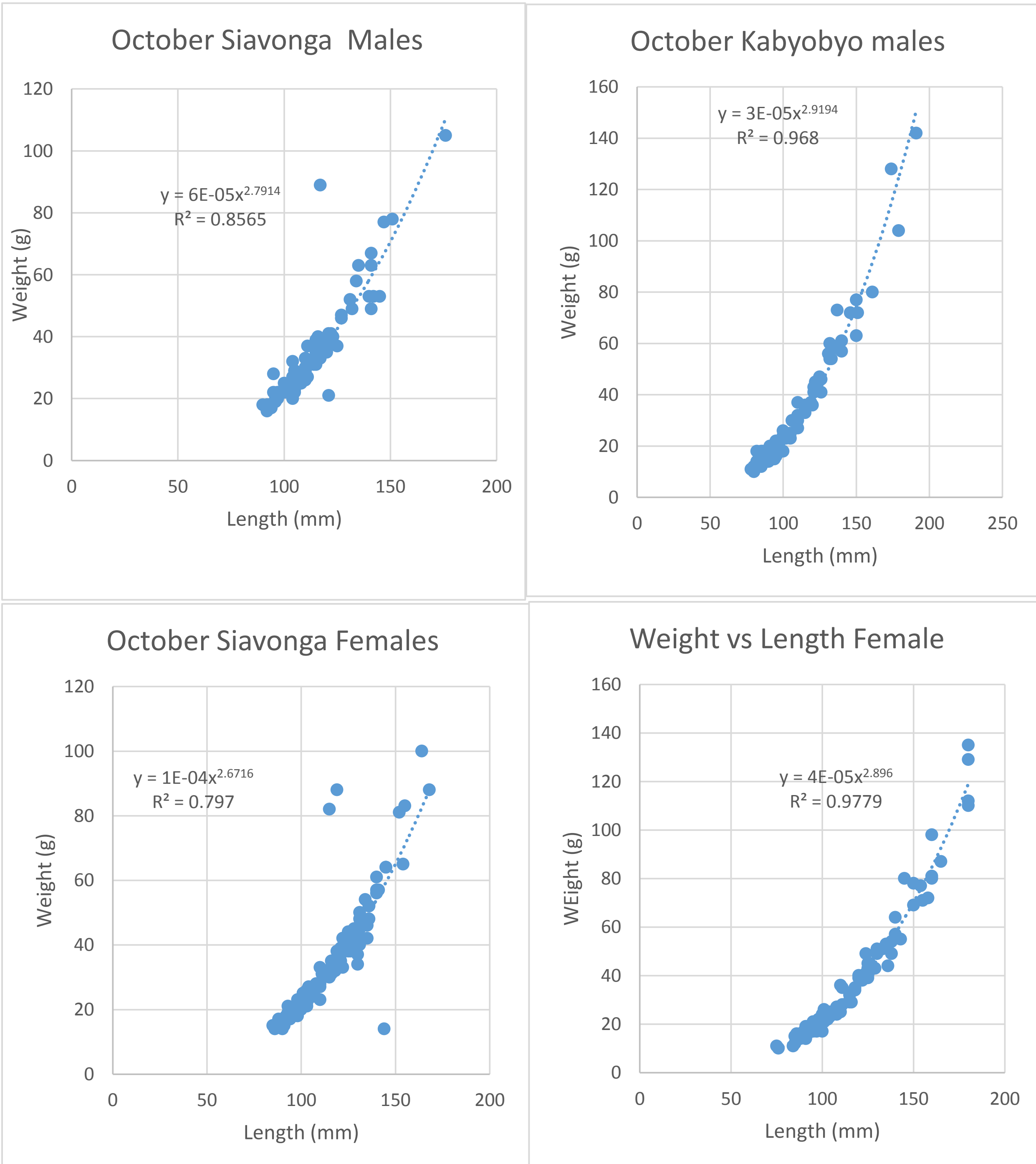



*Figure D2: Length–weight relationship curves for Kabyobyo and Siavonga in Lake Kariba for October 2022. No dissimilarities observed in the value of regression coefficient, b between Kabyobyo and Siavonga.*

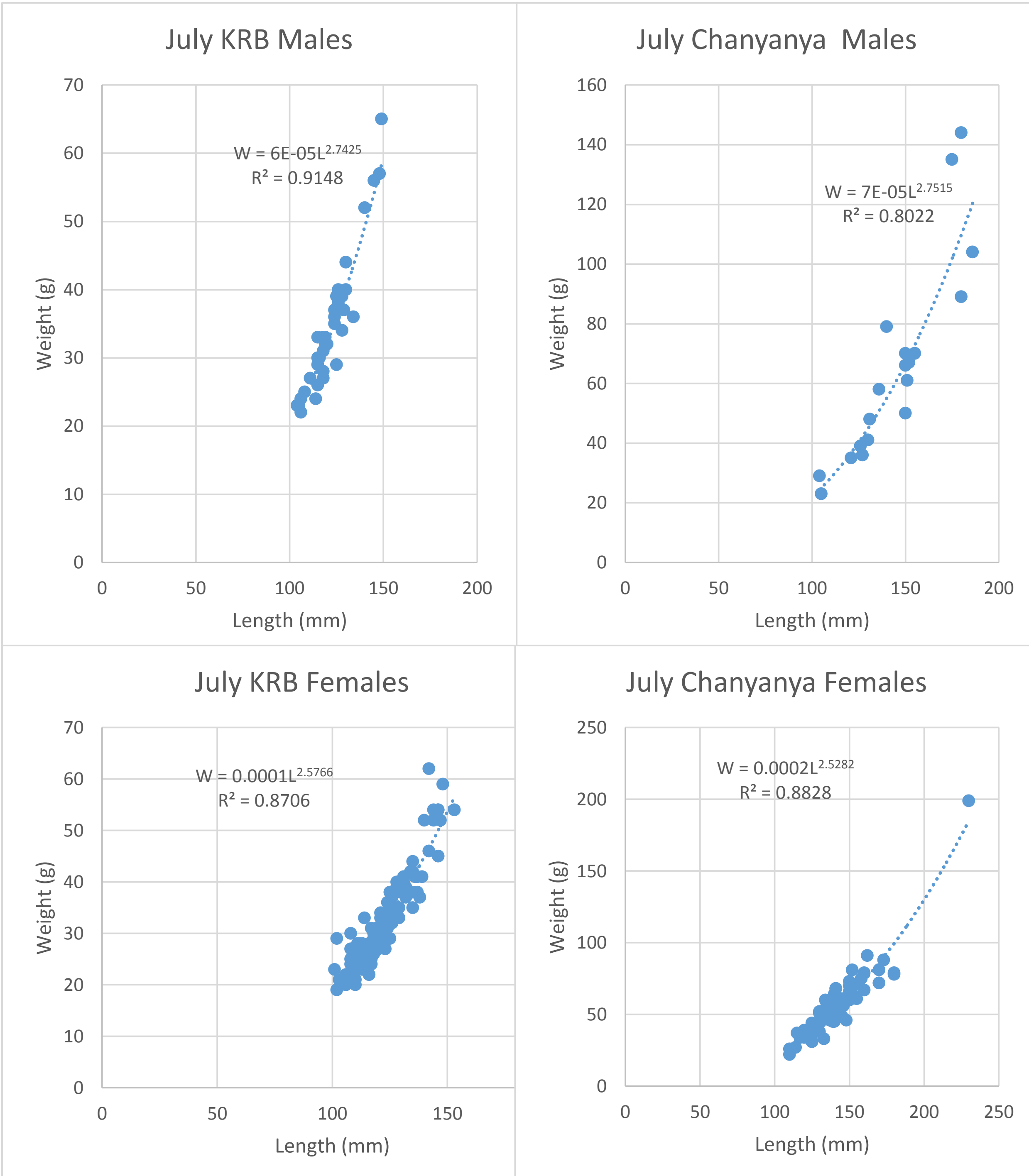



*Figure D3: Length–weight relationship curves for KRB and Chanyanya in Kafue Floodplain for July 2022. No dissimilarities observed in the value of regression coefficient, b between KRB and Chanyanya.*

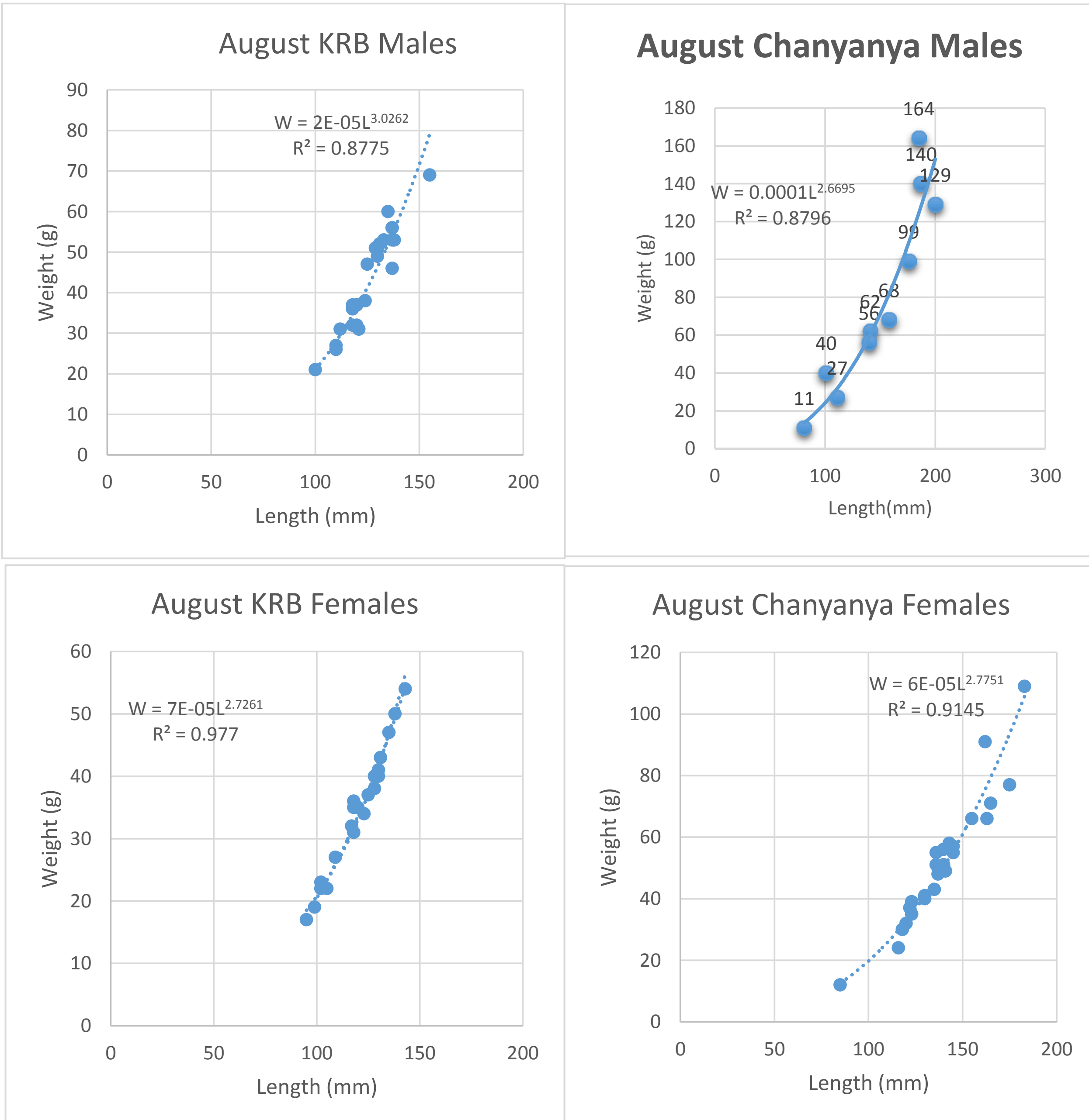



*Figure D4: Length–weight relationship curves for KRB and Chanyanya in Kafue Floodplain for August 2022. No dissimilarities observed in the value of regression coefficient, b between KRB and Chanyanya.*

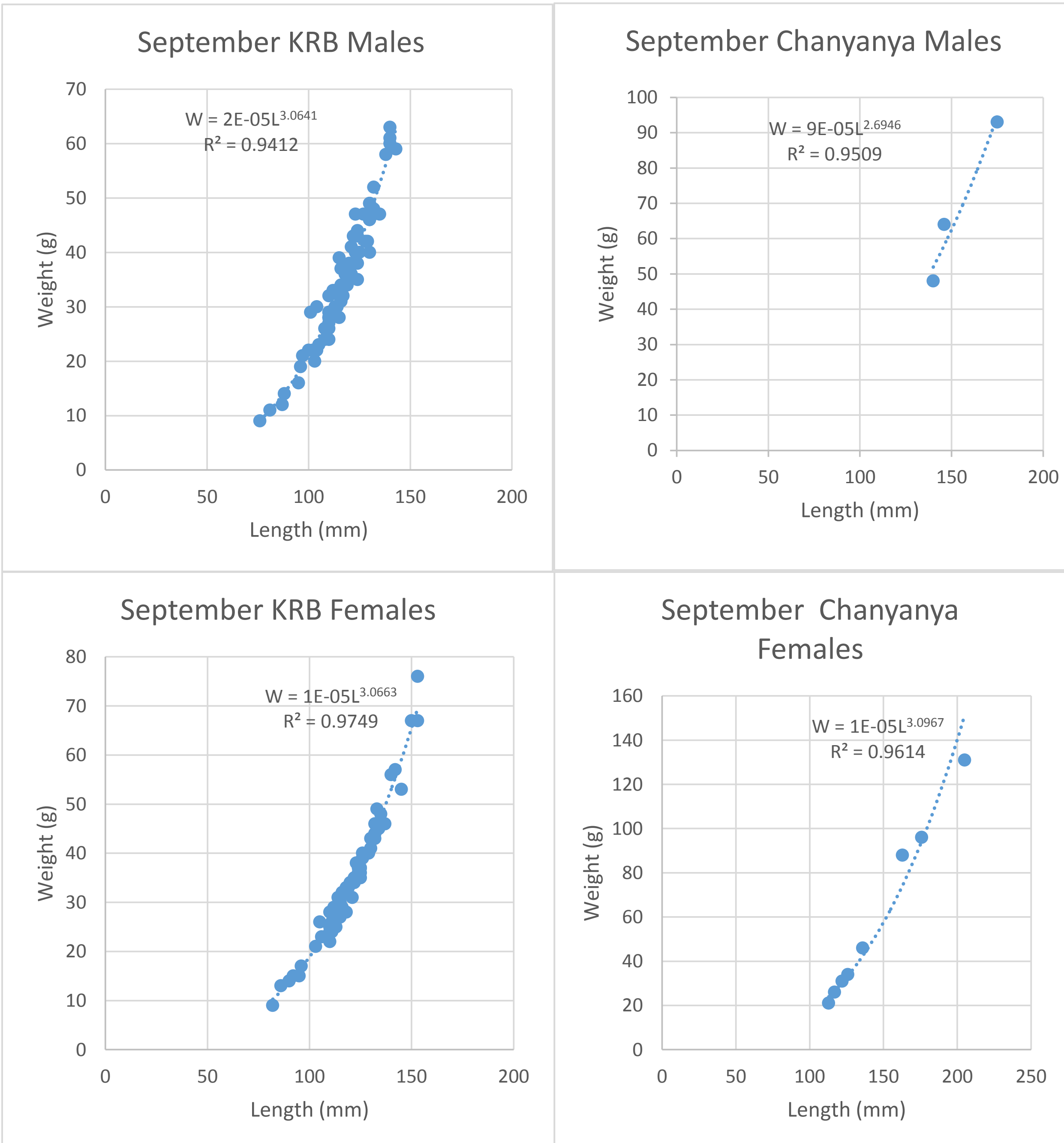



*Figure D5: Length–weight relationship curves for KRB and Chanyanya in Kafue Floodplain for September 2022. No dissimilarities observed in the value of regression coefficient, b between KRB and Chanyanya.*

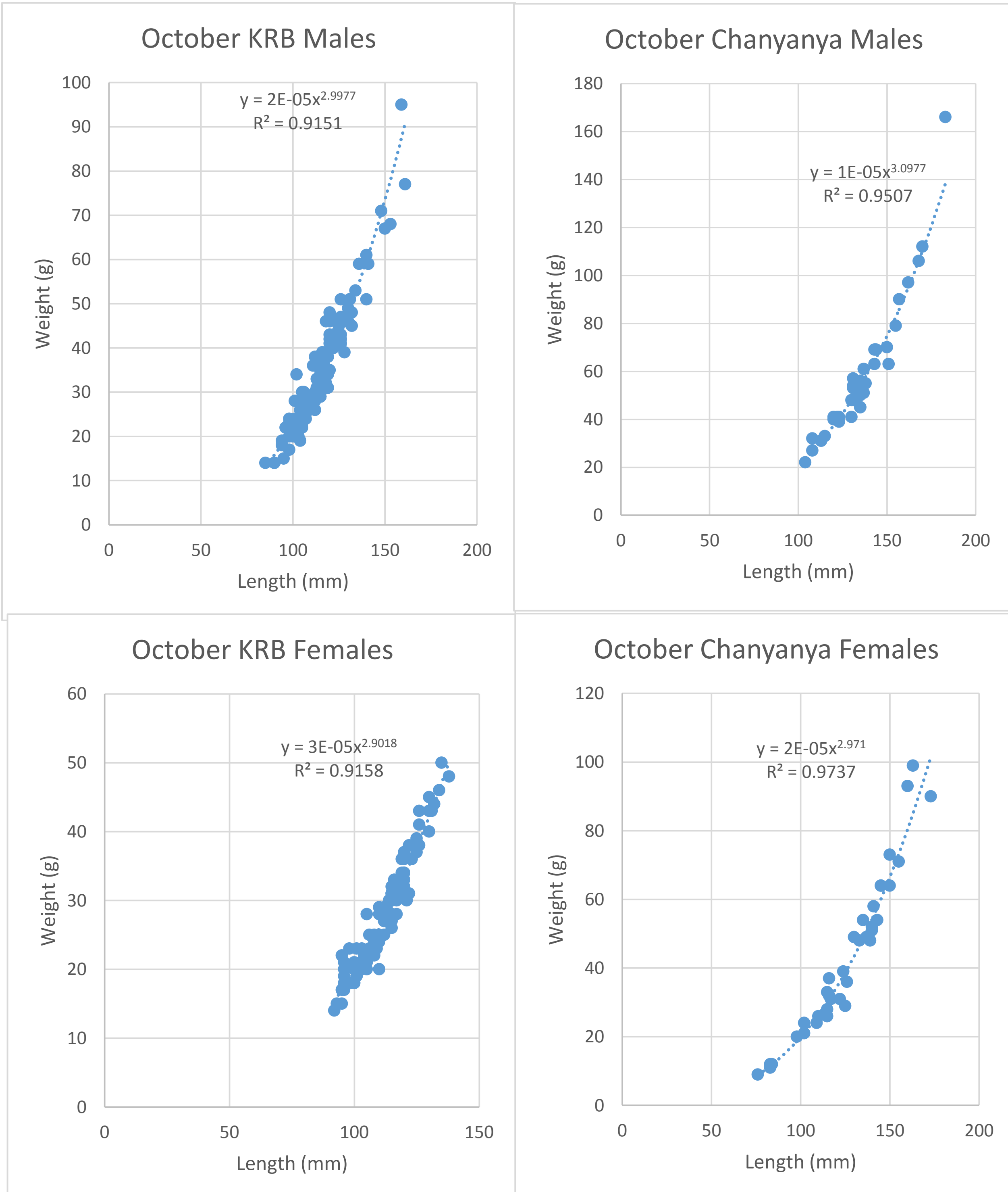



*Figure D6: Length–weight relationship curves for KRB and Chanyanya in Kafue Floodplain for October, 2022. No dissimilarities observed in the value of regression coefficient, b between KRB and Chanyanya.*

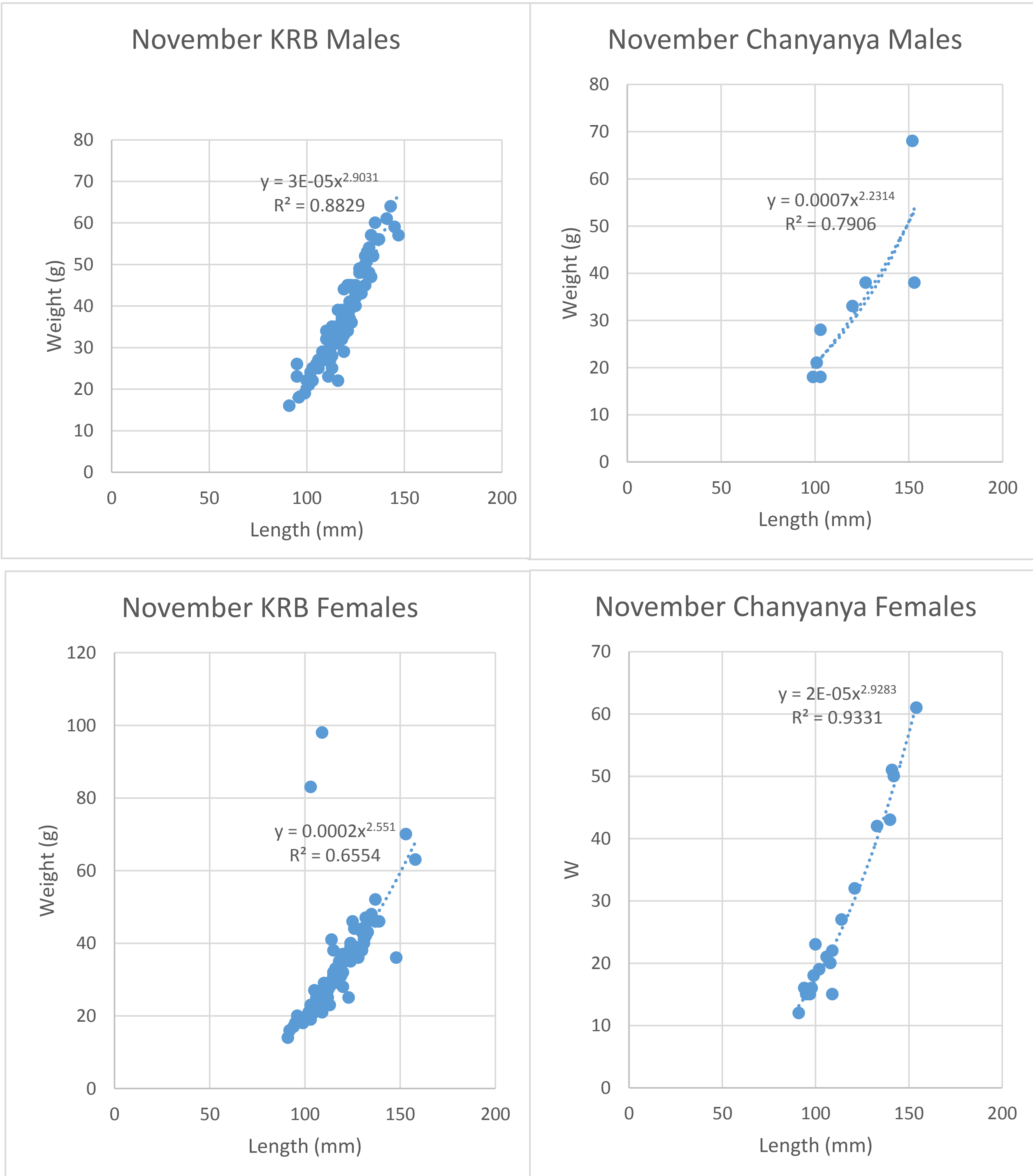



*Figure D7: Length–weight relationship curves for KRB and Chanyanya in Kafue Floodplain for November, 2022. No dissimilarities observed in the value of regression coefficient, b between KRB and Chanyanya.*