MAKERERE UNIVERSITY

POPULATION MORPHOMETRIC VARIATION AND CONDITION OF BARBUS *ALTIANALIS* (BOULENGER 1900) IN THE RIVER NILE, LAKE EDWARD AND KAZINGA CHANNEL – UGANDA

BY

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A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN ZOOLOGY (FISHERIES AND AQUATIC SCIENCES) OF MAKERERE UNIVERSITY

OCTOBER 2018

DECLARATION

I, Ondhoro Constantine Chobet, hereby declare that the work presented herein this dissertation is my original undertaking, except where acknowledged by reference and it has never been submitted to a University or any other institution of higher learning for any award.

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REG. No: 2011/HD13/2855U

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DEDICATION

Dedicated entirely to my family, especially my daughters Sangaalo Alowo Maria Thereza, Ageno Cleopatra and Morris Laetitia Chobet.

ACKNOWLEDGEMENTS

First, to a team of dedicated mentors who holistically supervised and guided me through the whole research period; Associate Professor Charles Masembe for leading the team, Dr. Jackson Efitre and Dr. Winnie Nalukenge Nkalubo for all the sacrifice.

Secondly, I appreciate Makerere University Directorate of Research and Graduate Training for bearing with me throughout the course period.

I am grateful to the Director General National Agricultural Research Organization through the Human Resources Directorate for partly paying my tuition.

Many thanks to the Director of Research, the Head Aquaculture Research and Development Centre Kajjansi, and all staff of NaFIRRI for partly sponsoring my research and for all the logistic support.

I am grateful to the Director of Research, Buginyanya Zonal Agricultural Research and Development Institute for according me time to accomplish the manuscripts and all final works related to this study.

Sincere appreciation to Professor Justus Rutaisire, Dr. John Stephen Balirwa and Dr. Akisoferi Owori Wadunde for continuously giving me professional mentorship.

Gratitude to Dr. John Walakira and Dr. Mathew Tenywa Mwanja for their close guidance in the design of the study and data collection.

Special thanks to Mr. Turyashemererwa Martin for ICT support.

Finally I wish to thank my dear team of Scientists and Technicians of NaFIRRI and BugiZARDI and in particular Ms. Ganda Grace from NaFIRRI for technical support, mainly in the field.

"Tibi sit gloria Domini omnipotens. Vivat Christum regi"

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ABSTRACT

This study used morphometric characteristics and fish condition to compare populations of *Barbus altianalis* from the River Nile, Lake Edward and Kazinga Channel. Morphological variation was determined using multivariate analysis of advanced truss and non-truss network systems for 251 individuals collected from commercial catches. Fish condition was assessed using relative condition index (K_n) computed using individual fish. Discriminant Function Analysis (DFA) indicated significantly ($P \leq 0.001$) higher level of heterogeneity between populations with the two factors (DFA1 and DFA2), collectively accounting for 100% of the variance; (DFA1) 84% and (DFA2) 16%. Group means on the DFA1 showed the River Nile (-0.8869) separated furthest from Lake Edward (0.796) and the Kazinga channel (0.6796). River Nile had the highest number (80.53%) of individuals correctly classified, while Lake Edward (67.2%) and Kazinga channel (60.5%) had more misclassifications between them, an indication they could be much harder to separate. There was a significant difference in mean relative condition among the three habitats ($F_{2, 239} = 9.73$, $P < 0.001$, $n = 240$). The Lake Edward population was in a better condition (1.05) compared to Kazinga Channel (1.04), while the River Nile population had the lowest condition (0.96). Catch rates were higher in Kazinga Channel 6.85±1.49 Kg boat^{-1} day^{-1}) and Lake Edward (6.20±1.86 Kg boat^{-1} day^{-1}) and lowest in the River Nile (1.92±0.59 Kg boat^{-1} day^{-1}). Dissolved oxygen was below the required minimum of 5 mgL^{-1} in all the water bodies. Conductivity was highest in Lake Edward (312 ±115.78 μS cm^{-1}), followed by Kazinga channel (298.06±131.89 μS cm^{-1}). The observed variations were mainly associated with environmental condition faced by *B. altianalis* as indicated by water quality and harvest pressure.

Key words: discriminant function analysis, stock identification, fishing effort, water quality

CHAPTER ONE

1.0 INTRODUCTION

1.1 General background on the *Barbus altianalis* fishery

Following episodes of poor fisheries management regimes and rapid environmental changes in the Lakes Victoria and Edward basins, rapid and severe angulations in the ichthyo-faunal composition have emerged (Ogutu-Ohwayo et al., 2013). Consequently, most native species, especially *Barbus altianalis*, have disappeared, and individuals that are caught show modification in form/morphology and changes in condition (Muwanika et al., 2012; Nakamya et al., 2012; Chemoiwa et al., 2013). The disappearance of some species from the aquatic food web have led to trophic instability within the Lakes Victoria and Edward systems (Ntiba et al., 2001; Njiru et al., 2010; Downing et al., 2012; Ogutu-Ohwayo et al., 2013). As many species continue to disappear from commercial catches in the Lakes Victoria and Edward basins, the current management efforts, unfortunately, remains focused on three major commercial fish species; the Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*) and Silver fish (*Rastrineobola argentea)* (Ogutu-Ohwayo, 1990a; 1990b; Mkumbo, 2002; Taabu, 2004; Mwanja et al., 2014; Nkambo et al., 2015; Ondhoro et al., 2016). High value native species such as *Barbus altianalis, Bagrus docmac* and others are getting extinct and undergoing several stochastic processes (Ogutu-Ohwayo, 1990a; Mkumbo, 2002; Taabu, 2004; Downing et al., 2012; Downing et al., 2013; IUCN, 2014; Mwanja et al., 2014).

Barbus altianalis in particular has been reduced to by-catch in all the water bodies within the East African region and indeed appears in the red list of the International Union for Conservation of Nature-IUCN (Ntakimazi, 2006; IUCN, 2014; Fishbase, 2015). Catch rates in the Lakes Victoria and Edward basins reached the lowest levels of 0.5 to $0.2 kghr^{-1}$ (Bekkevold et al., 2005; Chande and Mhitu, 2005; Ntakimazi, 2006) in the 1970s, and further declined to 0.06 $kghr^{-1}$ in Lake Victoria between 1990 and 2010 (Chande and Mhitu, 2005; Vuai et al., 2012). There seems to be no sign of recovery given the low catch rates amidst high fishing efforts and emerging physical and ecological barriers along the migration routes (Naiman et al., 1995; Graham et al., 2010; Nehemia et al., 2012; Ondhoro et al., 2016). Although some increment in abundance from 6500 to 13000 tonnes was recorded between 1950 and 1968, this was not sustained as the catches dropped to lowest levels of 1300 tonnes by 1988 in Lake Edward (FAO, 1992; 2012; 2014; 2016). Such increases however, have in most cases manifested increased fishing effort contrary to stock recovery.

In this study, a combination of systemic morphometric analysis, fish condition and water quality parameters were used to assess *B. altianalis* populations from River Nile, Lake Edward and Kazinga channel. Information on population morphometric variation provides a tool for traceability in capture fisheries management. Database of population morphometrics is necessary to guide selection criteria for *in-situ* and *ex-situ* conservation programs for capture fisheries management and aquaculture based on individual physical differences in Uganda. Knowledge of fish condition coupled with the fishing efforts and the environmental dynamics is key in monitoring the health and dynamics of fish populations.

The main aim of this study was to generate and provide information on the variation in morphology and condition of *B. altianalis* populations in River Nile, Lake Edward and Kazinga Channel, purposely to guide capture and captive *Barbus altianalis* stock management and conservation in Uganda.

1.2 Statement of the problem

The population of *B. altianalis* fish, a high valued cyprinid with high commercial potential has drastically reduced from amongst all the major water bodies of Uganda. The International Union for Conservation of Nature (IUCN) recently grouped the fish under the red list of species threatened to extinction, yet the causes of the threats to the species are not well documented. Integrating multivariate morphometric analysis, condition, fishing effort, and environmental dynamics, would guide management in ascertaining the factors underpinning population decline and consequently provide robust decision-making tools for assessing and conserving the populations. There is lack of knowledge on the differences among populations of *B. altianalis* from different water bodies. Yet integrated approaches to fisheries and aquaculture management is still lacking in Uganda.

1.3 Objectives of the study

1.3.1 General objective

To provide information on the variation in morphology and condition of *B. altianalis* populations in River Nile, Lake Edward and Kazinga Channel to aid design of appropriate monitoring and conservation policies.

1.3.2 Specific objectives

i. To determine morphometric variation among populations of *B. altianalis* from River Nile, Lake Edward and Kazinga Channel.

ii. To determine the condition of *B. altianalis* populations from the River Nile, Lake Edward and Kazinga Channel.

iii. To assess water quality among the water bodies where *B. altianalis* samples were collected in River Nile, Lake Edward and Kazinga Channel.

iv. To assess the influence of fishing effort on *B. altianalis* fishery in River Nile, Lake Edward and Kazinga Channel

1.4 Research questions

i. Are there morphometric differences among *B. altianalis* populations from River Nile, Lake Edward and Kazinga channel?

ii. Is there variation in condition of *B. altianalis* populations from River Nile, Lake Edward and Kazinga channel?

iii. Is there variation in water quality in *B. altianalis* fishery in River Nile, Lake Edward and Kazinga channel?

iv. Does fishing effort influence *B. altianalis* fishery in River Nile, Lake Edward and Kazinga channel?

1.5 Justification

Barbus altianalis is considered fish species with considerable potential for aquaculture and high commercial appeal among the East African Community. Indeed *B. altianalis* is a delicacy among the riparian communities, highly cherished for its white firm flesh that has low cholesterol levels and its edible scales. The white firm flesh and edible scales give the fish higher dressing percentage than most of the indigenous fish species and is highly similar to that of the highly valued Nile perch (*Lates niloticus*). Because of the above attributes, it has the potential to generate income to the captive and capture fish folks and the country from local, regional and international markets. Therefore, there is need to resolve challenges associated with variability in morphology, condition and the environment in order to design appropriate conservation programmes. These approaches, especially fish condition and morphological parameters are very important tools for monitoring ecological changes and selection pressures on fish populations. Therefore, they are useful parameters in capture fisheries management and aquaculture. Fish with better condition factor indicates better feeding and higher genetic vigor, traits that guide in brood stock selection for captive propagation. Because aquaculture mimics wild condition, information on water quality parameters from natural water systems provide benchmarks for ex-situ management processes. Morphometric characterization generates information on phenotypic/physical variables that can be used to quickly, phenotypically differentiate between two or more populations. Morphological classification is the cheapest and easiest approach fish farmers can use to select their breeding and table size stocks. Information on population morphometric and environmental variation provide tools for traceability in capture fisheries management and aquaculture in Uganda.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Description of *Barbus altianalis*

Barbus altianalis (Kisinja) belongs to the family *Cyprinidae* of the order Cypriniformes (Green wood, 1966; Sibbing et al., 2004; Fishbase, 2015). It has elongated body with protruded snout that is equipped with nasal orifice and pairs of branched barbells on each jaw, rayed fins and forked tail. The fish is wide at the posterior dorsal fin and steeply depressed at the anterior dorsal sections of the head to the snout. The body is externally covered with ctenoid scales (Balirwa, 1984; Ntakimazi, 2006; Fishbase, 2015).

2.2 Geographical distribution

The species is widely spread within Lakes Victoria, Kyoga, and Edward, George, the Kazinga channel and the River Nile in Uganda. Elsewhere, *B. altianalis* naturally occurs in Lake Kivu and its tributaries in the Democratic Republic of Congo, Lake Tanganyika in the Tanzania, River Akagera and Ruzizi in Central Africa and some areas of Lake Tana in Ethiopia (Sibbing et al., 2004). Also in small rivers such as Sundo in Kenya (Ojwang et al., 2007; Raburu and Okeyo-Owuor, 2012; Chemoiwa et al., 2013; 2017 (Fig.1)

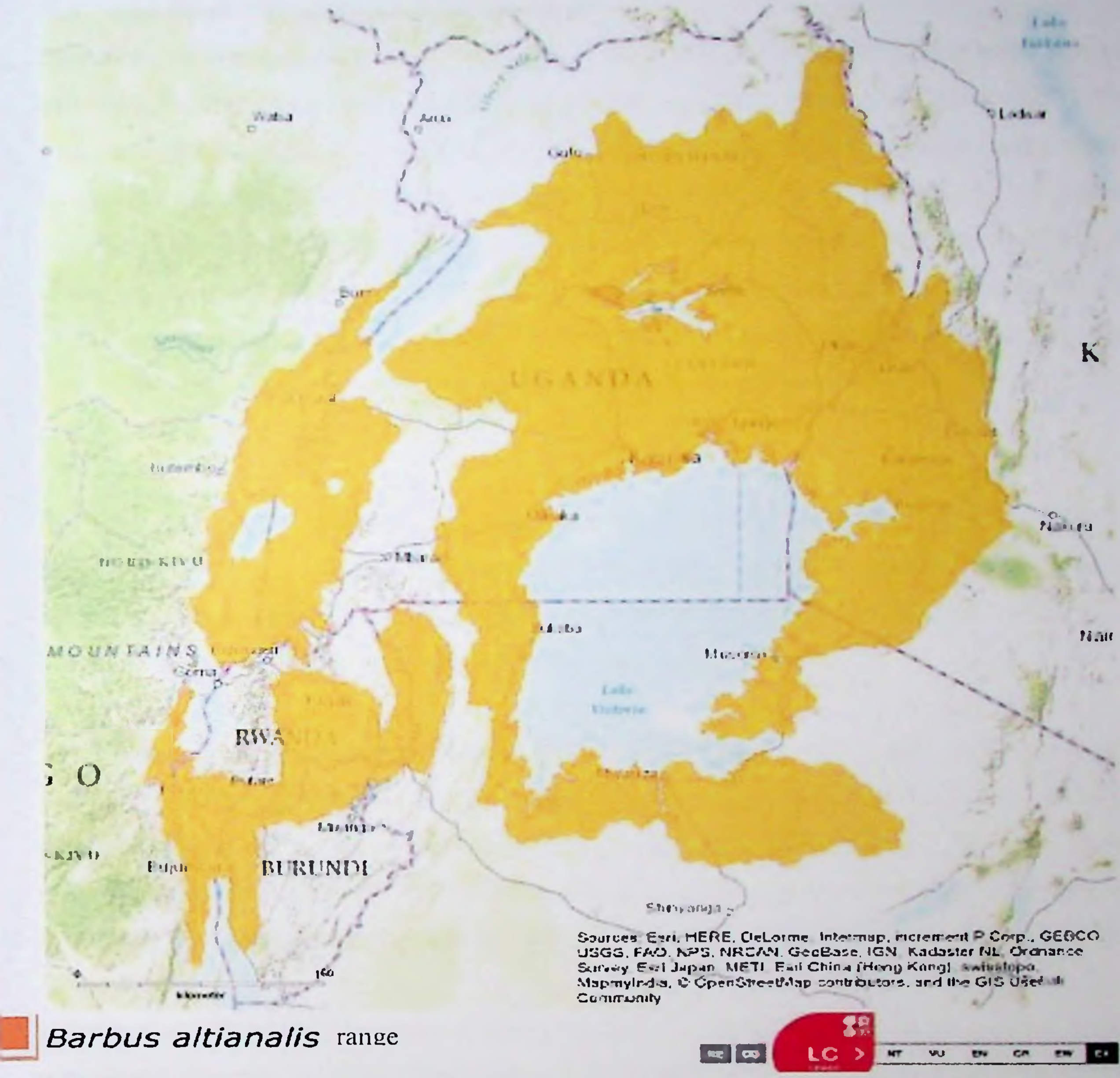

Figure 1: The IUCN map showing the distribution of *Barbus altianalis*

2.2.1 The River Nile and Lake Victoria basin

River Nile, is the longest river in the world, about 6,853 km (4,258 miles) long, flowing northwards from its source in Ripon Falls, Lake Victoria- Uganda (Otim, 2005; Oloo, 2007). The River provides a reliable link between Lake Victoria and Lake Edward through Lakes Albert, George and Kazinga channel systems. Although the biodiversity of the river is not widely published, a number of fish species especially Nile perch, Mormyrids, catfishes and the cyprinids are known to be distributed along the flow route downstream Lake Victoria. *Barbus altianalis* has for long time been a delicacy along the Nile with the catches being abundant downstream Owen falls dam where the dam barrier commonly isolate migrating cohort upstream Lake Victoria (NaFIRRI, 2008).

Given the emergency of more hydro power dams such as Bujagali, Isimba, and currently the ongoing construction of Karuma hydro power dam, regular flooding of the dam reservoirs has exposed stranded stocks to over fishing and environmental fluctuation, threatening the species to extinction along the Nile River (Ogutu-Ohwayo et al., 2013).

Lake Victoria is the world's second largest freshwater lake, after Lake Superior (Ogutu-Ohwayo et al., 2013). Over 1,500,000 people from Uganda alone derive their livelihood from the lake, with fishing being the main stay along with tourism, water transport services, agriculture among others (NEMA, 2010; MAAIF, 2011). Of the over thirteen fish families that inhabit the lake, the majority (45%) is known to be cichlids and cyprinids (Greenwood, 19966; Ogutu-Ohwayo; 1990a; 1990b; 2013).

At the turn of the twenty first century, many species were either reported endangered or extinct as evidence of trophic instability was apparent (Downing et al., 2012; Downing et al., 2013). The diversity of some of the native cichlids with over 300 species in the 19th century had reduced (Goldschmidt et al., 1993).

The Lake Victoria ecosystem was disrupted, resulting in considerable changes in limnological parameters and ichthyo-faunal composition (Ogutu-Ohwayo et al., 2013). Several studies have noted dramatic declines in fish diversity (Ogutu-Ohwayo, 1990a; Downing et al., 2013; Ogutu-

Ohwayo et al., 2013). There has also been increased level of pollution by nutrients from the catchment, primarily from fertilizers, resulting in artificially elevated primary productivity (Ochumba and Kibara, 1989; Mugidde, 1993; Graham et al., 2010; Vijerberg et al., 2013). The bottom layers of the lake became largely anoxic compared to the 1960s (Talling, 1965; 1966; Hecky, 1993). Plankton composition also changed (Kiggundu et al., 2012). Diatoms have been replaced by the blue green cyanobacteria, while the previously calanoid copepod dominated zooplankton has been replaced by cyclopoid copepods (Balirwa, 1979; Hecky, 1993; Balirwa et al., 2003; Balirwa, 2007). Turbidity has also increased with the Secchi transparency index having declined from five meters in the 1930s to less than one meter between 19th and 21st century (FAO, 1990; FAO, 1995; Bugenyi and Balirwa, 1998; Bugenyi, 2001; FAO, 2001; Osumo, 2001). In fact Osumo (2001), observed secchi transparency of 0.2 m and oxygen levels of 3-4 mgL^{-1} in the Winam Gulf of the Lake in Kenya. There has been a reduction in abundance with more than 200 indigenous haplochromines now considered extinct (NEMA, 2010; Downing et al., 2013). Observations by Bugenyi, (1991); Okaranon, (1994) and Kishe, (2004), have also indicated that the African lungfish *Protopterus aethiopicus*, and the catfishes *Clarias gariepinus* and *Bagrus docmak*, were disappearing from the catches. The commercial fishery on the Lake that was previously multi-specifies is now mesospecific based on two alien species *L. niloticus*, *Oreochromis niloticus*, and a small native cyprinid *Rastrineobola argentea* (Balirwa, 2007; Downing et al., 2013).

According to the National Environmental Management Authority, (NEMA, 1998; NEMA, 2010; Cajas et al., 2012), there has been a fish species diversity reduction by 45% between 1969 and 2000 (Rutaisire, 2003; Downing et al., 2013). Haplochromines and other indigenous fish species such as *B. altianalis* that originally constituted approximately 83% of the catches by weight have now dropped to about 0.6% and 0.2% respectively (NEMA, 1998; Chande and Mhitu, 2005; NEMA, 2010). Although there are reports of recovery of some haplochromines (Downing et al., 2012; Downing et al., 2013) *L. niloticus* still comprises 51% of the catch by weight from the Lake, while the other dominant alien fish *O. niloticus* comprises 24% (Ogutu-Ohwayo et al., 2013).

2.2.2 Lake Edward basin

Lake Edward (surface area: 2,325 km^2; average depth 17 m; maximum depth: 112 m) is located in the western Great Rift valley at an altitude of 920 m (NaFIRRI, 2008). It is a shared water body with 29% of its surface in Uganda and 71% in the Democratic Republic of Congo (Graham et al., 2010). The lake's major inflows are the Nyamusagani River from the southwest and the Ishasha, Rutshuru and Bwindi Rivers from the south and it is connected to Lake George by the 36 km long Kazinga channel. Lake Edward drains towards Lake Albert via the Semiliki River which has a series of rapids (Ibale, 1998; Efitre et al., 2009). Lake Edward experiences prolonged stratification and anoxic conditions below 80 m even though anoxic conditions may sometimes occur at depth 30 m and are associated with generally high concentrations of hydrogen sulfide (Graham et al., 2010) With surface temperatures of about 25^0C, high evaporation rates and conductivity above 920 μcm^{-1}. Lake Edward's water level and chemistry are sensitive to rainfall (average: 900 $mmyr^{-1}$) variability (MWE, 2014).

Lake Edward is home to many fish species, including cyprinids, catfishes, tilapiines and over 50 species of haplochromines (Nkambo et al., 2015). The fisheries are an important source of food, livelihood and income to residents in the immediate vicinity of the Lake shores and to urban dwellers in western and central Uganda. The commercial fisheries are dominated by *Oreochromis niloticus* (the Nile tilapia), *Bagrus docmak* (catfish/semutundu), *Protopterus aethiopicus* (lung fish) and *Clarias gariepinus* (African cat fish). However, the over 50 other species of fish, mostly the haplochromines cichlids (nkejje) dominate the fish biomass. Species such as *B. altianalis* that were abundant in the 1930s have of recent disappeared from the main catches (Holmes and Howard, 1932; NaFIRRI, 2008). A survey of the Edward basin water bodies (Lakes Edward and George, River Semiliki, Nyamisagani and Kazinga channel) recorded *B. altianalis* in only one landing site of Lake Edward in Rweshama (NaFIRRI, 2008).

The operation of Lake Edward fisheries still lags under the 1937 framework law which allowed administrative authorities to regulate, among other things, fishing permits, industrial fishing, protected fish zones and introduction of species (GOU, 1951). This law, which dates back to the colonial period, has lapsed. Whereas some provisions concerning protected zones and the introduction of species remain valid, overfishing and environmental degradation is on the rise (Nkambo et al., 2015).

While restructuring of fisheries management and the reinforcement of fisheries research is being emphasized, inadequacies are still notable. Management is suffering glaring setbacks from old policies which do not clearly provide punitive and deterrent measures to unsustainable exploitation methods. The weak laws coupled with inadequate enforcement and the lucrative fish trade across to the Democratic Republic of Congo, which procures immature fish, has catalyzed overfishing and stock depletion of *B. altianalis* (NaFIRRI, 2008).

2.3 Biology of *Barbus altianalis*

Barbus altianalis is migratory with adults occurring in both riverine and lacustrine habitats, where they alternate to feed or spawn (Greenwood, 1960; Greenwood, 1966; Balirwa, 1984; Tweddle and Skeleton, 2007; Rutaisire et al., 2013). There are reports of some adults increasingly becoming obligate lacustrine populations within the Lake Victoria where hydro-power dam barriers have isolated the lacustrine from riverine populations (Ondhoro et al., 2016). Physical and chemical barriers along migration routes have been reported to be among the greatest factors in evolution of different behaviors in *B. altianalis*. Obligate individuals are often locked upstream, becoming exposed to high fishing pressure and unfavorable water changes within lake-river interface. Similarly, migratory feeding and natal homing exposes the species to high mortality due to the high fishing effort deployed along the routes.

The juveniles mainly prefer the riverine habitats, while adults undergo natal homing upstream to spawn, along swift rocky upper reaches of rivers. Being a partial batch spawner, spawning migration is almost year-round, reaching the peak during rainy seasons of April-June and August December annually (Rutaisire et al., 2013).

The species is an omnivore, feeding mainly on benthic macro invertebrates such as mollusks, insect larvae, crustaceans and also on fish larvae and plants (Corbet, 1961; Balirwa, 1984; Rutaisire et al., 2013). Its known growth size is 15 kg and 90 cm maximum weight and length respectively (Greenwood, 1966; Ntakimazi, 2006; Fishbase, 2015).

2.4 Morphometric characterization and levels of morphometric differentiation

Morphometrics refer to the quantitative analysis of form (Strauss and Bookstein, 1982; Elliot et al., 1995; Turan, 1999; Beger et al., 2004; Turan, 2004; Mir et al., 2013), a concept that encompasses size and shape of organisms (Ward et al., 1994; Silva, 2003; Whitehead et al., 2011; Finlay and Cooper, 2015). Morphometric analyses of organisms are useful in analyzing their fossil record, the impact of mutations on shape, developmental changes in form, covariances between ecological factors and shape, as well for estimating quantitative-genetic parameters of shape (Klingenberg, 2008).

According to Klingenberg (2008); Svanback et al. (2009); Reece et al. (2013), morphometrics has successfully been applied to quantify traits of evolutionary significance and detecting changes in the shape during ontogenetic development (Bookstein, 1991).

The major objective of morphometrics is to statistically test hypotheses to the factors that affect shape and answer questions relating to whether there are morphological differences between and or among individuals with reference to the environment (Manimegalai et al., 2010).

Albaneze et al. (2007), applied geometric morphometric methods (GMMs), mainly with scale morphology to discriminate genera, species and geographical variants in stocks of Mullet (Mugilidae) along the Gulf of Mexico. The rationale for GMMs in this study was it being non destructive, less costly as opposed to genetic analysis and the opportunity of having each individual being screened.

Other studies in Texas fused traditional and geometric morphometrics to study Pinniped mammalian vibrissae hair shaft diversity to characterize populations based on repeating sequences of crests and troughs along their length (Ginter et al., 2012). Similar approach was applied with truss variables and land mark data in multivariate and geometric methods to investigate the homogeneity of shape and compare sardine (*Sardina pilchardus*) populations from the northeastern Atlantic and the western Mediterranean Sea (Silva, 2003). The same parameters (truss and land mark characters) confirmed the homogeneity among female and male estuarine catfish *Mystus gulio* in Bangladesh (Begum et al., 2008).

The application of biometric data especially measurements of body length and body weight has been reliably used for assessing the evolutionary adaptation of several fish species. Manimegalai et al. (2010) investigated the geometry of black spots in Orange chromid (*Etroplus maculates*) in India. In the latter study, total length and total weight were applied to ascertain the morphometric orientation to the environment.

Genotype-environment interaction has continued to affect the condition of a fishery (Jolicoeur and Mosimann, 1960; Muwanika et al., 2012; Nakamya et al., 2012). Growth and morphological relationship have closer link to environmental quality and changes over time. Feeding regimes and morphological studies indicated change in the gill attributes of the Irish form of Arctic Char *Salvelinus alpinus (*Clabaut et al., 2007*)*. The eco-morphological trophic diversity was used to discover cryptic species known as *Salvinus fimbriatus* (Clabaut et al., 2007; Von Cramon Taubadel et al., 2007; Kocovsky and Knight, 2012).

Morphometric and meristic characterization has been applied to assess many African tropical species. Turan et al. (2005); Weaver et al. (2014) compared populations of African catfish (*Clarias gariepinus*) from numerous numbers of fresh water bodies where the species were considered under severe environmental threats. The head region of African catfish among parameters provides the most important description of population characteristic. Similar description of morphometric, meristic and threatening factors for the critically endangered species of *Puntius sarana* in river Ganges, north western Bangladesh (Hossain et al., 2009; Khan et al., 2012).

Clabaut et al. (2007) point out body length, head size and caudle peduncle as the most suitable land mark characters that confirmed the relationship between eco-morphological diversity and phylogeny of the cichlids of Lake Tanganyika

2.5 Approaches to Morphometric study

There are three approaches to morphometric study;

2.5.1 Traditional Morphometrics

Traditional morphometrics analyzes lengths, widths, masses, angles, ratios and areas (Tzeng et al., 2007). In general, traditional morphometrics data are measurements of size. This approach is useful when either absolute or relative sizes are of particular interest, such as in studies of growth. The data are also useful when size measurements are of theoretical importance such as body mass and limb cross-sectional area and length in studies of functional morphology (Bianco and Dalmstro, 2004; Buller and Townsend, 2013). However, the challenge with using many measurements of size is, most will be highly correlated; as a result, there are few independent variables despite the many measurements (Elliot et al., 1995; Turan, 1999; Mir et al., 2013). For instance, tibia length varies with femur length and also with humerus and ulna length and even with measurements of the head. However, these measurements have one important limitation: they contain little information about the spatial distribution of shape changes across the organism and therefore, unsuitable for fish population studies involving comparison of populations from different water bodies (Mekkawy and Mohammad, 2011).

2.5.2 Landmark-based geometric morphometrics

In landmark-based geometric morphometrics infers that spatial information is contained in the data, because the data are coordinates of landmarks (landmark points): discrete anatomical loci that are arguably homologous in all individuals in the analysis (Mekkawy, 1990; Albanez et al., 2007; Mekkawy and Mohammad, 2011). For example, where sutures intersect is a landmark, as are intersections between veins on an insect wing or leaf. So are foramina, small holes through which veins and blood vessels pass. Similarly, fin insertions, orbital end points are land marks in fish (Bookstein, 1991; Akhter et al., 2003; Anticamara et al., 2011; Anvarifar et al., 2011). These points can be regarded as the "same" point in all specimens in the study. Landmark-based studies have traditionally analyzed two-dimensional (2D) data, but with the increasing availability of three-dimensional (3D) imaging techniques, 3D analysis is becoming more feasible even for small structures such as teeth (Klingenberg, 2010). Finding enough landmarks to provide a comprehensive description of shape can be difficult when working with fossils or easily damaged specimens. That is because all landmarks must be present in all specimens, although coordinates of missing landmarks can be estimated. The data for each individual consists of a configuration of landmarks. Land mark morphometrics is more applicable to teleosts since the morphometric features are permanent and sometimes conserved across the entire phylogenetic tree (Klingenberg, 2010). This henceforth, covers the mophometric analysis of *Barbus altianalis* given the availability structures such as fins, orbital distances, caudal endpoints and others that can been joined into coordinates.

2.5.2.1 Categories of morphometric landmarks

a) Type 1 landmarks are locally defined, meaning that they are defined in terms of structures close to that point; for example, an intersection between three sutures, or intersections between veins on an insect wing are locally defined and surrounded by tissue on all sides.

b) Type 3 landmarks, in contrast, are defined in terms of points far away from the landmark, and are often defined in terms of a point "furthest away" from another point.

c) Type 2 landmarks are intermediate; this category includes points such as the tip structure, or local minima and maxima of curvature. They are defined in terms of local features, but they are not surrounded on all sides. In addition to landmarks, there are "semi-landmarks," points along a curve. Their position along the curve is arbitrary but these points provide information about curvature in two or three dimensions.

2.5.3 Procrustes-based geometric morphometries

Shape analysis begins by removing the information that is not about shape. By definition, shape is not altered by translation, scaling or rotation. Thus, to compare shapes, the non-shape information is removed from the coordinates of landmarks (Strauss and Bookstein, 1982; Turan, 1999). There is more than one way to do these three operations. One method is to fix the coordinates of two points to (0, 0) and (0, 1), which are the two ends of a baseline. In one step, the shapes are translated to the same position (the same two coordinates are fixed to those values), the shapes are scaled (to unit baseline length) and the shapes are rotated. An alternative, and preferred method, is Procrustes superimposition. This method translates the centroid of the shapes to (0, 0); the x centroid of the centroid is the average of the x coordinates of the landmarks of an individual, and the y coordinate of the centroid is the average of the y-coordinates. Shapes are scaled to unit centroid size, which is the square root of the summed squared distances of each landmark to the centroid. The configuration is rotated to minimize the deviation between it and a reference, typically the mean shape. In the case of semi-landmarks, variation in position along the curve is also removed. Because shape space is curved, analyses are done by projecting shapes onto a space tangent to shape space. Within the tangent space, conventional multivariate statistical methods such as multivariate analysis of variance and multivariate regression can be used to test statistical questions about shape.

Procrustes-based analyses have some limitations. One is that the Procrustes superimposition uses a least-squares criterion to find the optimal rotation; consequently, variation that is localized to a single landmark will be smeared out across many. This is called the "Pinocchio Effect." Another is that the superimposition may itself impose a pattern of covariation on the landmarks. Additionally, any information that cannot be captured by landmarks and semi-landmarks cannot be analyzed, including classical measurements like "greatest skull breadth." Moreover, there are criticisms of Procrustes-based methods that motivate an alternative approach to analyzing landmark data.

2.6 Differences between Morphometric and Meristic techniques

Whereas both morphometric and meristic techniques are used to identify fish populations, the variables and the extent to which each of them can be applied are different. Meristic techniques involve the use of countable traits such as such as number of gill rakers, dorsal fin spines, number of teeth in each jaw, myomeres, vertebrae (Tsigenopoulos and Berrebi, 2000). To the contrary, morphometrics examines the size and shape using measureable traits such as standard length, total length and all designated body lengths, gauged as length, mass, angle or ratio of other body measurements (Strauss and Bookstein, 1982; Turan, 1999; Turan et al., 2005; Bwanika et al., 2007).

2.7 Fish condition and fishing effort

The condition of a fishery defines the measure of physical and biological circumstances during some previous period (Lloret et al., 2002). Relative fish condition compares the wellbeing of a fish and assumes that heavier fish of a given length are in better condition. The condition of a fish/fishery is affected by interactions among food availability, physical factors, parasitic infections, and the physiology of the fish (Abowei, 2010). Various criteria such as morphometric (length-weight) relationship (Le Cren, 1951); endocrine (Taranger et al., 2010), physiological (liver and gonad weights) (Lloret et al., 2002) and biochemical measures such as lipid or protein content (Able et al., 2008) have been used to assess fish condition in both single and multiple fisheries concepts.

Extensive use of morphometric criterion has often been applied with assumption that weight and length of healthy fish are proportional to one another in a bio-logarithmic fashion (Bortone, 2003). A fish that is heavier for a given length (higher condition index) is generally considered to be a healthier fish, because extra weight means extra energy reserves. Lighter fish lack energy reserves and tend to be more susceptible to environmental stressors. A low body condition may also suggest muscle wasting (proteolysis) indicating a starvation response (Bortone, 2003). Because of differences in environmental conditions, between systems, different fish populations display different levels of condition according to exploitation pressure such as quality and type of fishing gears, level of fishing efforts, food availability or catchment characteristics (Lloret et al., 2002; Boys et al., 2012). According to Lloret et al. (2002), it is estimated that the quality of a given habitat and therefore, separate ecosystems affect the condition of different fish species and stocks differently. Therefore, the higher the quality of the system, the higher the fish condition and therefore, better welfare. Integrated analysis of Fish condition, components of environmental quality such as water quality and fishing effort provide indices of the direction of the fishery. However, in the current management of Ugandan fisheries resources, considerable efforts have been geared towards monitoring stock and control of mortalities (Taabu, 2004; Njiru et al., 2010; Ogutu-Ohwayo et al., 2013) at the expense of multi-disciplinary approach to holistically understand the health of the fishery.

2.8 Importance of length frequency distribution

Accurate examination and estimation of the distribution of the different length classes of is critical for the conservation of exploited stock. The distribution of different length classes of a given stock combined with other population monitoring tools such as morphometric analysis, fish condition, environmental and fishing effort provide important predictors of the risk of over exploitation (Reynold et al., 2005).

For *B. altianalis* fish from the Lakes Victoria and Edward basins data on condition and maturity stages are scarce. However, Greenwood (1966); Ntakimazi (2006); Fishbase (2015) indicate that the maturity stage of B. *altianalis* being 15kg and 90 cm maximum weight respectively, with length at first maturity of 54 cm.

Fundamental to the establishment of the means of avoiding exploitation of immature and consequent reduction of spawning stock (Nandikeswari, 2016). The differentiation in maturity between stocks/populations explains the differences in duration of life. Males and females maturing at different lengths and periods explain the relationship between maturity and environmental conditions. For example, Brusle (1981); Nandikeswari (2016) observed positive relationship between length at first maturity and water temperature of *Terapon puta* at different seasons from the Pondicherry coast, India.

Similarly, fluctuation in maturity stages and sizes with the intensity of fishing effort has been widely reported for different fish species in Lakes Victoria and Edward basins. For example; Njiru et al. (2006) recorded 21 cm TL and 22.7 cm TL for male and female Nile tilapia respectively in Lake Victoria. Balirwa (1998) reported that Nile tilapia in Lake Victoria shows signs of maturity at 25 cm TL which is higher than that reported by Njiru et al. (2006) in Lake Victoria eight years later. Bwanika et al. (2004) suggested that Nile tilapia delays maturation when living in large lakes but breeds at younger ages when in smaller lakes and ponds.

Sharpe et al. (2012) showed that *Rastrineobolla argentea* decreased body size, maturation at smaller sizes, and increased reproductive effort (larger eggs; and higher relative fecundity, clutch volume, and ovary weight) in response to various fishing efforts and fish species diversity in Lake Victoria.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

Fish specimen used in this study were obtained from four landing sites in the River Nile (upstream - Ripon and downstream -Kiira, Kalange and Bukeka) of the Owen Falls dam while on Lake Edward samples were obtained from two landing sites (Katwe and Kayanja). Fish were also sampled from two landing sites (Katunguru and Kazinga) in the Kazinga channel, upstream Lake Edward, Uganda. Given its location, the fishers at Ripon landing site conduct their fishing activities both in the lacustrine and the riverine systems. Other than Ripon, the other landing sites along the River Nile; Kiira and Kalange are downstream Kiira and Owen Falls dams while Bukeka landing site is separated from Kiira and Owen Falls hydropower dams by Bujagali hydropower dam upstream Isimba and Karuma hydropower dams currently under construction. The fisher folk, fishing vessels and gears in Kiira, Kalange and Bukeka landing sites are restricted to fishing within the riverine system between the dams along River Nile. Katwe, Kayanja, Katunguru and Kazinga are situated in water bodies located within Queen Elizabeth National Park, where fishing activities have some level of restriction given their location in a protected area (Fig.2).

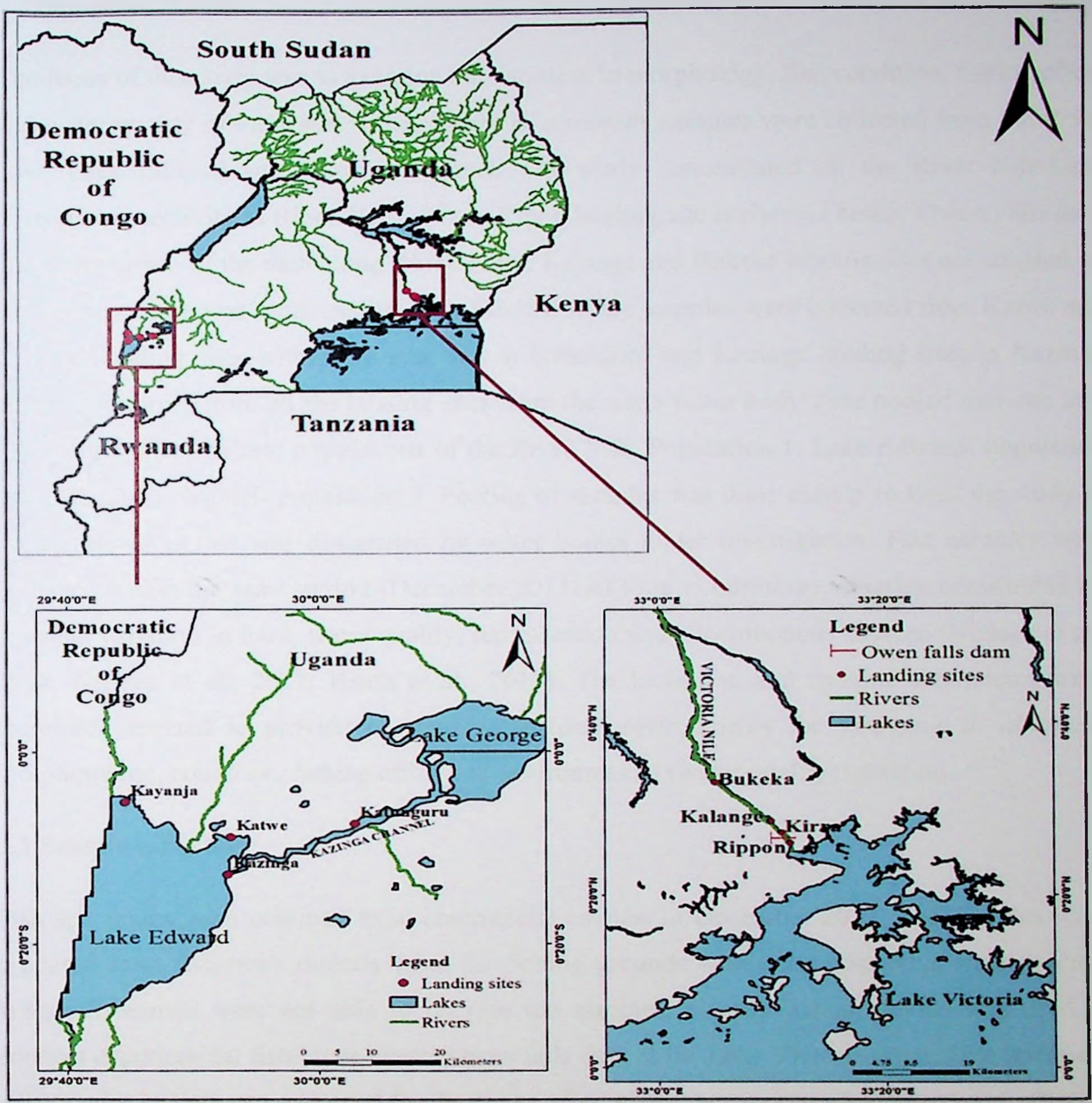

Figure 2: Location of the landing sites where samples of *B. altianalis* were obtained on the River Nile, Lake Edward and Kazinga Channel –Uganda in 2013.

3.2 Sampling design

The focus of this study was to examine the variation in morphology, fish condition, fishing effort and water quality of the water bodies where B. *altianalis* samples were collected from the River Nile, Lake Edward and Kazinga channel. The study concentrated on the River Nile-Lake Victoria connectivity in Ripon Falls, where Ripon landing site is situated before Owen Falls dam and downstream of the dam along which Kiira, Kalange and Bukeka landing sites are situated. A similar procedure was replicated in Lake Edward where samples were collected from Katwe and Kayanja landing sites within the lake and in Katunguru and Kazinga landing sites in Kazinga channel. Samples from all the landing sites from the same water body were pooled into one unit to generate three discrete populations of the River Nile- Population 1, Lake Edward- population 2 and Kazinga channel- population 3. Pooling of samples was done mainly to limit the study to population level that was designated by water bodies under investigation. Fish samples were collected within the same period (December 2013) of time to minimize variation contributed by seasonal variation in food, water quality, reproduction and allochthonous sources (Nielsen et al., 1998; Nielsen et al., 2012; Heath et al., 2015). The lacustrine and riverine ecosystems were therefore, selected to provide comparative natural environments for assessing *B. altianalis* morphometric, condition, fishing effort and environmental (water quality) variation.

3.3 Sample collection

Fish specimens were obtained from commercial catches in December 2013. The samples were procured from fishermen directly from the fishing grounds within the respective water bodies. Where fishermen were not able to provide the samples, electric fishing device was used to conduct experimental fishing upstream Owen falls dam at the Lake Victoria-River Nile interface. All samples landed were obtained for the study, after which the carcasses were disposed off at no cost to the landing site community (humans and other animals). A truss dimension of each fish was constructed from the left side of the fish, using Vernier calipers, following landmarks adopted from previous studies (Flemming et al., 1994; Turan et al., 2005). A total of 13 truss and 6 non-truss morphometric variables were measured on each specimen to the nearest centimeter 0.1 cm (Table 1).

Table 1: Truss and non-truss dimensions measured for the morphometric analysis of *B. altianalis* collected from Lake Edward, Kazinga Channel and R. Nile in 2013 as in Fig. 3.

ss	Non-truss
nout to ventral operculum junction distance (a)	1. Orbital distance (obd)
nout to lower pectoral fin insertion (b)	2. Pectoral fin length (pfl)
nout to posterior end of supra orbital (c)	3.Dorsal fin length (dfl)
osterior end of supra orbital to lower pectoral fin insertion (d)	4.Pelvic fin length (pvfl)
osterior end of supra orbital- posterior end of pelvic fin origin (e)	5. Anal fin length (afl)
nterior dorsal fin to lower pectoral fin insertion (f)	6.Caudal fin length (cfl)
nterior dorsal fin to posterior end of pelvic fin origin (g)	
nterior dorsal fin to anterior anal fin insertion (h)	
osterior dorsal fin insertions to posterior pelvic fin insertion (i)	
Posterior dorsal fin insertion to anterior anal fin insertion (j)	
Posterior dorsal fin insertion to ventral caudal fin insertion (k)	
Dorsal caudal fin insertion to ventral caudal fin insertion (l)	
Anterior anal fin insertion to dorsal caudal fin insertion (m)	

The non-truss variables were measured individually from the tip of each fin anterior of the end of the fin to the body muscles

3.4 Construction of the truss dimensions

A truss dimension is series of measured distances calculated between landmarks that form a regular pattern of connected quadrilaterals or cells across the body form (Strauss and Bookstein, 1982; Turan, 1999).The truss procedure used for this study was based on 10 landmarks whereby the truss dimensions were constructed by interconnecting landmarks to form a total of 13 measurements. The measurements were conducted by inserting a pin on an insertion of the first landmark (A-snout) followed by a similar insertion on the second landmark (B- Ventral junction of operculum). The reading was then taken by vernier calipers along a straight edge.The same procedure was also repeated for all other measurements along different landmarks.

The measurement of non-truss (measured distances along the length of a single landmark i.e fin length), was done by inserting a pin on a point of attachment of the fin to the trunk and a vernier caliper then run through a straight edge to the tip and a record of the readings was taken (Fig. 3)

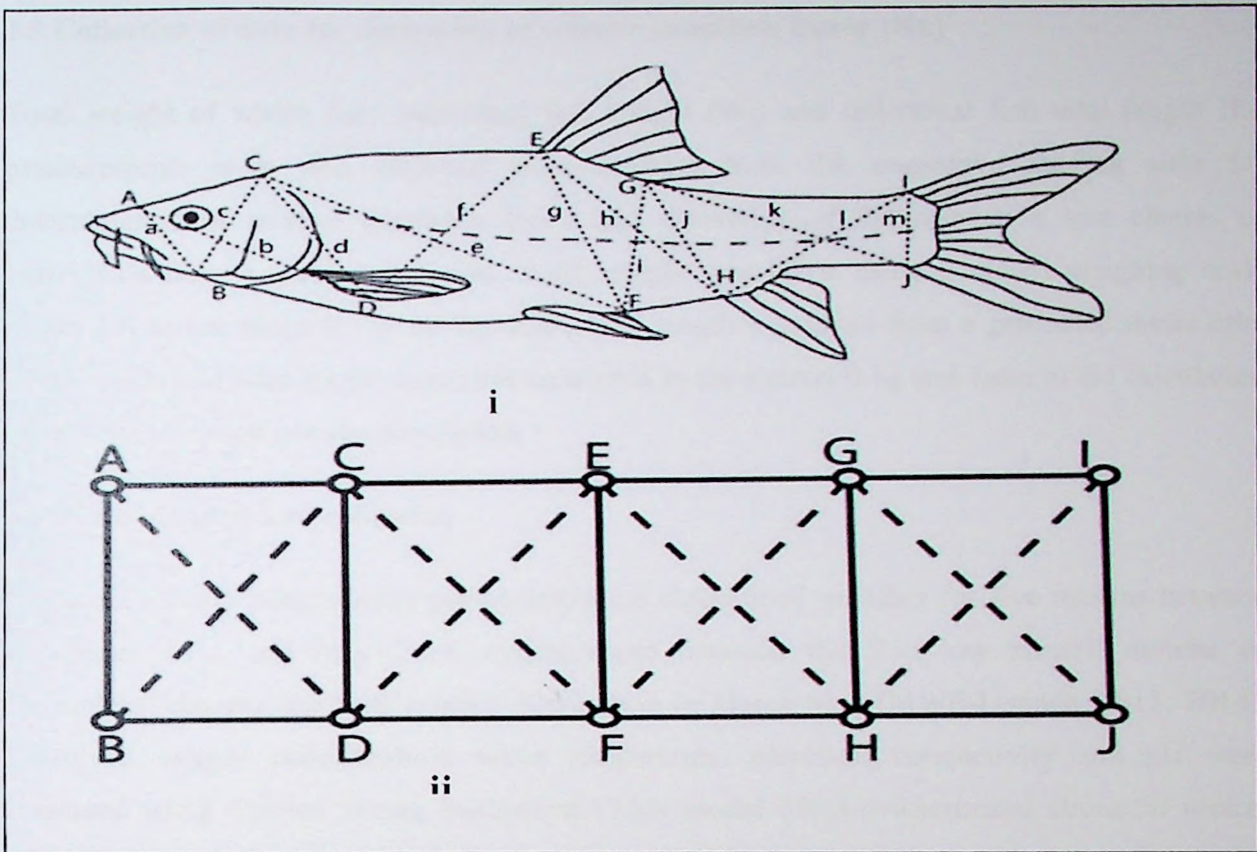

Figure 3: Data recording procedure. Top 19 distance parameters recorded on vernier calipers. Top (i) marked in lower case letters are distances measured between landmarks and marked (ii) in upper case letters are the morphometric land marks in *B. altianalis* (Modified from Strauss and Bookstein (1982); Corti et al. (1988); Turan (1999); Rutaisire (2003).

a, Snout; b, Ventral junction of operculum junction; c, Supra orbital; d, Lower Pectoral Fin insertion; e, Anterior Dorsal Fin insertion; f, Posterior end of Pelvic Fin insertion; g, Posterior end of Dorsal Fin insertion; h, Anterior end of Anal Fin insertion; i, Dorsal Caudal fin Insertion; j, Ventral Caudal fin insertion; k, posterior dorsal fin insertion to ventral caudal fin insertion; l, Dorsal caudal fin insertion to ventral caudal fin insertion; m, Anterior anal fin insertion to dorsal caudal fin insertion . Bottom: Geometric representation of the data recording procedure. Each single cell is determined by four sides and two diagonals.

3.5 Collection of data for derivation of relative condition factor (Kn)

Total weight of whole fish/ individual fish weight (W_i) and individual fish total length (L_i) measurements were also obtained from samples from the respective landing sites for determination of relative condition factor and derivation of the respective size classes of individuals from a given population. Total weight was taken using a digital weighing scale model LN series, range 0.1 to 10 kg, while total length was taken from a graduated meter rule. Total weight and total length were later converted to the nearest 0.1g and 1mm to aid calculation of relative condition per site/population.

3.6 Water quality data collection

Physico-chemical water quality parameters were determined monthly for five months between November 2013 and May 2014, synchronized between the first low rainfall months of December-February and peak rainfall distribution in March-May (MWE-Uganda, 2013; 2014). Dissolved oxygen concentration, water temperature, electrical conductivity and pH were measured using Yellow Spring Instrument (YSI) model 556-Environmental about 50 meters offshore, between 0700 to 0830 hrs to generate monthly average water quality observations for each population. The water quality measurements were used to investigate the relationship between water quality and the morphometric variables.

3.7 Estimation of fishing effort

Monthly head count of the fisher folk was documented to assess the demography and as part of assessing fishing effort in every population. Daily landing volume of *B. altianalis* in each landing site was recorded to enable calculation of mean catch rates. The quantity of *B. altianalis* landed per boat per day (mean catch rates) was estimated following the protocol for the Standard Operating Procedure (SOP) of the Lake Victoria Fisheries Organization (LVFO, 2005). Type and size of fishing vessels, gears and the duration taken to fish were recorded. The fishing gears were classified according to technical specification. Fishing gears whose frequency of occurrence was ≤ 3 in every ten sampled gears were regarded inconsequential and therefore, dropped out of the analyses (LVFO, 2005). Fishing vessels were classified according to overall length (LOA) and the mode of propulsion as either wooden manual powered or as wooden engine powered. The demography, fish abundance, and the fishing infrastructure/equipment were all corroborated to the variation in morphology and the condition of *B. altianalis* in the study areas. The corroboration was based statistical comparison of the observed morphological variation with different components of fishing effort.

3.8 Statistical data analysis

3.8.1 Multivariate data analysis

Size dependent morphometric variables were log transformed to normalize the dataset. The log transformed data were each correlated to fish total length to establish the relationship between total length and each morphometric variable. After establishing the relationship between total length and morphometric variables, the log transformed variables were then corrected to eliminate correlation of the variables with size. This was done by adopting an allometric method suggested by Elliot et al. (1995); Turan (1999) and Mir et al. (2013) using the formula;

$$Madj = M\ (L_s/L_o)^b$$

Where;

M is the original truss and non-truss measurement of morphometric variable;

Madj is the size adjusted truss and non-truss measurement of morphometric variable;

L_o is the total length of the fish

L_s is the overall mean total length and b was estimated for each variable from the observed data as the slope of the regression of log M on log L_o using the fish from every population.

The results derived from the allometric method were confirmed by testing the correlation between transformed variables and total length (L_o).

The differentiation among the populations was based on the percentage of correctly and incorrectly classified fish. The degree of intermingling among the population was indicated by the number of misclassified individuals. The first and the second F-ratios that test both canonical correlations were explored for significance to describe the differences between the three populations. The canonical correlations for dimension one and two were explored.

The separation among the populations was explored using discriminant function analysis score plot.

In order to identify the contribution of each individual morphometric variable to the observed variation, loading plot that provides the graphical way of looking at the standardized discriminant function coefficient was used.

3.8.2 Calculation of relative condition factor (K_n)

To compare populations among water systems and for the generation of predictive models of fish condition, relative condition factor of *B. altianalis*, was calculated as the ratio of observed individual fish weight to expected weight of an individual of a given length, using the formula: $K_n = W_i/aL_i^b$ (Le Cren, 1951); where W_i is observed individual fish weight, L_i is observed individual fish total length, and a and b are species-specific constants. These regression constants were obtained from the population length-weight relationship ($W=aL^b$) derived for each water body. Where W = weight (g), L = total length (cm).

Length and weight data for each water body/ population were log-transformed and the resulting linear relationships fitted by least square regression using weight as the dependent variable.

3.8.3 Condition factor, water quality and fishing effort

Length frequency distribution was computed for each population to evaluate the variation in size and evaluate distribution of the different size classes as gauged by the Fish Act (GOU, 1951) among populations.

The condition factor, water quality and catch rates were compared to establish their relationship as means of assessing the health of the *B. altianalis* fishery in the current study. The mean relative condition of fish in each water body was computed to explore relationships between environmental variables and fish condition. One-way Analysis of Variance (ANOVA) was used to test for differences in mean relative condition of each population in the water bodies exposed to different fishing pressures (effort) and different levels of water quality conditions. All statistical analyses were carried out using STATA.

CHAPTER FOUR

4.0 RESULTS

4.1 Fish population characteristics

A total of 251 freshly caught fish samples were obtained; 113 specimens from River Nile, (only 4 from the lake- River interface upstream from the Owen Falls hydro power dam and 109 downstream the dam); 61 were from Lake Edward while 77 from Kazinga channel. (Table 2).

Table 2: Location of sampling sites, fishing effort and size (±StDev) of *B. altianalis* used in the study from different landing sites of River Nile, Lake Edward and Kazinga channel collected in 2013.

Fishing ground/ Landing sites	Shoreline coordinates	Total specimen	Fishing duration (days)	Fish size (kg)	(cm)
Kalange	N00.47690 E033.16570	34	3	2.52±0.7	57.62±4.8
Bukeka	N00.55221 E033.08302	36	1	0.83±0.5	36.95±10.5
Kiira	N00.45398 E033.18178	39	2	2.55+0.9	57.69+7.0
Ripon(before dam)	N00.43393 E033.19382	04	7	1.65±1.5	47.78±10.7
Katunguru	S00.12522 E030.04763	37	2	0.19±0.2	24.58±5.1
Kazinga	S00.20813 E29.74357	40	2	0.32±0.1	29.45±7.9
Katwe	S00.14745 E029.88352	31	3	2.20±2.0	49.46±21.4
Kayanja	S00.08747 E029.74357	30	3	2.60±1.9	53.20±19.8

All the morphometric characters were linear with total length, indicating significant correlation between the variables with size before allometric transformation (Table 3).

Table 3: Regression models of TL, truss and non-truss variables of *B. altianalis* collected from River Nile, Lake Edward and the Kazinga channel in 2013.

Relationship	Equation	r^2
TL and a	a = 0.2 + 0.14TL	0.9
TL and b	b = -0.08 + 0.16TL	0.9
TL and c	c = -0.84 + 0.21TL	0.93
TL and d	d = 0.48 + 0.23TL	0.93
TL and e	e = 0.47 + 0.28TL	0.94
TL and f	f = -0.12 + 0.27TL	0.91
TL and g	g = -0.01 + 0.39TL	0.94
TL and h	h = 0.004 + 0.24TL	0.89
TL and i	i = 0.002 + 0.23TL	0.92
TL and j	j = 0.33 + 0.32TL	0.91
TL and k	k = -0.01 + 0.25TL	0.94
TL and l	l = -0.29 + 0.13TL	0.83
TL and m	m = 0.71 + 0.31TL	0.87
TL and obd	obd = -0.58 + 0.10TL	0.58
TL and pfl	pfl = 0.36 + 0.15TL	0.93
TL and dfl	dfl = 1.50 + 0.13TL	0.93
TL and pvfl	pvfl = 0.85 + 0.13TL	0.5
TL and afl	afl = 0.52 + 0.14TL	0.95
TL and cfl	cfl = 1.64 + 0.17TL	0.41

Regression model of TL, truss and non-truss variables ($P \leq 0.0\ 5$). TL is total length of each fish sample obtained from respective landing sites. The different letters marked in lower case represent respective truss and non-truss variables measured from each fish sample as elaborated in Table 1 above.

The size correlated morphometric variables showed no relationship with size after allometric transformation. None of the 19 morphometric variables showed a significant correlation with total length, indicating the size effect was removed from the dataset as showed by standardized discriminant function coefficients below. None of the variables showed significant correlation of ≥ 0.9 in both function one (DFA 1) and two (DFA 2) Table 4).

Table 4: Coefficients of correlation of adjusted morphometric variables with discriminant functions of *B. altianalis* collected from three water bodies

Size adjusted morphometric variable	DFA 1	DFA 2
Badj	0.0782379	0.4325121
Cadj	0.0012114	0.2965586
Dadj	-0.0501821	0.2630142
Eadj	0.0903308	0.2694192
Fadj	0.0535007	0.1789762
Gadj	0.0138467	0.2338929
Hadj	0.1330427	0.2639298
Iadj	0.1095107	0.3081632
Jadj	0.0019803	0.2394415
Kadj	-0.0323128	0.3549375
Ladj	-0.0644008	0.1503315
Madj	0.0069744	0.4603842
OBDadj	-0.0129624	0.1976076
PFLadj	-0.1129453	0.2749095
DFLadj	-0.2550584	0.304675
PVFLadj	-0.2550584	0.1493597
AFLadj	-0.1048381	0.314537

The different letters marked in upper case represent respective size adjusted/corrected truss and non-truss variables measured from each fish sample as elaborated in Table 1 above.

4.2 Morphometric variation

The re-substitution classification table (confusion matrix) indicated population 1 had the highest number (80.53%) of individuals classified correctly while populations 2 (67.2%) and 3 (60.5%) had more misclassifications between them indicating that the latter groups could be harder to separate (Table 5).

Table 5: Re-substitution classification summary of three populations of *B. altianalis* from River Nile, Lake Edward and Kazinga channel.

True population	Classified			Total
	1	2	3	
1	91.0	10.0	12.0	113
	80.5	8.9	10.6	100
2	7.0	41.0	13.0	61
	11.5	67.21	21.3	100
3	13.0	17.0	46.0	76
	17.1	22.4	60.5	100
Total	111	68	71	250
	44.4	27.2	28.4	100
Priors	0.33	0.33	0.33	

Among the 19 variables, OBDadji, PVFLadj and CFLadji, which were the orbital distance, pelvic fin length and caudal fin length respectively, were not significantly ($P<0.001$) different in population one. Wilk's lambda (λ) test of DFA showed significant differences in morphometric variables and confirmed significant separation of the three populations from each other ($P<0.001$); Table 6)

Table 6: Results of Wilk's lambda tests (function 1 and 2) for the verifying and classifying differences among three populations of *B altianalis* from River Nile, Lake Edward and Kazinga channel when morphometric variables are separately compared using discriminant function analysis

Test of function	Wilk's lambda (λ)	Chi-square	Df
1 through 2	0.08	209.76	458
2	0.53	529.0	230

The results of the factor analysis between the three populations indicated that the two factors (DFA1 and DFA2) collectively explained 100% of the total morphometric variation. With exception of OBDadji, PVFLadj and CFLadji, all other variables had higher loadings. Those with higher loadings accounted for 84% of the variance while the second factor loading accounted for 16% of the variance (Table 7)

Table 7: Canonical linear discriminant analysis of morphometric variables of *B. altianalis* from River Nile, Lake Edward and Kazinga channel

DFA	Canonical correlation	Eigen value	Variance	Likelihood ratio	F	df1	df2	p-value
1	0.6301	0.658569	0.8396	0.5356	4.4168	38	458	0.000
2	0.3343	0.125794	0.1604	0.8883	1.6074	18	230	0.059

The group means on canonical variables of the first function showed that population1 (River Nile (-0.8869) separated farthest from populations 2 (Lake Edward (0.796) and 3 (Kazinga channel (0.6796 (Table 8).

Table 8: Group means on canonical variables of population functions 1 and 2 of *B. altianalis* from River Nile, Lake Edward and Kazinga channel

Population	DFA 1	DFA 2
1	-0.8869162	0.0206888
2	0.7963681	0.5137493
3	0.6795142	-0.4431124

The score plot illustrated that the three populations were reasonably well separated from each other with minimum intermingling. There was clear separation in the second dimension between the lacustrine (Lake Edward) from riverine (River Nile and Kazinga channel) but with substantial overlap (Fig. 4)

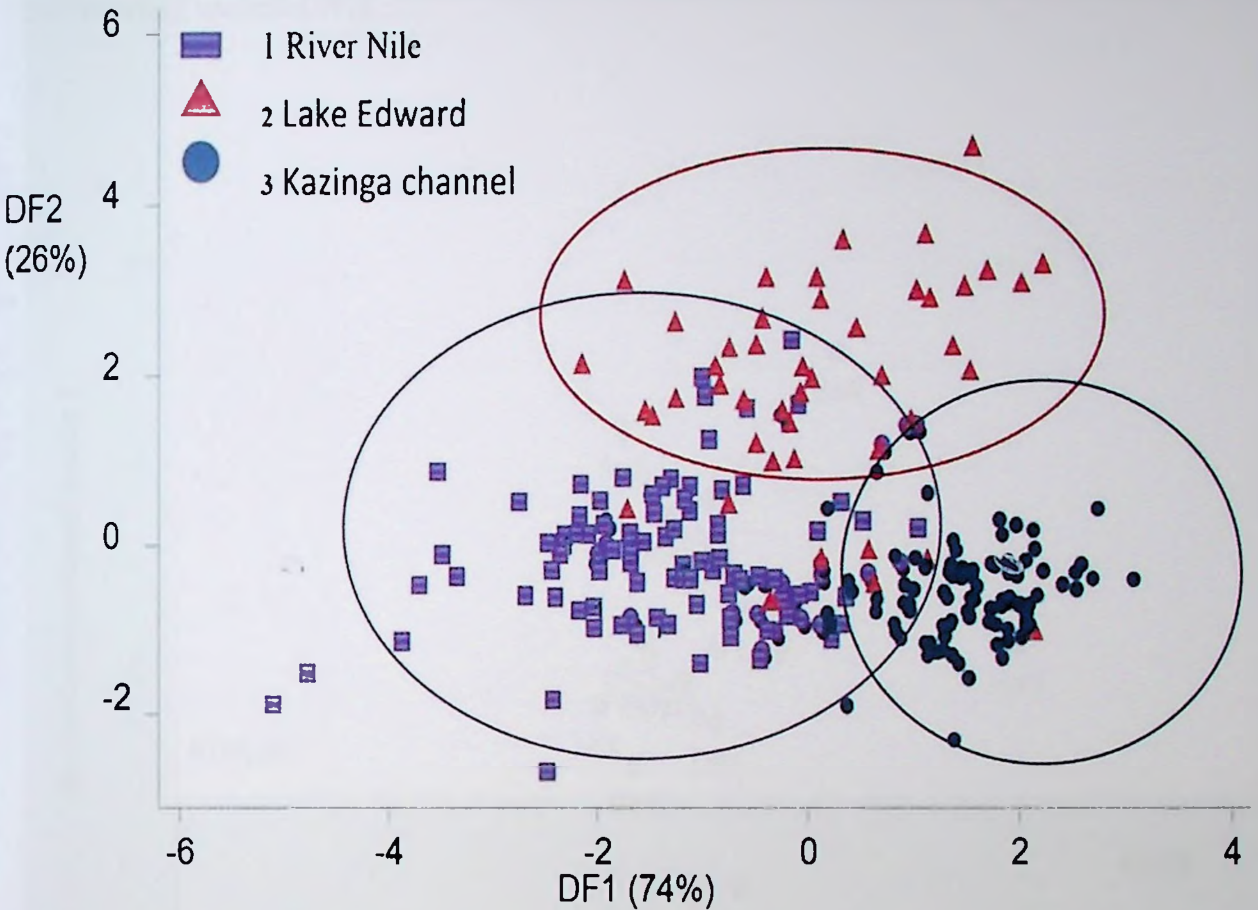

Figure 4: DFA graph of 19 morphometric variables used for *B. altianalis* from River Nile, Lake Edward and Kazinga channel. Labels 1, 2, and 3 represent River Nile, Lake Edward and Kazinga Channel respectively.

Observations of the loading plot indicated variables OBDadji, PVFLadj and CFLadji near the origin, implying that they provide almost no discriminating ability in comparison to the other discriminating variables (Fig. 5).

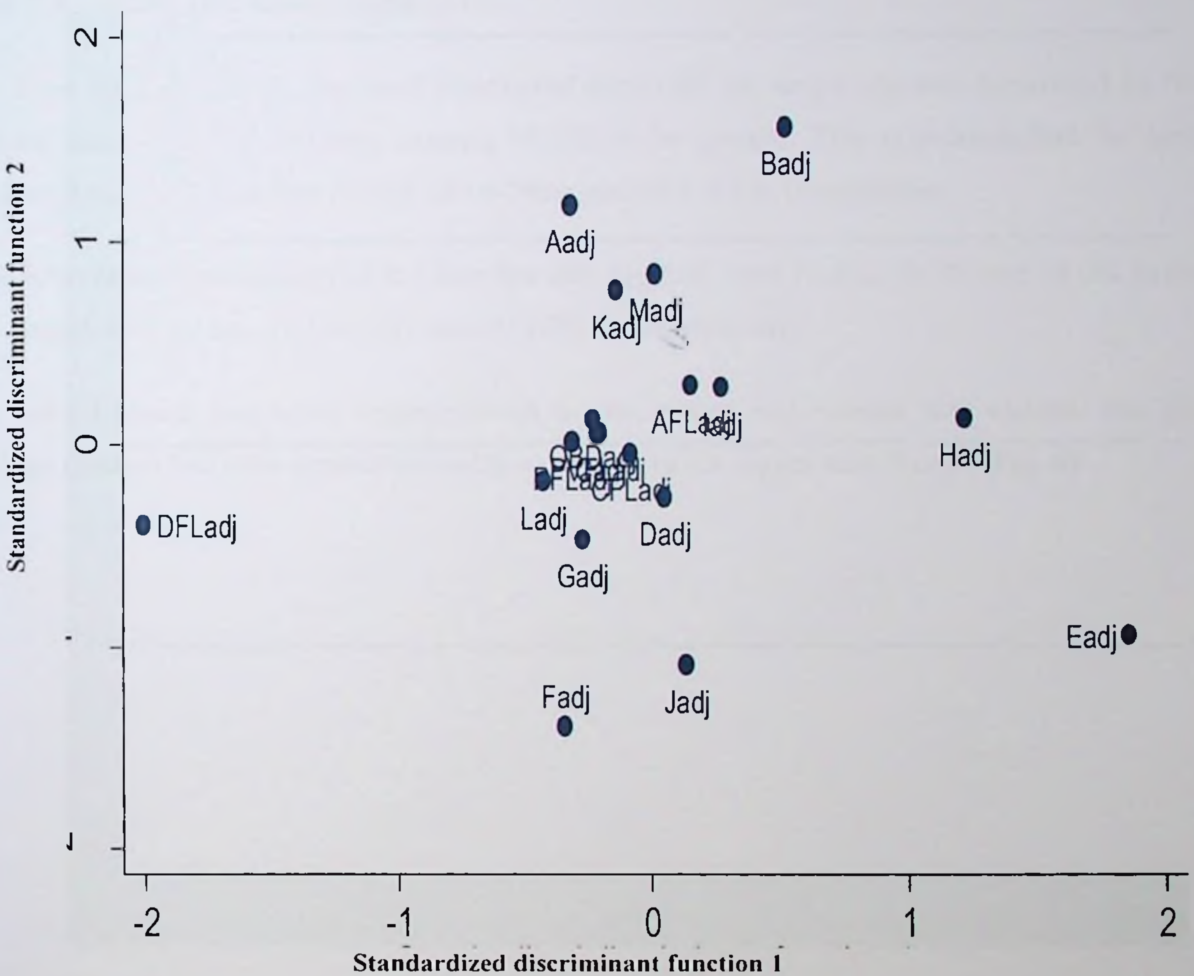

Figure 5: Standardized discriminant function factor loading plot of size adjusted variables used to analyze the morphometric variation among *B. altianalis* populations from River Nile, Lake Edward and Kazinga channel. ***The different letters marked in upper case represent respective size adjusted/corrected truss and non-truss variables measured from each fish sample as elaborated in Table 1 above.***

4.3 Population length class distribution

Altogether, fish total length ranged from 19-79 cm. The number of smaller fish (19-29 cm) was highest in Kazinga channel population, where the same category comprised 50.6% and 48.1% in the length class 29.1-39.0 cm.

Similarly the biggest size class in Kazinga channel was under the range of 39.1-49%, making about 1.3% of the total sample population.

The River Nile population was well distributed across all the length classes, dominated by the medium size class (39.1-49 cm), making 33.6% of the sample. This population had the least number of individuals in size classes of 19-29cm and 69.1-79cm respectively.

Lake Edward had the majority of the samples with big fish, with 11.5%, 35.7% and 18.0% in the size classes 49.1-59 cm, 59.1-69 cm. and 69.1-79 cm respectively.

The Lake Edward had better representation in the bigger and smaller size classes. But the Kazinga channel had only smaller fish with no sample in the bigger size classes (Fig. 6)

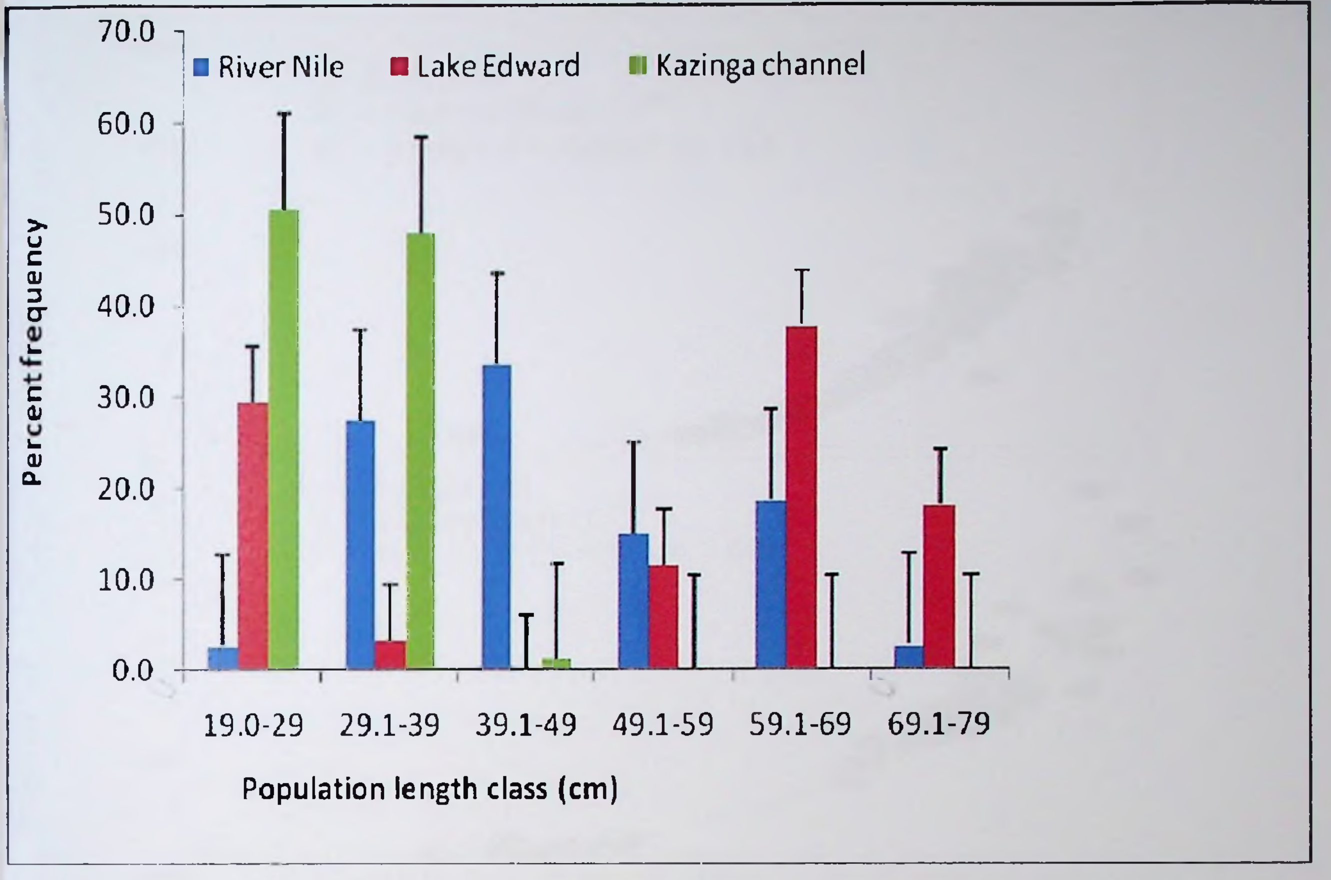

Figure 6: Total length frequency distribution for *B. altianalis* populations from River Nile, Lake Edward and the Kazinga channel as taken in December 2013

4.4 Relative fish condition in River Nile, Lake Edward and Kazinga channel

Post-hoc test indicated highly significant differences in the mean relative condition (K_n) of *B. altianalis* between River Nile (population 1, mean dif 0.0880, P<0.004) and Lake Edward (population 2,) and between River Nile and Kazinga channel (mean dif. 0.0796, P< 0.001). There was no significant difference in the mean relative condition between Kazinga channel and Lake Edward (mean diff. 0.0840, P<0.95). The relationship between weight and length for each population, obtained by assessing individuals across systems was significant (P<0.001). The length-weight allometry between the populations was also significantly different ($F_{(2, 237)} = 9.73$, P< 0.001 (Fig. 7).

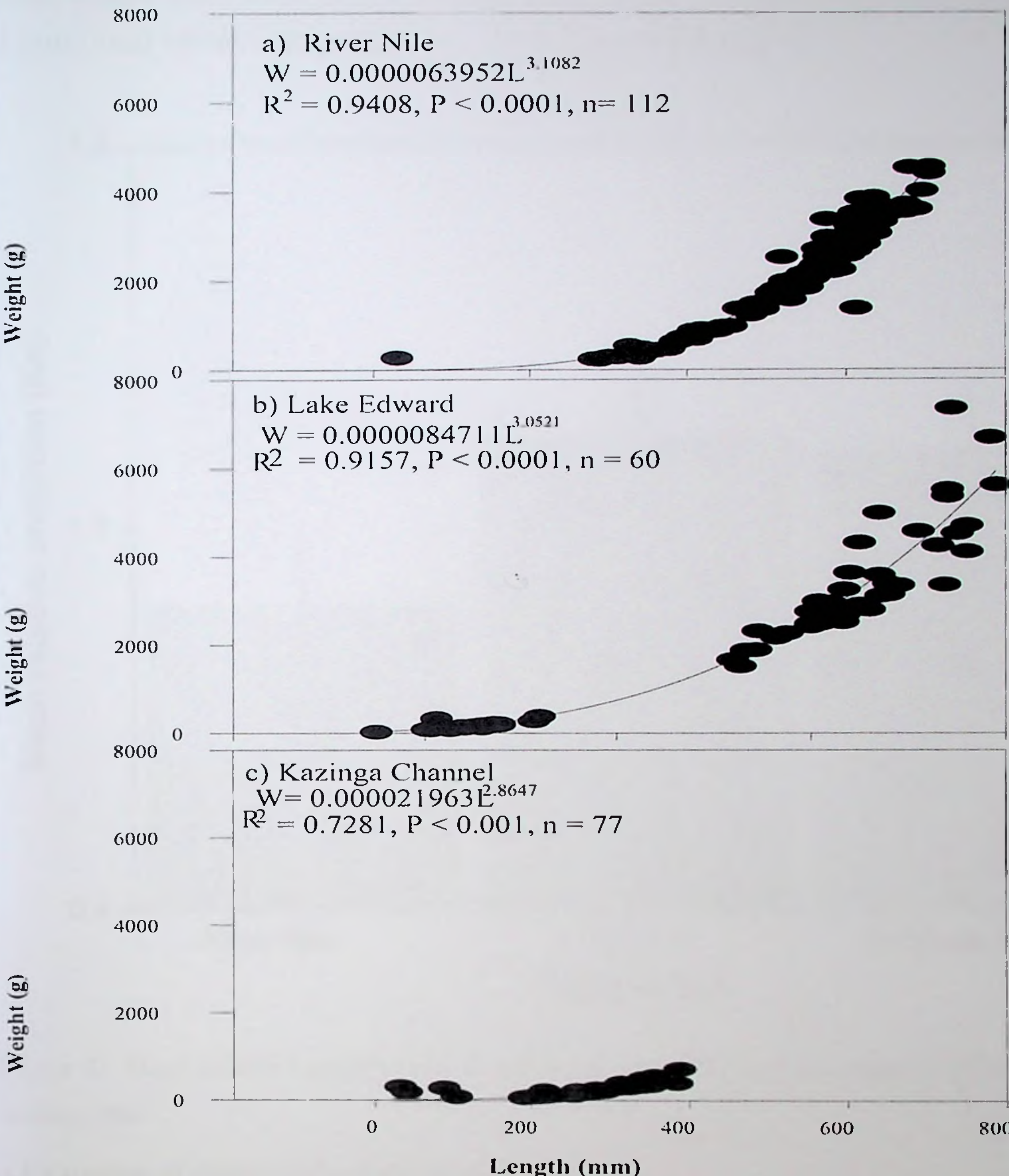

Figure 7: Relationship between total weight (g) and total length (mm) for *Barbus altianalis* sampled from River Nile (a), Lake Edward (b) and Kazinga Channel (c).

Mean relative conditions (K_n) for the respective populations at ($P<0.05$) were 0.96±0.145, 1.05±0.15 and 1.04±0.13 for populations 1, 2 and 3 respectively (Fig. 8)

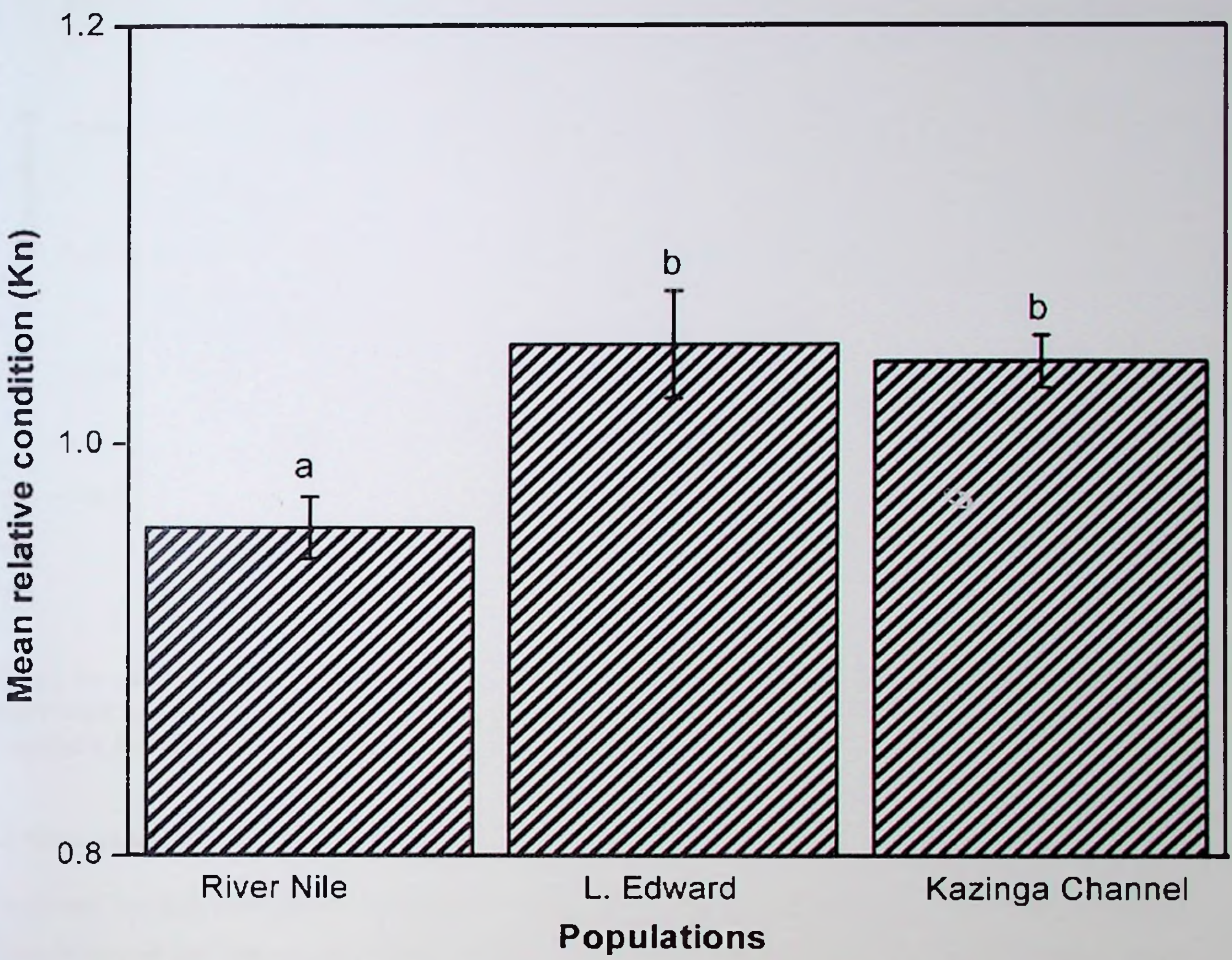

Figure 8: Mean relative condition of *B. altianalis* derived by pooling data from eight fish landing sites

4.5 Variation of relative fish condition with size

There was no observed relationship between relative condition and fish size. The MDS graph indicated all morphometric variables clustered apart from the relative condition index (Fig. 9).

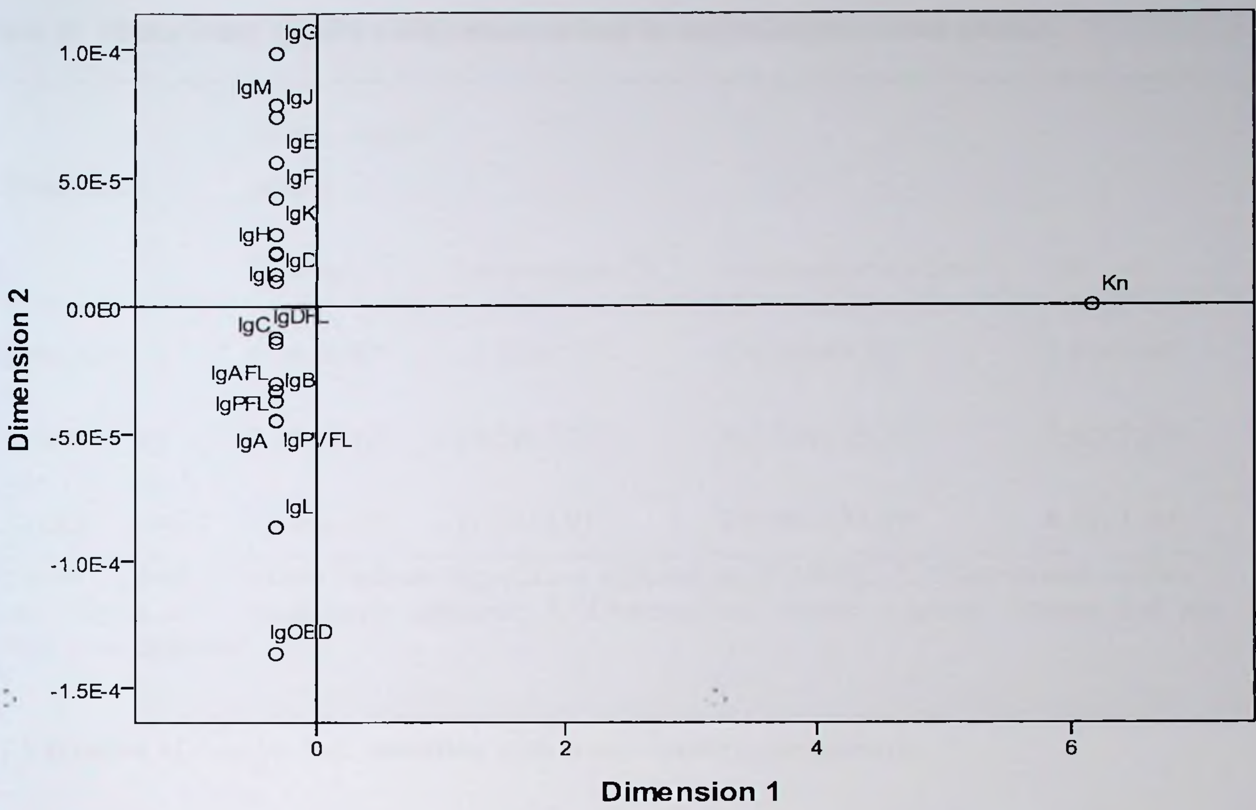

Figure 9: Variation of Relative fish condition with size. ***The different letters marked in upper case represent respective size adjusted/corrected truss and non-truss variables measured from each fish sample as elaborated in Table 1 above.***

4.6 Water quality

Dissolved oxygen and water temperature levels were significantly different ($P<0.05$) between River Nile and the other water bodies. Higher dissolved oxygen level of 4.20±0.80 mgL^{-1}, and lower temperature of 26.52±0.75 ^{O}C, were recorded in River Nile, than 3.54±2.32 and 3.34±2.30 mgL^{-1} in Kazinga channel and Lake Edward respectively. Conductivity varied significantly ($P<0.05$) across all the water bodies, with the highest of 312.47±115.78 μScm^{-1} in Lake Edward, 298.06±131.89 μScm^{-1} in Kazinga channel than170.38±41.89 μScm^{-1} in River Nile. The pH varied significantly between River Nile and the other water bodies. P^{H} recording in River Nile was slightly above neutral 7.43±0.60 while much higher readings of 8.41±1.29 and 8.69±1.00 were observed in Lake Edward and Kazinga channel respectively (Table 8).

Table 9: Mean water quality (±SE) observations in the respective water bodies

Water body	Mean water quality			
	DO(mgL^{-1})	Temperature (^{O}C)	Conductivity (μScm^{-1})	pH
River Nile	4.20 ± 0.80^{a}	26.52 ± 0.75^{a}	170.38 ± 41.89^{a}	7.43 ± 0.60^{a}
Lake Edward	3.34 ± 2.30^{b}	29.04 ± 1.25^{b}	312.47 ± 115.78^{b}	8.41 ± 1.29^{b}
Kazinga channel	3.54 ± 2.32^{b}	27.24 ± 2.91^{b}	298.06 ± 131.89^{c}	8.69 ± 1.00^{b}

Different alphabetic letters indicate significant differences (P<0.05); ^{a}. Observations within a given column are significantly different; ^{b}. Observations within a given column are not significantly different

4.7 Variation of relative fish condition with water quality parameters

The extent to which water quality affected fish condition was different among the populations/systems. Total dissolved solids and conductivity had negative effects on relative fish condition within the Lake Edward system, while dissolved oxygen, water temperature and pH influenced relative fish condition among the three water bodies positively (Fig. 10).

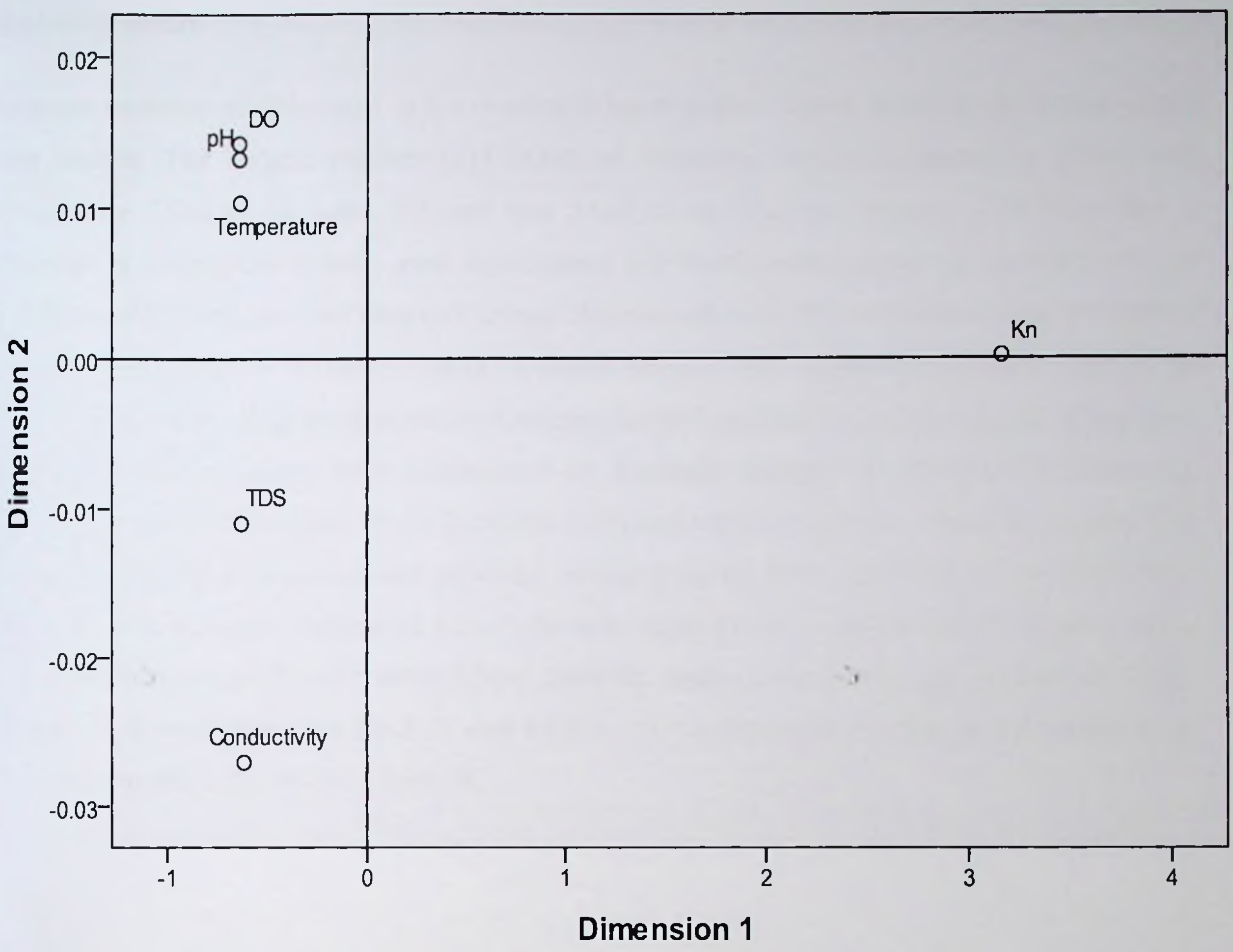

Figure 10: Variation of relative fish condition of *B. altianalis* with water quality parameters from different water bodies of River Nile, Lake Edward and Kazinga channel. DO, dissolved oxygen; pH, Hydrogen potential; Kn, Relative condition factor; TDS, Total dissolved solids.

4.8 Fishing effort

The mean numbers of fishermen in the respective landing sites varied significantly across all the water bodies. The largest number (311±0.88) of fishermen was encountered in River Nile followed by 75±2.45 in Lake Edward and 33±9.12 in Kazinga channel. The majority of fishermen in River Nile system used significantly (($P<0.05$) smaller number (56.64±31.51) of multifilament gillnets per boat than in Kazinga channel and Lake Edward where mean number of gill nets were 63.03±19.90 and 65.5±23.59 panels respectively. Significantly larger number of hooks (466.8±61.66) was enumerated in Kazinga channel compared to 27.5±10.0 in River Nile. Majority of fishing boats were enumerated in Kazinga channel (64.95±1.55; 59.04±2.31), followed by Lake Edward (60.18±1.72; 56.00±1.08) and least (56.2±1.32; 30) in River Nile. The boats were mainly wooden manual powered vessels ranging from 4.69±0.46 m in River Nile, 6.06±1.49 m in Kazinga channel to 6.67±1.80 m in Lake Edward length overall (LOA). Mean catch rates varied significantly with fishing duration. Fishermen in Kazinga channel and Lake Edward spent more time (14.29±1.57 and 14.23±1.11) h fishing compared to 6.21±0.88 h for their counterparts in River Nile (Table 9).

Table 10: Mean ± stdev fishing efforts in River Nile, Lake Edward and Kazinga channel between November 2013 and May 2014.

Fishing effort	Water body		
	River Nile	**Lake Edward**	**Kazinga channel**
No. of fishers	311±1[a]	75±2[a]	33±9[a]
No. of Fishing gears (Gill nets)	56.64±31.51[a]	63.03±19.90[b]	65.50±23.59[b]
Long line	27.50±10.0[a]	0±0.00	466.80±61.66[b]
No. of Fishing vessel (manual)	56.20±1.32[a]	60.18±1.72[b]	64.95±1.55[b]
Motorized	30.0±0.00[a]	56.00±1.08[b]	59.04±2.31[b]
LOA fishing vessel(m)	4.69±0.46[a]	6.67±1.80[b]	6.06±1.49[b]
Daily fishing duration(h day^{-1})	6.21±0.88[a]	14.23±1.11[b]	14.29±1.57[b]
Landing biomass(Kg $boat^{-1}$ day^{-1})	1.92±0.59[a]	6.20±1.86[b]	6.85±1.49[b]

Different alphabetic letters in the same row indicate significant differences (P<0.05).

The variation in fishing hours also corresponded to the catch rates of 6.85±1.49, 6.20±1.86 and 1.92±0.59 Kg $boat^{-1}$ day^{-1} in Kazinga channel, Lake Edward and River Nile respectively (Fig. 11).

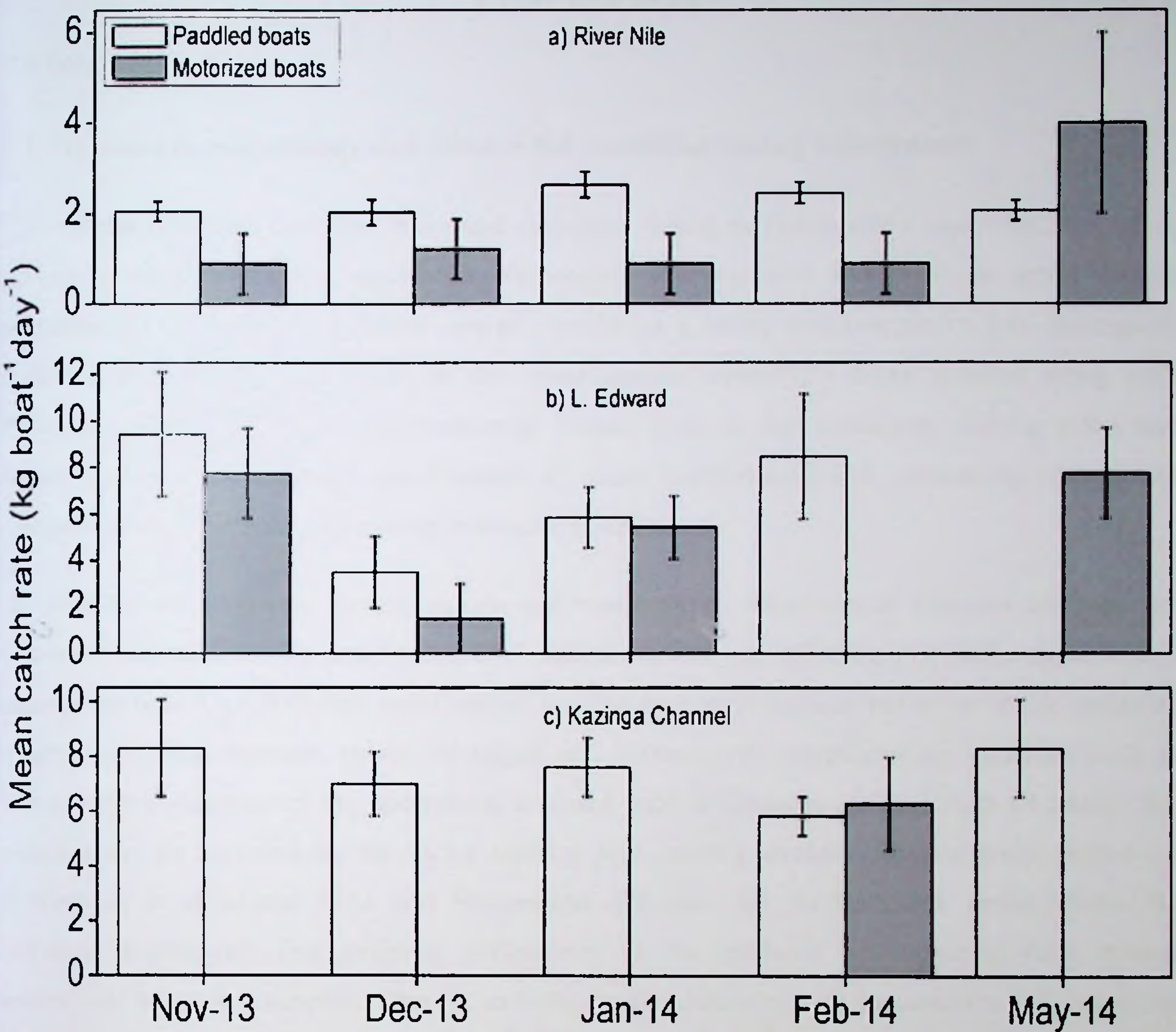

Figure 11: Comparative mean catch rates (±SE) of *B. altianalis* caught using manual and engine powered boats across the water bodies of River Nile, Lake Edward and Kazinga channel in 2013.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Variation in morphology and relative fish condition among populations

The results obtained from the truss and non-truss based morphometrics and condition of *B. altianalis* strongly suggest significant phenotypic heterogeneity and different status among populations. Discriminant function analysis could be a better multivariate tool to distinguish different populations and stocks of the same species especially when applied along with biological and management/ environmental indices such as fish condition, fishing effort and water quality parameters. A combination of such multidimensional evaluation often merit comprehensive inference of population structure variation.

As revealed by allometric transformation and standardized discriminant function analysis, the observed variation among populations of *B. altianalis* was not influenced by differences in size among the fish from different water bodies but due to morphological variation in the variables other than orbital distance, pelvic fin length etc. Variation in morphometric variables such as snout, ventral junction of the operculum, coupled with differences in the length of caudal fin, pectoral fin, as revealed by the factor loading plot, mainly explains the variation caused by differences in obtaining food and locomotion. Because the environment under which the different populations live differed, differences in the methods of acquiring food causes individuals to evolve adaptive features to mitigate the difficulties in locomotion and capturing food. The latter scenario was supported by over 80.5%, 67.2% and 60.5% of individuals correctly classified into respective populations of River Nile, Lake Edward and the Kazinga channel respectively by DFA, indicating that the three populations were under different selection pressures. The observed variability conforms to other studies elsewhere which rank fishes higher in morphological plasticity within and between populations due to higher degree of susceptibility to environmentally induced morphological changes (Mir et al., 2013; Chemoiwa et al., 2017).

The observed variation in morphometric characteristics may be related to differences in environmental conditions such as water quality, especially the separation between River Nile and the other water bodies (Lake Edward and Kazinga channel).

The River Nile flows from Lake Victoria at Ripon falls, few nautical miles away from Owen-falls dam through Bujagali, Isimba hydropower dams and the Karuma falls. The Kazinga channel waters which consist of River Nyamisagni and the outflows from Lake George, flows through Lake Edward to the Similiki River in the Boarder with the Democratic Republic of Congo, where the system flows back to Lake Albert. The Lake Edward-Kazinga channel areas experience teeming human activities including bad fishing practices, game and tourism activities associated with indiscriminate dumping of food refuse, poor crop and livestock farming practices that mainly encourages nutrient enrichment of water systems due to soil erosion by runoff, mining of salt in the nearby Lake Katwe and Copper and Cobalt from Kilembe mines (Graham et al., 2010).

The morphological segregation and the differences in the condition of fish from River Nile from Lake Edward follows the over 50 years of physical barriers created by the Owen-falls dam embankment along River Nile. Hydropower dam embankment creates areas of low oxygen concentration and sedimentation of suspended solid wastes at the reservoir as seen with low dissolved oxygen in this study, thus River Nile 4.20±0.8 mgL^{-1}; Lake Edward 3.54±2.32 and Kazinga channel 3.34±2.30 mgL^{-1}.

Similarly, the barrier created by the dam reservoir also exposes stranded individual fish to high fishing and environmental stress. However, following the theory of natural selection, surviving individuals in populations were induced to develop physiological and phenotypic plasticity in order to perpetuate (Swain et al., 1991; Cadrin, 2000; Lauder, 2000; Cadrin et al., 2004; Monet et al., 2006; Mir et al., 2013). Such features for survival and perpetuity amidst environmental threats according to other authors include camouflage, development of better swimming agility, conversion of somatic energy reserve to mobility, modification of morphology to aid physiological demands (Turan et al., 2005; Mir et al., 2013; Finlay and Cooper, 2015).

In the latter processes, individuals within a population grow at slower rate, hence poor condition but reach reproductive maturity at relatively smaller size as seen with individuals from Kazinga channel in this study (Njiru et al., 2006). Such physiological adaptation has also been demonstrated by other fish species. For example, it has been demonstrated that fish condition and sizes fluctuate with the intensity of fishing effort (Njiru et al., 2006). Njiru et al. (2006) recorded 21 cm TL and 22.7 cm TL for male and female Nile tilapia respectively in Lake Victoria. Balirwa (1998) reported that Nile tilapia in Lake Victoria shows signs of maturity at 25 cm TL which is higher than that reported by Njiru et al. (2006) in Lake Victoria eight years later. Bwanika et al. (2004) suggested that Nile tilapia delays maturation when living in larger lakes but breeds at younger ages when in smaller lakes and ponds.

Sharpe et al. (2012) showed that *Rastrineobolla argentea* decreased body size, maturation at smaller sizes, and increased reproductive effort (larger eggs; and higher relative fecundity, clutch volume, and ovary weight) in response to various fishing efforts and fish species diversity in Lake Victoria. Likewise, Taabu (2004) showed decrease in abundance of Nile perch with increase in fishing effort and seasons of the year in five major lakes of Uganda (Lakes Victoria, Kyoga, Edward, Albert and George).

It should further be noted that, hydroelectric power dams have been classified among barriers that change the velocity and flow regimes of water, exceeding the swimming ability of the fish, leading to confinement and isolation of stocks to restricted habitats (Noatch and Suski, 2012). Whereas *B. altianalis* is a riverine species that swim against water current, all fish have physiological limitation in their ability to move upstream against a current (Noatch and Suski, 2012). Therefore, natural or artificial zones of high-water velocity function as barriers against upstream migration of riverine fishes, denying them natal homing instinct (Leong, 1989; Noatch and Suski, 2012).

Several authors suggest that growth and therefore, condition are food limited and are widely affected by environmental conditions (Blaxter and Hunter, 1982; Arrhenius and Hansson, 1993; 1999). Winters and Wheeler (1994); Cardinale and Arrhenius (2000) observed that fish condition is inversely related to stock abundance. The latter conforms to stock status of *B. altianalis* upstream Owen Falls dam where the lowest abundance and low condition were obtained among populations. Similarly, it has been noticed that an extremely high increase in abundance of pelagic species causes density dependence in individual food intake (Cardinale et al., 2002). Aps (1985) noticed that an extremely high increase in sprat abundance in the second half of the 1950s in the Northern Baltic Sea coincided with a noticeable decrease of the asymptotic values of length and weight. This observation takes into account fish growth as being closely related to its feeding condition, which in turn, is influenced by both stock abundance and dynamics of planktonic food (Aps, 1985). Horbowy and Swinder (1989) found a linear relationship between the reciprocal of length increment and stock density as well as between the reciprocal of length increment and the ratio of stock density to food biomass.

Nevertheless, focusing on length as a measure of adult growth should be considered with caution (Winters and Wheeler, 1994). Growth in length is a trait controlled by temperature-dependent chemical processes that measures only a marginal fraction of the annual production (Beverton, 1987). Condition factor (length-specific weight) is a compensatory trait, which reflects the seasonal accumulation and depletion of energy and therefore, is a reliable index of total annual production (Winters and Wheeler, 1994). As shown by Winters and Wheeler (1994); Cardinale and Arrhenius (2000a), the length-weight relationship is the only reliable index of growth in pelagic fishes.

There was no significant difference in the condition of *B. altianalis* from Lake Edward and Kazinga channel probably due to restricted fishing activity imposed by the guidelines governing the Queen Elizabeth National Park. Additionally, whereas the water quality dynamics generates non-physical barriers, proximity of the two systems could have played a role in aiding vertical-horizontal migration of stocks and availability of food within the two systems. Chemoiwa et al. (2017) attributed the lack of morphometric variation in *B. altianalis* from Rivers Sondu-Miriu and Nyando to similarity in common food types, similar catchment activities and geographical proximity.

Deterioration in dissolved oxygen levels and the rise in carbon dioxide in water systems have been linked to degradation of catchment vegetation and pollution of water bodies (Moyini et al., 2002; Cardinale et al., 2002; Hilborn and Litzinger, 2009; Mungai et al., 2011; Noatch and Suski, 2012). Similarly, anoxic and hyperoxic aquatic systems potentially act as chemical barriers to deter fish movements through the alteration of water chemistry (Noatch and Suski 2012). Oxygen availability has long been recognized as a limiting resource to many forms of aquatic life (Kramer, 1987; Kumar, 2010), and regions of hypoxic water have been reported to negatively influence fish distribution (Pihl et al., 1991; Maes et al., 1998; Rothschild, 2000; Hasler et al., 2009; Nehemia et al., 2012). Many studies report the ability of fish to detect and avoid low oxygen gradients (Whitmore et al., 1960; Miranda and Hodges, 2000; Burleson et al., 2001), as well as high carbon dioxide (Perry and Gilmore, 2002; Seehausen, 2004).

As cultivation and human settlement intensify along the river banks and lakeshores, environmental degradation of such catchment's areas is apparently manifested in deteriorating water quality, poor stock condition and low abundance due to natural mortality. According to Ochumba and Manyala (1992), habitat alteration through anthropogenic processes caused growth of dense papyrus at the mouth of the River Sondu-Miriu in Kenya and hampered upstream migration for spawning among potamodromous fish species. Such vegetation also limited the entry of newly hatched fry into the lake from the river (Ochumba and Manyala, 1992), predisposing the fry to higher predation pressure and lack of suitable diets.

Furthermore, oxygen concentrations in water bodies are not only a measure of environmental health of the aquatic ecosystems, but are also the lifeline of the whole biodiversity. Low oxygen levels below the recommended minimum threshold of $\geq 5 mgL^{-1}$ (Boyd, 1998) as observed in this study is a threat to fish production in the natural water bodies. The levels of dissolved oxygen observed of 4.20 ± 0.80, 3.34 ± 2.30, 3.54 ± 2.32 mgL^{-1} in River Nile, Lake Edward and Kazinga channel respectively, were associated with several factors. For example, respective temperature levels of 26.52 ± 0.75, 29.04 ± 1.25, $27.24 \pm 2.91^{O}C$, conductivity of 170.38 ± 41.89, 312.47 ± 115.78, 298.06 ± 131.89 μScm^{-1} and pH above neutral would reduce the solubility of oxygen in the water column, thereby reducing re-oxygenation through mixing particularly at shallow waters (Worthington, 1930; Wetzel, 1983; Masese et al., 2012). The concentrations of dissolved oxygen obtained under this study corresponds to those reported by Hecky (1993); Talling (1966); Osumo (2001) and Kishe (2004) who found out that the water column of Lake Victoria was becoming more stable and total circulation of water was more limited with increasing depth and accumulation of both biological and chemical pollutants. However, whereas the surveyed areas had oxygen levels above 3 mg/L^{-1}, which is considered as a critical level for survival of major commercial fish species (Wetzel, 1983; Muli, 1996), this is still lower than the minimum level of 5 mgL^{-1} recommended by Boyd (1998) for fresh water fish. Dissolved oxygen levels 2-5 mgL^{-1}, implies slow growth but an optimum of about 7-8 mgL^{-1} is desirable. Similarly, 8.7 mgL^{-1} (Abowei and Hart, 2009), 5.54-7.98 mgL^{-1}(Arumlampalam et al., 1998) dissolved oxygen level ranges where documented in fresh water fisheries of the upper Gulf of Thailand and Malaysia respectively.

Conductivity of waters varied significantly among the water bodies. This shows that water in the sampled areas contained different dissolved nutrients that are responsible for carrying electric current. The highest value (312.47±115.78 μScm^{-1}), that was recorded at Lake Edward could be attributed to the autochthonous nature of the Lake and being a sediment reservoir for the Katwe salt lake and the many mineral mines, including the Kilembe copper and cobalt mines and the enrichment downstream the Rwenzori mountains.

5.2 High fishing effort- decreasing abundance

Fishing effort was significantly high across all the water bodies; however, River Nile had the highest number of fishermen, averaging 311±88. High fishing effort exerts excessive harvest pressure on stock. Some of the observable consequences of high fishing effort were reduced abundance and low relative fish condition. Coupled with high fishing effort in the system, was deterioration in water quality, across the water systems. Degenerated water quality is also a result of instability in trophic levels originating from the depletion of grazers, giving an opportunity for phytoplankton to colonize the water system. The results indicated equally high fishing effort in Lake Edward and Kazinga channel with at least 60.18±1.72 and 56.00±1.08 manual and motorized fishing boats operating an average of 63.03±19.09 multifilament gill nets in every landing site for over 14.23±1.10 hours daily.

Similarly, in Kazinga channel, over 64.95±1.55 and 59.04±2.31, motorized and manual vessels operating over 65.5±23.59 multifilament gillnets and 466.8±61.66 hooks for the same fishing duration were observed. It is also important to note that fishing boats were alternatively used by different groups of fishermen who operated in shifts between day and night especially in River Nile where the number of fishermen more than tripled that of the vessels. In Kazinga channel and Lake Edward, fishing vessels outnumbered the fishermen because being a protected area, fishing activities are restricted and also sometimes in seasons of low fish abundance, fishermen tend to diversify livelihood activities to crop cultivation, mining salt in the nearby Lake Katwe and return to fishing when catches improve.

Furthermore, the catch rates were relatively higher in Lake Edward and Kazinga channel, with each recording 6.20±1.86 and 6.85±1.49 Kg boat^{-1} day^{-1} as opposed to the lowest of (1.92±0.59 Kg boat^{-1} day^{-1}) in River Nile.
Higher abundance of *B. altianalis* in the Lake Edward basin should be treated with caution given the large number vessels, fishing gears and long fishing hours. Alternatively, fishers could be increasingly using more efficient and illegal fishing gears in the Lake to over fish, thereby setting unsustainable precedence in the management of the species (Graham, 1929; Njiru et al., 2010). The legal gillnet mesh size for the Lake Edward fishery is 5 inches (127 mm, stretched) or more, but gill nets with mesh size less than five inches were still prevalent. Banned gears like beach seines nets and monofilament gill nets were still used in the lake. Illegal fishing gears like beach seines disrupt spawners, capture immature fish, and destroy breeding areas, especially those of the substratum where *B. altianalis* lays its eggs.

In this study, the abundance of *B. altianalis* estimated was generally low but much lower upstream the Owen Falls dam at the Lake Victoria-River Nile connectivity. Because of confinement to the Owen Falls dam embankment the stocks that remained stranded could were subjected to high fishing pressure, unfavorable ecological conditions such as poor water quality and heavy predation by the Nile perch (Ogutu-Ohwayo et al., 2013). Studies elsewhere showed the potential danger of hydropower dams on migrating fish species (Gutzemer et al., 1996; Conover et al., 2006; Nguyen, 2008; Drake and Klingenberg, 2010; Ziva et al., 2012). Gutzmer et al., (1996) recorded significant reduction in the abundance of cyprinid (*Cyprinus carpio*) upstream the Niobrara River in Nebraska. In this study, higher abundance of (1.27 catch per unit effort-CPUE) was observed downstream than (0.46 CPUE) upstream. Similarly, among the many species monitored, common carp reduced from 4 down to 1CPUE in a span of a year, from 1993 to 1994 as result of dam embankment. Mass fish kills and poor condition was reported in the Mekong River due to trans-boundary impact of tributary dam development (Johnson et al., 1996; Gunawickrama, 2007; Nguyen, 2008). The activities associated with hydropower dams, such as clearing bank vegetation can lead to bank collapse, increased sediment loads in the river, clogged fish gills and blanketing of spawning grounds, as well as reduced life of downstream reservoirs. Dams reduce habitat heterogeneity, due to barriers that concentrate fish within a narrow locality hence significantly threaten fish abundance (Johnson et al., 1996; Gunawickrama, 2007; Nguyen, 2008). .

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. This study has shown apparent morphological and ecological differences between the *Barbus altianalis* stocks in the riverine and lacustrine systems.

2. *Barbus altianalis* is now very rare in the Lake Victoria- River Nile interface pointing to a stock that could have been locked upstream by the dam exposing it to high fishing pressure and low rate of recruitment.

3. Whereas morphological differences may still require more robust methods to prove, insights from relative fish condition, water quality and fishing efforts clearly demonstrate emerging ecological differences to which the different stocks adapt...

6.2 Recommendations

1. This information is therefore, relevant for development of appropriate capture fisheries and ecological monitoring policy based on periodic integrated fish condition as gauged by morphometric (Length-Weight) relationships, environmental parameters and exploitation efforts.

2. For aquaculture practitioners, fish with high relative condition factor indicates better health and probably good genetic vigor and therefore, such stocks could be better source of brood stock for captive conditioning.

3. With three more hydropower dams (Bujagali, Isimba and Karuma) coming up along River Nile, this study provides a baseline for monitoring the effects of such facilities on migratory fish stocks, but further multidisciplinary studies using integrated systemic morphometrics and meristic characters are recommended combined to other available tools, such as SNP markers, otolith chemistry, and electronic tags, to substantiate the findings from this study.

4. Finally, future investigation of fish health should avail sufficient resources to broaden the scope of investigation to include more parameters such as bioenergetics, endocrine and gonado-somatic (GSI) indices

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8.0 APPENDICES

8.1 APPENDIX I

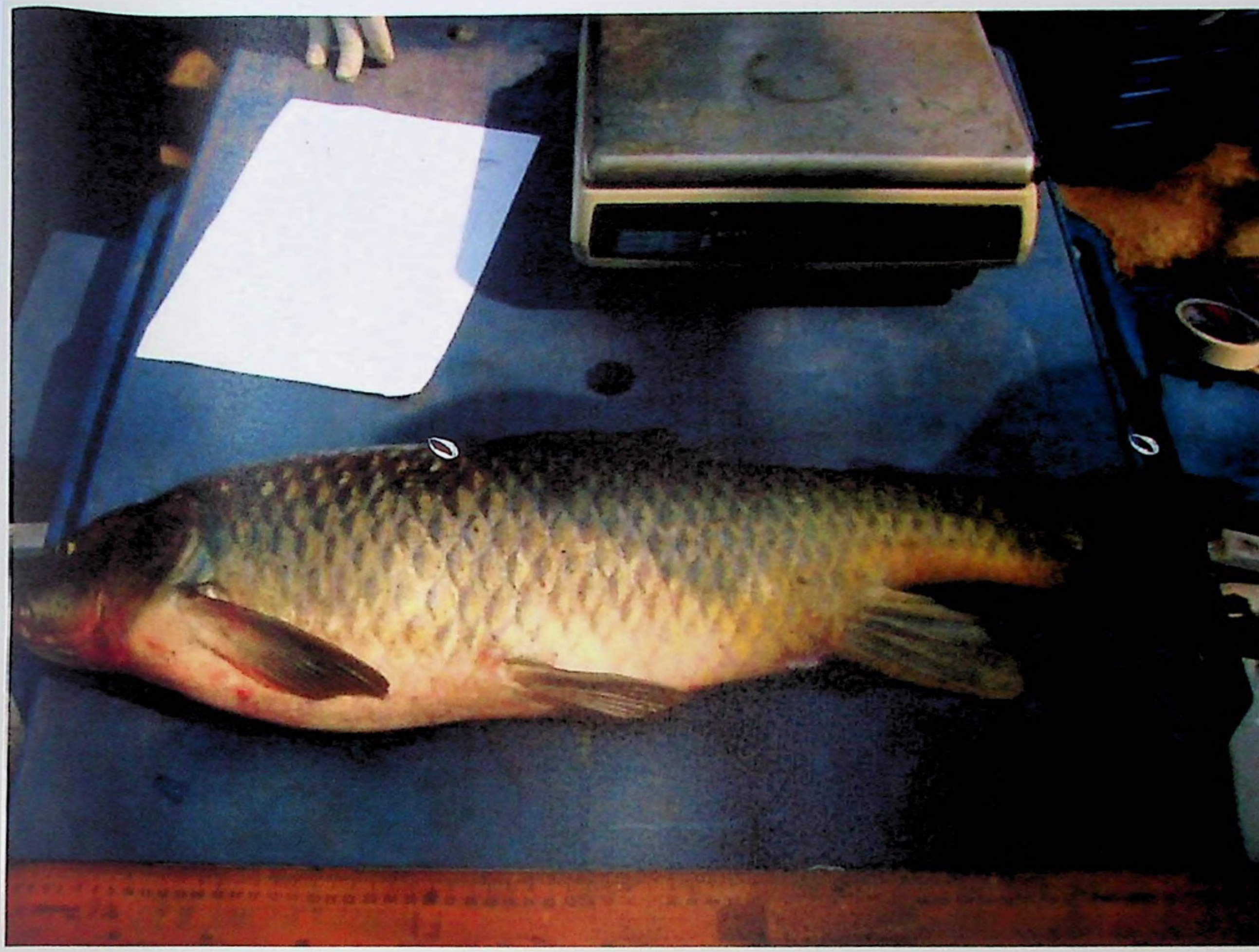
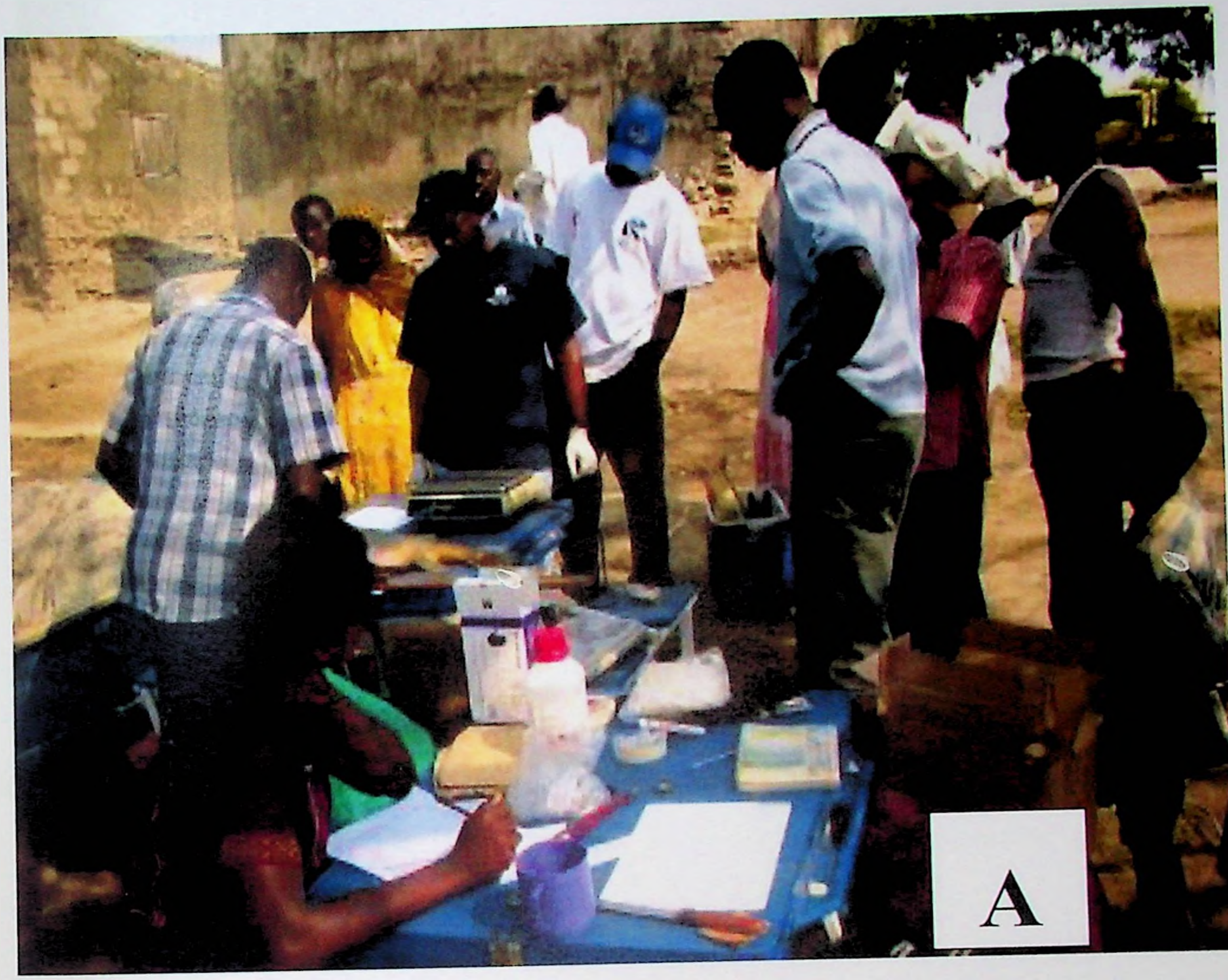


Plate 1: Specimen sample of Barbus altianalis caught from Lake Edward.

8.2 APPENDIX II

Plate 2: Two phenotypic variables of B. altianalis based on body color and orbital distance. Specimen (A) is silver grey, with elongated narrow orbital distance. (B) is yellowish with short wide orbital distance

8.3 APPENDIX III



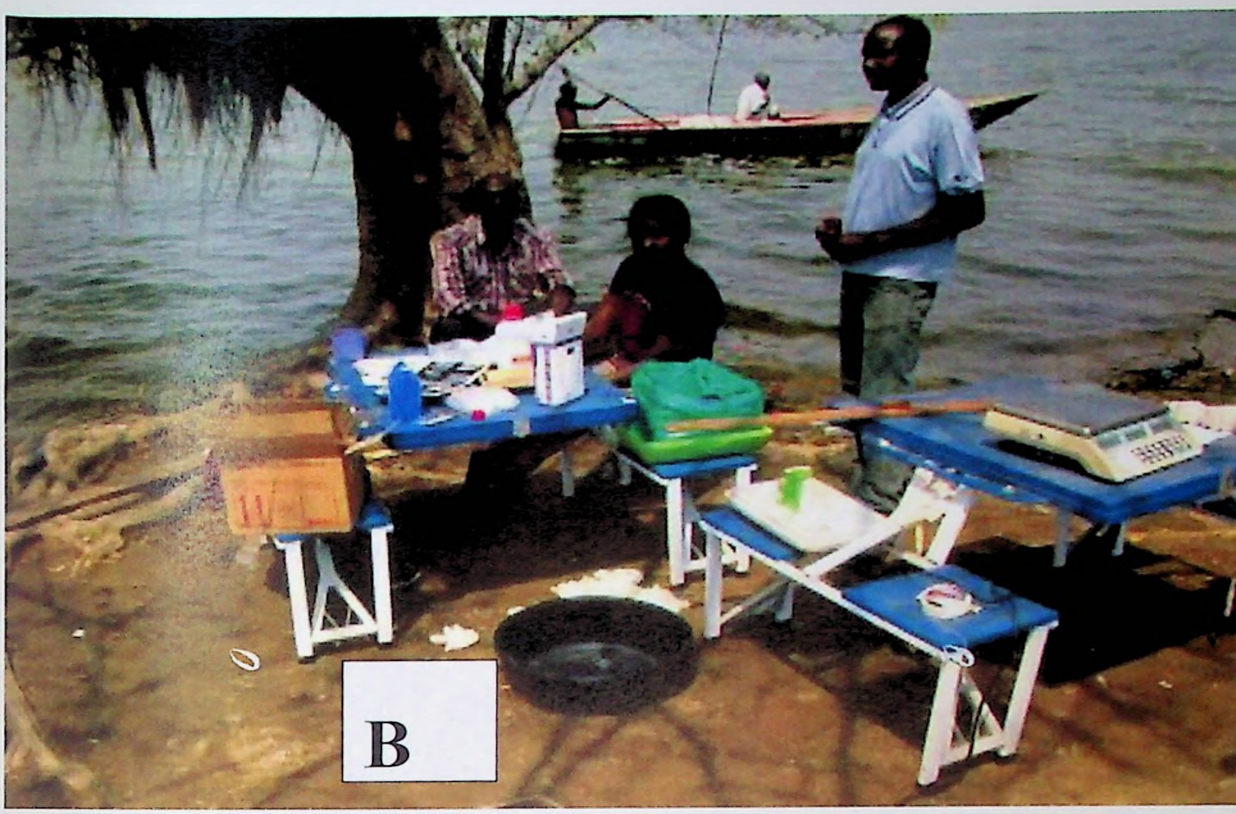


Plate 3: A and B: Field laboratory set-up for morphometric and fish condition data record.

"A" above shows macroscopic physical examination of the specimen during construction of truss dimensions. "B" below shows display of instruments and reagents used.