STUDIES ON THE REPRODUCTIVE BIOLOGY AND FEEDING HABITS OF SOME FISH SPECIES AND DETERMINATION OF SOME PHYSICO-CHEMICAL CHARACTERISTICS OF LAKE BOYO, ETHIOPIA



O. niloticus ***E. paludinosus*** ***G. quadrimaculata***

PHD DISSERTATION

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

JUNE, 2024

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DECLARATION

I hereby declare that this PhD dissertation is my original work and has not been presented for a degree in any other university, and all sources of material used for this dissertation have been duly acknowledged.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
EWNHS	Ethiopian Wildlife and Natural History Society
FAO	Food and Agriculture Organization
FCF	Fulton`s Condition Factor
FL	Fork Length
Lm50	Length at first Maturity
LWR	Length Weight Relationship
SL	Standard Length
TDS	Total Dissolved Solids
TL	Total Length
TW	Total Weight
WHO	World Health Organization

EXECUTIVE SUMMARY

Lake Boyo is among the few neglected and unexplored small lakes in the Central Ethiopian Rift Valley Region. It is a shallow and turbid lake with surface area of 3.2 square kilometres and surrounded by wetland. Three fish species are known to exist in the lake, namely Nile Tilapia *Oreochromis Niloticus* (Linnaeus, 1758), the straightfin barb *Enteromius paludinosus* (Peters 1852) and the lapping minnow *Garra quadrimaculata* (Rüppell, 1835). Neither fishery activity nor fishery research has ever been conducted so far in Lake Boyo. This research was conducted to provide baseline information on some aspects of the reproductive biology and feeding habits of fish species, and physicochemical characteristics of the lake. All the data for this study were collected and analyzed using standardized methods and sampling techniques. For the analysis of reproductive biology and feeding habits, samples of the three fish species were collected from two sites (littoral and open) of the eastern part of the lake from May 2021 to May, 2022 using gill nets of 6, 8, and 10 cm mesh size and a beach seine of 6 mm mesh size. A total of 379 *O. niloticus*, 513 *E. paludinosus*, and 290 *G. quadrimaculata* samples were examined. The water samples for the analyses of physicochemical parameters were collected from two selected sampling sites (littoral and open water area) in wet months (June to September), and dry months (October to December) of 2022.

The three fish species breed throughout the year and showed a bi-modal major and minor breeding period. The first peak breeding months occur from February to March and the second minor peak from July to September for *O. niloticus*, whereas the main breeding season for *E. paludinosus* was between October and January with a less pronounced reproductive period between March and April. On the otherhand, the first peak breeding period was from June to September and the second peak from January to February for *G. quadrimaculata*. The fecundity of *O.niloticus* ranged

from 216 to 1,157 eggs per fish while it ranged from 1,078 to 9,683 eggs per fish for *E. paludinosus*. The result of length at first maturity (L_m50) depicted that the fishes reached sexual maturity at a smaller size and shows early maturity of all the fish species in the lake. The results of the analysis of sex ratio for the fish species examined showed that the distribution of male and female fishes in the lake was not significantly different from the hypothetical 1:1(Male: Female) ratio for *O. niloticus* and *E. paludinosus* (1:0.92, $p>0.05$ and 1:1.03, $p>0.05$, respectively), while it was significantly different for *G. quadrimaculata* (1: 0.73, $p<0.05$). The results of the length weight relationship (LWR) of the fish species suggested a curvilinear relationship (R^2= 0.9911, 0.9812 and 0.9766 for *O.niloticus*, *E. paludinosus* and *G. quadrimaculata*, respectively) and, a positive allometric growth pattern (b= 3.1268 and 3.1042 for *O.niloticus*, *E. paludinosus*, respectively) while nearly isometric growth pattern (b= 2.977) for *G. quadrimaculata*. The result of Fulton`s conditon factor (FCF) for the fish species revealed that *O.niloticus* and *E. paludinosus* had moderate body condition (FCF= 1.73 and 1.77 for males and females of *O.niloticus*, respectively, and 1.21 and 1.27 for males and females of *E. paludinosus*, respectively), while it was low for *G. quadrimaculata* (FCF= 0.011 and 0.0112 for males and females, respectively).

The feeding habits of the fish species showed that the fishes feed on a variety of food items including detritus, phytoplankton, macrophytes, insects and zooplankton and they are ominivorous in their feeding habits. Detritus was the main food item for the fish species in general. The fishes showed seasonal variations in feeding habits during the dry and wet months. From these results it was concluded that the fishes are omnivorous in Lake Boyo. The results of the physical and chemical features of the lake shows that the lake water was slightly warm, alkaline, contained more TDS and EC, very turbid, low transparency and with relatively high inorganic nutrients (NO_3^- and PO_4^{3-}) which support most of the aquatic life. Generally, based on

the results it is concluded that Lake Boyo is a low productive inland freshwater ecosystem in the Ethiopian Rift Valley basin. The high amount of detritus in the stomachs/guts of the fishes and lower condition factor of the fish with reference to other lakes indicate that productivity of Lake Boyo is low. Further research is recommended on macrophyte, phytoplankton and zooplankton composition, biomass and productivity of Lake Boyo.

Key words: Condition factor, *E. paludinosus*, fecundity, feeding, *G. quadrimaculata*, growth pattern, Lake Boyo, *O. niloticus*, physico-chemical characteristics.

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background and justification

Fish plays a vital role for human beings as cheap source of highly nutritive protein (Tesfaye Wudneh, 1998) and it also provides essential fatty acids, micronutrients and minerals required by the body. It is an important source of nutrients for many populations, particularly those near larger water bodies and the coastal regions (Assefa Tesema *et al.,* 2012). Fishes are important source of omega-3 fatty acid and it is required to support an everincreasing human population, particularly in Ethiopia. Aquatic resources like fish can alleviate poverty by providing food security for the population (Zenebe Tadesse *et al.*, 1998).

The number of indigenous species and endemics (in percentage) in Ethiopia are as follows:106 (12%) in the White Nile system within the limits of Ethiopia, 64 (36 %) in the Blue Nile system (including the Lake Tana basin), 32(few) in the Atbara–Tekeze system, 79 (19 %) in the Omo-Turkana system (including Lake Turkana itself), 31 (19 %) in the Ethiopian Rift Valley and 31 (61 %) in the Wabishebele–Juba system (Golubtsov and Mina, 2003). There are also about 10 exotic fish species introduced from abroad into Ethiopian fresh waters (Shibru Tedla and Fisseha Hailemeskel, 1981). The Rift Valley is the region of Ethiopia with highest number of introduced fish species.

The freshwater fish fauna of Ethiopia contains a mixture of Nilo Sudanic, highland East African and Endemic forms (Abebe Getahun and Stiassny, 1998). The Nilo Sudanic forms are the dominant forms in terms of diversity and represented by a large number of species found in the Baro-Akobo, Omo-Gibe, Tekeze and Abay drainage basins (e.g. the genera Alestes, Bagrus, Citharinus, Hydrocynus, Hyperopisus, Labeo, Mormyrus etc.) (Abebe Getahun, 2002). These forms dominate the Nile basin fishes (Abebe Getahun, 2002). De Graff (2002) has described some of the elements of the Nilosudanic species from the Southern Rift Valley lakes (Chamo and Abaya). These include the families Mormyridae, Cyprinidae, Bagridae, Clariidae and Mockokidae.

The estimate of potential yield (94,500t/yr + 5.2% distributed as 73,100t/yr + 3.3% for lentic and about 21,400 t/yr + 11.9% for lotic ecosystems) is far above the current yield levels, suggesting substantial scope for fisheries expansion. Small water bodies in Ethiopia covered an area of 4450 km^2 and their potential fish yield to be 25,996 tones/year. However, some lakes have already shown signs of overfishing of target species, while others appear to have been grown or stable fisheries. Major challenges of the fisheries are high post-harvest loss and lack of stringent sanitary standards for assuring good quality products, and overfishing of valuable fish species in some lakes (Gashaw Tesfaye and Wolff, 2014).

The Nile tilapia *(O. niloticus*), African Catfish (*Clarias gariepinus*), Barbus species and Nile perch (*Lates niloticus*) are ecologically and economically most important species of fish among others and accounts for over 95% Ethiopia`s fishery (Zenebe Tadesse, 1998). In addition to these, *Labeobarbus* species, the common carp *Cyprinus carpio* and the crucian carp *Carassius carassius* are the most commercially important fishes in Ethiopian water bodies. Besides this, the trend of fish demand has increased over the past three decades in major cities of Ethiopia (Mathewos Temesgen and Abebe Getahun, 2016).

Lakes and rivers are very important part of our natural heritage. They have widely been utilized by mankind over the centuries to the extent that very few are now in a natural condition (Adakole *et al.*, 2008). The maintenance of healthy aquatic ecosystem is dependent on the physicochemical properties and biological diversity (Venkatesharaju *et al.*, 2010).

For optimum development and management of aquatic resources for the beneficial uses, current information is needed which is provided by water quality programmers. In addition, to benefit from lakes, it is crucial to know the characteristics of the lakes under investigation (Shinde *et al.*, 2011). Therefore, it has become mandatory to analyze at least the important water parameters when ecological studies on aquatic ecosystems are carried out (Zinabu Gebremariam *et al.*, 2002).

So far, neither fishery activity nor fishery research has ever been conducted in Lake Boyo. This was the gap of fisheries of Lake Boyo. This research was conducted to provide baseline information on the reproductive biology and feeding habits of *O. niloticus*, *E. paludinosus* and *G. quadrimaculata*. The aim of this study was to provide basic information on the reproductive biology and feeding habits of fish species, and physico-chemical characteristics of Lake Boyo suggest the wise utilization of this small water body for fish production. Lake Boyo is one of the Rift Valley lakes found in the southern part of Ethiopia that has drawn considerable attention since its fish resource and limnological aspect have not been studied before.

1.2 Statement of the problem

The fishery in Ethiopia exclusively comes from in-land water bodies and it is mainly both artisanal and subsistence. Despite the existence of high fish diversity, only few fish species are targeted and constitute the bulk of the commercial catches. The current production is still far below the estimated potential yield, which suggests scope for further expansion of fishery. Since the fish species (*O. niloticus*, *E. paludinosus* and *G. quadrimaculata*), and the physicochemical characteristics of Lake Boyo have not been studied before in the Lake Boyo, leaving a scope to conduct a study about the fish species and the physicochemical characteristics to enhance sustainable fish population. The information on the reproductive biology and feeding habits of the fish species in Lake Boyo is lacking. The limnology of some of the Ethiopian lakes is unexplored. Lake Boyo, is one of such lakes, which has not been given due attention. The inaccessiblty and small size of the lake as compared to the other big rift valley lakes of Ethiopia might be the reason for the less attention given for the lake's fishery. Studying the physicochemical characteristics of Lake Boyo would contribute to acquiring knowledge for the proper management and conservation of the aquatic resources. The lack of such knowledge about the population of the fish species and physicochemical characteristics of Lake Boyo has hindered access from gaining vital information used to ensure sustainable production of the fishes of the lake. Therefore, the present study was aimed to fill this gap with basic information about the fish species of the lake.

1.3 Significance of the study

This study will generate base line information on reproductive biology, food and feeding habits of the fish species (*O. niloticus*, *E. paludinosus* and *G. quadrimaculata*), and determine some physicochemical characteristics of Lake Boyo. The understanding of the reproductive biology would reveal the breeding season, breeding peak, and the sites of breeding of the fish species which would help to properly manage the production of the fish species and protect them from unwise exploitation. Details on size at first maturity would help to determine mesh size of the fishing gear used for catching fish and enforcing mesh regulations in capture fisheries. The nature and composition of food and feeding habits of fish provide key information on trophic relationships which would help in rational exploitation and suitable fisheries' management programs. Information on condition- factor would help in understanding the wellbeing and growth condition of the species. The physicochemical characteristics (temperature, pH, alkalinity, turbidity, nitrate, phosphate, etc.) of the lake would give crucial information for fish production. Thus, the results of this study will generally provide basic biological information vital for sustainable production and management of the fish species in Lake Boyo.

1.4 Objectives of the study

1.4.1 General objective

- ❖ To assess some aspects of reproductive biology and feeding habits of three fish species, and determine some water physicochemical characteristics of Lake Boyo.

1.4.2 Specific objectives

1. To assess the reproductive biology such as breeding season, length at first maturity, fecundity and sex ratio, and feeding habits of the Nile tilapia *O. niloticus*.
2. To investigate the reproductive biology such breeding season, length at first maturity, fecundity and sex ratio, and feeding habits of the straightfin barb *E. paludinosus*
3. To determine the reproductive biology such as breeding season, length at first maturity, fecundity and sex ratio, and feeding habits of the lapping minnow *G. quadrimaculata*.
4. To determine some physicochemical parameters of Lake Boyo.

1.5 Research questions

What is the length at first maturity, fecundity, breeding season and sex ratio of the three fish species harboring Lake Boyo?

What are the major food items consumed by the three fish species in Lake Boyo?

How do the length-weight relationship and condition-factor of the fish species are defined in lake?

How do we characterize the physicochemical characteristics of Lake Boyo?

1.6 Scope and limitations of the study

Due to remote location of the lake and difficulty to access and reach sites, the samples collected for some months were small. Even though there was budget constraints and accessibility problem, the researcher conducted the study by resisting the challenges.

1.7 Thesis outline

This work is organized in to eight principal chapters. The **first chapter** is an introductory part of the dissertation, which gives the brief outline on the background of the study, short introduction of the study area, which includes the location, climate, biodiversity, socio-economic importance and fishes of the lake. The **second chapter** deals with the review of the related literature. The **third chapter** deals with the materials and methods of the study. The **fourth chapter** discusses the reproductive biology and feeding habits of the Nile tilapia *O. niloticus*. The **fifth chapter** deals with the reproductive biology and feeding habits of the straightfin barb *E. paludinosus*. The **sixth chapter** discusses the feeding habits, size at first maturity, sex ratio and breeding season of the lapping minnow *G. quadrimaculata*. The **seventh chapter** discusses the physicochemical characteristics of Lake Boyo. Finally, the **last chapter (chapter eight)** concludes the whole work and provides suggestions for the future studies.

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CHAPTER 2: RELATED LITERATURE REVIEW

2.1 Reproductive biology

2.1.1 Determinattion of the breeding season

Fish reproduction starts with the release of unfertilized eggs by the female fish. These eggs are then fertilized by male fish as soon as possible. This process normally continues for the whole year. However, most of the fish populations have their own peak or intense breeding season. Therefore, the spawning condition of the fish is directly linked to various internal and external factors. The maturity of eggs and the breeding (spawning) season are governed by hormones, nutrition of the female and external (ecological) factors. Moreover, physiological factors like endocrine system (hormonal), fish stress, water quality, and ecological and environmental factors such as temperature, photoperiod, periodicity, water currents (tides), latitude, water depth, substrate type, hormonal influence and rain can affect the fish's migration, timing of reproduction, morphological changes, mobilization of energy reserves and courtship behaviour (Pankhurst *et al.*, 2011).

Human impacts on spawning habitats are also other factors. Fishing activity at the reproduction nursery grounds has its own effect during the spawning period for the recruitment of number and quality of newly recruited fishes to the populations. Several species use spawning substrate to lay their eggs in the pelagic zone at where they will be exposed to fishing gear. Other fish species lay their eggs on the bottom of the sediment, deposit on the gravel, attach on the plant surface and bury the eggs into the substrate; at this time using proper fishing method is critical (Harriet *et al.*, 2014).

Table 2.1 Gonad maturity stages of fishes and their descriptions (Adapted from Holden and Raitt, 1974; Nagelkerke, 1997).

Gonad stage	Testes	Ovaries
I	Immature, impossible to distinguish females from males. Gonads are a pair of transparent strings running along the body cavity.	Immature, impossible to distinguish females from males. Gonads are a pair of transparent strings running along the body cavity.
II	Unambiguously male, very small testes, white-reddish, not lobed, tube-shaped strings.	Unambiguously female, very small ovaries, tube-shaped and reddish, eggs not visible (recovery spent or developing virgin).
III	Larger testes, white-reddish, somewhat lobed starting to flatten sideways (Ripening).	Ovary somewhat larger and starting to flatten sideways, eggs visible, but very small (Ripening).
IV	Large testes, white-reddish, lobed, flattened sideways(Ripe).	Large ovary flattened sideways and almost covering body cavity wall, eggs yellowish (Ripe).
V	Large, white testes, some milt runs out when testis is cut (for *Labeobarbus* species). *This stage is marked as spent for other fish species	Large and full ovary, completely covering body cavity wall, yellowish eggs run out when ovary is cut (for *Labeobarbus* species). *This stage is marked as spent for the other fish species
VI	Large white testes, running, large amount of milt runs out when testis is cut	Running, yellow eggs can be extruded by puttingpressure on the abdomen
VII	Spent, empty testes, reddish and wrinkled	Spent, wrinkled ovary, reddish, containing a few yellow eggs

Determination of breeding season of fishes involved the use of visual examination or five-point gonad maturity stages developed by Holden and Raitt (1974). The study on the maturity stages of the gonad scales showed that their stages of development was based on their sizes and the space they occupied in the body cavity of fish (Nagelkerke, 1997). Following this precedence, gonad maturity stages are classified as immature (I), recovering spent or developing virgin (II), ripening (III), ripe (IV) and spent (V). Gonad maturity stages of the Labeobarbus fish species were given a seven-level stage (I-VII). Therefore, the breeding seasons of fishes could be estimated from the percentages of fish with ripe gonads obtained each month (Ameha *et al.*, 2006). The breeding season could be considered as the period of the year in which relatively higher proportions of fishes were in breeding condition (Elias Dadebo *et al.*, 2011).

The main breeding activity of fish species in tropical waters has been associated with factors such as light intensity, temperature, rainfall and water level or seasonal flooding. The presence of sufficient food in the aquatic environments is also important for the breeding condition of fish (Zenebe Tadesse, 1997).

2.1.2 Size at first maturity (L_m50)

L_m50 is the length at which 50% of fish attain sexual maturity for the first time (Reynolds *et al.*, 2001). The length at first capture is the length at which 50% of fish are retained and the remaining 50% escape through the mesh, or the probability of 50% of the fish being caught (King 1995). It is considered to be the length of onset of sexual maturity (Pitt, 1970). Size often plays an important role in reaching sexual maturity and reproductive success. The fastest growing individuals within a population will often reach sexual maturity the earliest (Dunham, 1990).

Maturation tends to be relatively more rapid in river fish species than in lakes as river systems are in most cases unstable, and fish; therefore, respond to unfavourable circumstances by accelerating maturation. Such behaviour is typical of species of the genus *Oreochromis* (Welcomme, 1985). Tilapia living in stressful environments often exhibits earlier maturation in life and protracted reproductive periods as a means of maximizing reproductive success and such behaviours are possibly linked to a population response towards over-fishing (Cowx *et. al.,* 2003).

2.1.3 Fecundity

The knowledge of fish fecundity has much relevance in fish population studies and in successful management and exploitation of the fishery (Crim and Glebe, 1990). In mouth brooding cichlids, fecundity is considerably low due to habits of parental care in which females protect the young in the mouth cavity for several weeks until they are able to survive on their own, therefore limited space available for rearing the young makes them produce small number of offspring at a time (Moyle and Cech, 2000). Fecundity and size of eggs are known to be affected by temperature (Donelson *et al.,* 2010).

2.1.4 Sex ratio

2.1.4.1 Sex ratio of *O. niloticus*

The sex ratios (Males: Females) of *O. niloticus* studied in different water bodies of Ethiopia were 1:3.49 in Lake Chamo (Buchale Shishitu *et al.,* 2021), 1.63:1 in Lake Hayq (Assefa Tessema *et al.,* 2019), 0.93:1 in Lake Shalla (Solomon Wagaw *et al.,* 2022), and 1:2.38 *in Lake* Ardibo (Endalh Mekonnen *et al.,* 2018). The sex ratios of the same species where male population dominate over females were reported in Lake Tana (Zenebe Tadesse, 1997) and in Lake Victoria (Njiru *et al.,* 2006).

2.1.4.2 Sex ratio of *E. paludinosus*

The sex ratio of *E. paludinosus* is most often dominated by the female fishes. For instance, in Lake Chilwa, Malawi females were more abundant than males, and the overall sex ratio is approximately 1:3 (Messias *et al.* 2009). The findings of Ngesa *et al.*, (2019) in Lake Naivasha (1:1.981), Mutia *et al.*, (2010) and Mathewos Temesgen, (2018) in Lake Langeno (1:1.24) also reveal the dominance of females over males.

2.1.4.3 Sex ratio of *G. quadrimaculata*

Sex ratio of *G. quadrimaculata* studied in different water bodies indicates that the number of females is relatively higher than that of males. For instance, in upper Awash River, Ethiopia (Bacha Temesgen *et al.*, 2023), females showed abundance over the males.

2.2 Food and feeding habits

The survival, growth and reproduction of a fish depend on the income of energy and nutrients generated by its feeding activities. Although fishes have a considerable capacity to resist starvation (Love, 1980) and many species normally cease to feed at times during their life cycle and the capacity of individuals to survive such periods depends on their ability to lay down reserves which can be mobilized when feeding ceases. The size of such reserves will reflect feeding success (Wootton, 1979).

The knowledge of food and feeding habits of fish provides answers to practical problems which arise in relation to human exploitation. The primary problems in the study of the fish feeding habits is to have broad knowledge of the different species of prey in other to understand the qualitative and quantitative breed between fish and their food organisms. Fish especially in the tropical and sub-tropical water bodies are known to experience growth fluctuation which is due to factors such as changes in environmental parameters and food composition (Obasohan *et al.*, 2012). The studies of the food and feeding habits of freshwater fish species is a subject of continuous research because it constitutes the basis for developing successful fisheries management programme on fish capture and culture (Kamal *et al.*, 2010). Food availability determines the wellbeing of fishes and their reproductive potentialities in any aquatic ecological system (Elias Dadebo *et al.*, 2014).

Studies on natural feeding of fish enable to identify the tropic relationships present in aquatic ecosystems, identifying feeding composition, structure and stability of food webs in the ecosystem (Otieno *et al.*, 2014). The information is also vital for management of the fish in the controlled environment and for formulation of the appropriate dietary given to the fish in aquaculture (Adeyemi, 2009). Therefore, understanding of its food and feeding behavior is a key factor to its successful culture in a controlled environment (Shalloof and Khalifa, 2009).

The study of fish feeding, characteristics of their feeding behaviour, effects of various environmental factors and physiological status on feeding efficiency is the basic directions of ichthyological research (Moyle and Cech, 2000). Fishes are characterized by very high diversity of species adaptations, including feeding adaptations (Wooton, 1990). The composition of the consumed food, the width and variability of the food spectrum, the way of obtaining the food and dynamics of feeding may differ. Food habits of fish are highly variable and depend on a wide range of factors including the species and age of the fish, the availability of preferred food and the combination of fish species (Antony *et al.*, 2014).

Studies on natural feeding of fishes are crucial to identify the trophic relationships present in aquatic ecosystems, identifying feeding composition, structure and stability of food webs (Abdel-Aziz, and Gharib, 2007). Food and feeding habit of fish are also important biological factors for selecting a group of fish for culture in ponds to avoid competition for food among themselves and live in an association and to utilize all the available food (Dewan and Saha, 1979).

The study of the feeding habits of fish and other animals based on analysis of stomach content has become a standard practice (Hyslop, 1980; Zacharia and Abdurahiman, 2004). Stomach content analysis is widely used in the study of fish feeding habits and provides an important means of investigating trophic relationships in aquatic communities (Zacharia and Abdurahiman, 2004). Weight and size of fish reflect food availability in the aquatic ecosystem (Olurin and Aderibigbe, 2006). According to the same authors, quantitative determination of the components of the diet, their nutritive values, and seasonal availability are the basic parts for the understanding of environmental impacts on the condition and growth of fish. Therefore, an understanding of fish diet and its influence can be essential for understanding the ecological role and the productive capacity of fish populations (Elias Dadebo *et al.*, 2014).

Some scholars stated that food and feeding habits of fish can be affected by different factors like fish size, maturity level, water volume, depth, velocity, latitude, longitude, habitat types and others (Persson and Crowder, 1998). Diversity and abundance of fish diet can also vary significantly with the water level fluctuation (Cabana, 1994). Ingestion of food items depends on the availability of food (Werner, 1988). The same species inhabiting different ecological environments may not have similar food items in their guts because of the variation in their feeding habits. For instance, small fish prefer shaded habitat as a means to escape from external predators which attack them and prefer to feed on benthic organisms (Zerihun Desta *et al.,* 2006). Some scholars also related the food composition in the gut of fish to the seasonal availability of food items in the habitat (Elias Dadebo *et al.,* 2013).

2.3 Length-weight relationship (LWR) and condition factor (FCF)

In fishery studies, the length and weight of fish can often be measured more rapidly and easily (Kara and Bayhan, 2008). The relationships between the two parameters can be used to assess the wellbeing of individual fish and the possible differences between separate stocks of the same species (Hossain, 2010). Length-weight regressions have been also used to estimate the condition factor of fishes, an index which often used to compare the wellbeing or welfare of a fish. Fish can attain either isometric, negative allometric or positive allometric growth in its life (Nehemia *et al.,* 2012). Isometric growth is the type of growth when all the body parts grow at an approximately the same rate as an organism grows. In another way, negative allometric growth is the type of growth in which fish become slender as it increases in length, but it is called positive allometric growth when fish become relatively stouter or deeper-bodied as it increases in length (Riedel *et al.,* 2007).

LWR gives information on the condition and growth patterns of fish (Bagenal and Tesch, 1978). It is a useful tool in a wide range of applications such as estimation of biomass from length data, estimation of a species condition factor and comparisons among life history and morphologic differentiations of the same species in other aquatic systems. LWR measurement is also a useful tool that provides important information concerning the structure and function of fish populations in any aquatic systems (Anderson and Neumann, 1996).

LWR of a fish species can serve as baseline information for the development of proper utilization and management schemes of fish resources of anywater bodies, because it can assist in estimating the average weight of fishes at a given length. Length-weight relationship measurement is also a useful tool that provides important information concerning the structure and function of fish populations in any aquatic systems (Anderson and Neumann, 1996). Biotic and abiotic environmental factors, genetic make-up of the fish species, and trophic status of a given aquatic ecosystem are considered as the main cause for the difference in length- weight values.

The study of LWR and condition factor of freshwater fish species is abasis for the development of a successful management program on fish capture and culture in wild and controlled environments. Hence, the information is vital for management of the fish taken from their habitats, feeding habits and species interaction under culture systems (Elias Dadebo *et al.,* 2012).

The relationship between the length (L) and weight (W) of a fish is usually expressed by the equation $W=aL^b$, where 'a' is the intercept and 'b' is the allometry coefficient. Values of the exponent 'b' provide information on fish growth. The exact relationship between length and weight of the fish species depends on their inherited body shape and within a species on the condition (robustness) of individual fish (James *et al.,* 2000). According to Safran (1992) the isometric growth (b=3) exists when the fish has unchanging body form and specific gravity as it grows older. When the value of 'b' is other than 3, weight increase is allometric (positive if 'b' >3, negative if 'b' <3). This is a useful tool that provides important information concerning the structure and function of fish populations (Anderson and Neumann, 1996). When the *b* value is less than 3, the fish has a negative allometric growth but when it is greater than 3, it has a positive allometric growth and when it is equal to 3, the fish has isometric growth (Khairenizam and

Norma- Rashid, 2002). Change of *b* values depend primarily on the shape and fatness of the fish species as well as physical, chemical and biological factors such as temperature, salinity, food, stomach fullness, sex and stage of maturity (Sarkar *et al.,* 2013).

FCF is the volume of fish relative to its length and taken to mean the well-being degree of an individual fish respect to its habitat where it lives so as to understand how well a given habitat supports life of an individual in terms of nutritional requirements and other environmental conditions (Weatherly, 1987). It is a measure of various ecological and biological factors, such as the degree of fitness, gonad development and the suitability of environment (Weatherly and Gill, 1987).

The role of the condition indices as stated by Stevenson and Woods (2006) is to quantify the health of individuals in a population or to tell whether a population is healthy relative to other populations. FCF is used in studies of fisheries' biology to indicate the degree of fish stock well-being in the environment in which they live and to verify if they make good use of the foods available (Weatherly, 1987). FCF is an important index reflecting interaction between biotic and abiotic factors in the physiological conditions of fishes. Hence, the condition factor may vary among fish species in different locations (Blackwell *et al.,* 2000). This factor is also used as an index of growth and feeding intensity (Seher and Suleyman, 2012). Condition factors of ≥1 indicate a good level of feeding and proper environmental conditions (Ujjania *et al.,* 2012).

Condition factor (the coefficient of body condition) is a good parameter that shows the wellbeing of fishes in their natural habitats or in aquaculture, because it indicates different biological and ecological factors in relation to the fishes' feeding habits (Nehemia *et al.,* 2012). However, condition factor is also influenced by stress, sex, season, availability of food and the water quality in the environment in which the fishes live. Better body condition is correlated with high values of condition factor and poor body condition is obtained when the values of condition factor is less (Gupta and Tripathi, 2017). The health of water bodies, in relation to pollution, can also be detected with the mathematical approach of the LWR and condition factor (wellness) of the fishes as these variables are directly affected by any water polluting substances (Kumar *et al.*, 2017). Condition factor has been generically described as the well-being or robustness of an individual fish (Blackwell *et al.*, 2000) and has typically been estimated by comparing individual fish weight of a given length to a standard weight.

According to Medri *et al.*, (1990), different environments have influence on the well-being of fish. For instance, the development of tilapia in a habitat can be determined by total biomass, increase in length and weight, and the condition factor of fish in tropical freshwaters varies with seasons and breeding periods. Starvation during breeding and dry seasons causes fish to lose condition factor. Studies on Tilapia zillii in River Niger (Weatherly, 1987) showed little variation in weight over dry seasons but remarkable reduction during breeding periods. Sexual differences, age, changes in seasons, gonad maturity levels, nutritional levels and maturity of fishes can influence the condition factor (K) value (Kotos, 1990).

The study of condition factor assumes that heavier fish of a given length are in better physiological condition (Bagenal and Tesch, 1978). Generally, the measure of fish condition can be associated with the general health of fish, prey or food availability, reproductive potential, environmental conditions and water level fluctuations (Zeleke Berie, 2007). Moreover, the higher condition factor is associated with the higher energy (fat) content; increased food base, reproductive potential, or more favourable environmental conditions (Pauker and Roger, 2004). Various factors including temperature, number and availability of prey, life history and reproductive style play crucial roles for the development of fish gonads (Pankhurst and Munday, 2011).

2.4 Physico-chemical characteristics

2.4.1 Physical characteristics

The physical and chemical properties of water greatly influence the distribution and richness of biota (Zinabu Gebremariam, 1994). A property such as high dissolved oxygen in water is an essential pre-requisite for satisfactory aquatic life (Yezbie Kassa, 2016). The techniques of using physical and chemical properties to assess water bodies are essential. They also reveal the concentrations of known environmental contaminants which could render such water unfit for human consumption and other purposes (Venkatesharaju *et al.*, 2010).

Water quality deals with the physical, chemical, and biological characteristics in relation to all other hydrological properties (Aminu *et al.*, 2017). The quality of water in any ecosystem provides significant information about the available resources for supporting life in that ecosystem and it provides the basis for judging the suitability of water for its designated uses and to improve existing conditions (Shined *et al.*, 2011). The quality of water generally refers to the component of water present at the optimum level for suitable growth of plants and animals. Aquatic organisms need a healthy environment to live and adequate nutrients for their growth; the productivity depends on the physicochemical characteristics of the water body (Verma *et al.*, 2012). The maximum productivity can be obtained only when the physical and chemical parameters are present at optimum level.

Water quality parameters such as temperature, turbidity, nutrients, hardness, alkalinity, dissolved oxygen, etc. are some of the important factors that determines the growth of living organisms in the water body (Smitha, 2013). The important water parameters influencing the aquatic ecosystem are temperature, pH, total solids, dissolved oxygen and nutrient content; and these parameters are the limiting factors for the survival of aquatic organisms (Lawson, 2011). Therefore, water quality assessment involves the analysis of physico-chemical, biological and microbiological parameters that reflect the biotic and abiotic status of the ecosystem (Verma *et al.,* 2012). Dissolved oxygen is one of the important water quality parameters that determine the dynamics of the biota in natural waters because it is a regulator of metabolic processes. In tropical water bodies vertical distribution of dissolved oxygen shows a progressive decrease from water surface to the bottom (Beadle,1981) and the surface water is kept with higher values due to oxygen diffusion at the air-water interface (Wetzel,1983).

Fish populations are highly dependent upon the variations of physicochemical characteristics of their aquatic habitat which supports their biological functions (Ojutiku and Kolo, 2011; Mushahida-Al-Noor and Kamruzzaman, 2013). Among the physicochemical factors, temperature, dissolved oxygen, pH, turbidity, water transparency and current among others, and their regular or irregular fluctuations, have been identified as determinants in riverine fish ecology (Thirumala *et al.,* 2011; Mushahida-Al-Noor and Kamruzzaman, 2013). Marshall and Elliot (1998), noted significant correlations between a number of individual fish species and water temperature, salinity, dissolved oxygen and depth.

Temperature

Temperature influences metabolic rates, reproductive cycles, and oxygen solubility. Extreme temperatures can lead to stress or mortality in fish. Standard range of temperature for fish varies by species; generally it is between 15^{o}C-25^{o}C for most freshwater fish (Cech, 1990). It plays an important role for controlling the physico-chemical and biological parameters of water and considered as one among the most important factors in the aquatic environment particularly for freshwater (Singh and Mathur, 2005). Temperature plays a crucial role in the feeding and reproduction of fish species in freshwater bodies. It is critical factor in the reproductive success of fish species, hence, influences the timing of spawning, egg development, and larval survival. It also influences the metabolic rate of fish, which inturn affects their feeding behavior. In general, as temperature increases, the metabolic rate of fish also increases, leading to higher energy requirements for growth and maintenance.

Studies have shown that *O. niloticus* exhibit increased feeding activity at higher temperature due to the acceleration of their metabolic processes (Jobling, 1981). Conversely, extremely high or low temperatures can negatively impact the feeding behavior of fish, leading to reduced appetite and growth rates (Brett and Groves, 1979). *O. niloticus* exhibit optimal reproductive performance within a specific temperature range. For example, temperatures between 25-30^{o}C are considered ideal for spawning and egg development in *O. niloticus* (El-Sayed, 2006).

E. paludinosus shows temperature-dependent feeding behavior. Studies indicate that *E. paludinosus* displays optimal feeding rates at tempertures ranging from 22-26^{o}C, where their metabolic processes are most efficient for nutrient assimilation and growth (Froese and Pauly, 2021). Extreme fluctuations outside the ideal range can affect the feeding behavior of *E.*

paludinosus, leading to changes in appetite and growth patterns. Temperature also influences the reproductive biology of *E. paludinosus.* The species requires specific temperature conditions for successful spawning, egg development, and larval survival. Optimal reproductive performance in *E. paludinosus* is typically observed within a temperature range of 24-28^{o}C (Balon, 1987). Deviations from this range can impact the timing of spawning events and reduce egg viability.

The feeding activity of *G. qudrimaculata* is influenced by temperature, with optimal feeding rates observed within a specific temperature range. Studies have shown that *G. qudrimaculata* exhibit increased feeding activity at temperatures between 20-25^{o}C, which corresponds to their metabolic requirements for growth and maintenance (Froese and Pauly, 2021). Extreme temperatures outside the optimal range can disrupt the feeding behavior of *G. qudrimaculata*, leading to reduced appetite and growth rates. Reseach suggests that *G. qudrimaculata* exhibit successful spawning and egg development within a temperature range of 22-28^{o}C (Liu *et al.,* 2014). Deviations from this optimal range can result in reduced reproductive success poor egg viability. Understanding the optimal temperature range for feeding and reproduction is crucial for management and conservation of fishes in freshwater bodies.

pH

The pH of natural waters is kept constant by the carbon dioxide, bicarbonates and carbonate systems. It usually decreases with increasing depth possibly due to increase in amount of decomposition. High production of carbon dioxide in the bottom waters by the aerobic decomposition coupled with some reducing substances in the mud causes relative decrease in pH values (Wetzel, 1983).

pH affects the solubility of nutrients and metals, which can be toxic to aquatic life at extreme levels. Fish generally thrive in neutral to slightly alkaline conditions with the standard range of pHvalue 6.5 to 9.0 (EPA, 2001). Other studies have also determined that fish move away from alkaline waters when pH levels approach 9.06-10.0, unless more important survival factors outweigh avoidance, including food availability or lower predation levels (Scott *et al.*, 2005).

The optimum pH for the feeding and reproduction of fish species in freshwater bodies can vary slightly depending on the specific species. The optimum pH range for *O. niloticus* is typically between 6.5 and 9.0. According to a study by El-Sayed (2006), *O. niloticus* performed best in terms of growth and reproduction at a pH range of 7.0-8.5. The optimum pH range for *E. paludinosus* is generally between 6.0 and 8.0. While specific studies on the pH of this species are limited, it is known that they prefer slightly acidic to neutral water conditions.

The optimum pH range for *G. quadrimaculata* is is typically between 6.5 and 8.0. A study by Vishwanath and Shanta (2010) found that *G. quadrimaculata* exhibited optimal growth and reproduction at a pH range of 7.0-7.5.

Electric conductivity (EC)

According to Environment Canada (2001) the standard range for EC is 50 - 1500 µS/cm for most freshwater fish. High electrical conductivity indicates high levels of dissolved salts, which can affect osmoregulation in fish. The optimum range of electric conductivity for fishes inhabiting fresh water bodies vary depending on the specific requirements of the species. Studies have shown that *O. niloticus* can tolerate electric conductivity levels ranging from 100 to 800 µS/cm for optimal feeding and reproduction (El-Sayed, 2006). *E. paludinosus* is generally recommended to maintain electric conductivity levels below 500 µS/cm to support the feeding and reproduction in freshwater bodies (IUCN Red List, 2021). Electric conductivity for *G. quadrimaculata* is generally advisable to keep levels below 800 µS/cm to ensure optimal feeding and reproduction condition (Kottelat and Freyhof, 2007).

Turbidity

Turbidity refers to the cloudness or haziness of water caused by suspended particles, can also affect the feeding and reproduction of fish species. High turbidity can reduce light penetration, affecting photosynthesis and habitat quality for fish. It can also carry pollutants. According to New Zealand Ministry for the Environment, (2001) the standard range is <5NTU for optimal conditions; >25 NTU can be harmful.

The optimum turbidity range for *O. niloticus* can vary but generally falls between 10-100 NTU. According El-Sayed (2006), *O. niloticus* can adapt to a range of turbidity levels, but they tend to thrive in waters with moderate turbidity. The optimum turbidity range for *E. paludinosus* is usually between 5-30 NTU. While specific studies on the turbidity requirements of this species are limited, they are generally found in waters with low to moderate turbidity levels. The optimum range of turbidity for *G. quadrimaculata* is typically between 10-50 NTU (Nephlometric Units). A study by Vishwanth and Shanta (2010) found that *G. quadrimaculta* prefer moderately clear waters for feeding and reproduction. Maintaining optimal turbidity levels is crucial for the well-being and reproductive success of fish species as it can impact their feeding behaviour, visual acuity, and overall health. Monitoring and controlling turbidity within the recommended ranges can help support the growth and sustainability of fish populations in freshwater environments.

Total dissolved solids (TDS)

TDS is an important water quality parameter that can impact the feeding and reproduction of fish species. According to WHO (2011), the standard range of TDS is 100 to 500 mg/L for most freshwater species; levels above 1000 mg/L can be harmful. High TDS can indicate pollution and affect aquatic life through osmotic stress.

The optimum TDS range for *O. niloticus* is generally 200-1000 mg/L. According to the study by El-Sayed (2006), on tilapia culture, *O. niloticus* can tolerate a wide range of TDS levels but perform best within this range. The optimum TDS range for *E. paludinosus* is typically 100-300mg/L. While specific studies on the TDS requirements of *E. paludinosus* are limited, they are known to prefer low to moderate TDS levels in their habitat. The optimum range of TDS for *G. quadrimaculata* can vary, but generally falls between 100-500 mg/L. A study by Vishwanath and Shanta Kumar (2010) on the breeding biology of the species in the Cauvery River basin, Karnataka, India, indicated that they thrive in waters with moderate TDS levels.

2.4.2 Chemical characteristics

Major algal nutrients (nitrate, phosphate)

Nitrate

According to EPA (2013), the standard range for nitrate is <10 mg/L for protection of aquatic life; levels above this can lead to eutrophication and harmful algal blooms. Excessive nitrates can result in hypoxia and dead zones in aquatic environments, harming fish popultions.

With increasing agricultural and industrial activities, eutrophication has become one of the most serious environmental problems affecting freshwater lakes and reservoirs (Fisher *et al.*, 1995).

Nitrate and phosphate are essential nutrients for aquatic organisms, but excessive levels can lead to water quality issues and negatively impact fish health and reproduction.

Phosphate

According to Canadian Council of Ministers of the Environment (CCME, 2004), the standard range for phosphate is <0.1mg/L for protection of aquatic ecosystems; higher concentrations can lead to eutrophication. Similar to nitrates, elevated phosphate levels can trigger algal blooms that deplete oxygen levels in water, negatively impacting fish.

O. niloticus requires adequate levels of nitrate and phosphate for optimal growth and reproduction. Studies have shown that nitrate levels between 0.5 to 10mg/L and phosphate levels of 0.05 to 0.5 mg/L are considered suitable for Nile tilapia aquaculture (FAO, 2011). *E. paludinosus* is also sensitie to nitrate and phosphate levels. It is generally recommended to maintain nitate levels below 10mg/L and phosphate level below 0.5 mg/L to support the feeding and reproduction of *E. paludinosus* in freshwater bodies. *G.quadrimaculata* requires balanced nutrient levels for optimal health and reproduction. It is advisable to keep nitrate levels below 10 mg/L and phosphate level below 0.5 mg/L to ensure a suitable environment for *G. quadrimaculata*. In conclusion, maintaining nitrate levels between 0.5 mg/L and phosphate levels between 0.05 to 0.5 mg/L is likely to be suitable for the feeding and reproduction of *O. niloticus*, *E. paludinosus* and *G. quadrimaculata* in freshwater bodies.

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CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the study area

Lake Boyo (Figure 1) is among the least explored few lakes in Central Ethiopian Rift Valley Region. Lake Boyo is located in Central Ethiopia Regional State, Hadiya Zone, Shashogo district, about 230 km away from Addis Ababa, the capital city of Ethiopia, and 50 km north of Hosaena town, the capital of Hadiya Zone. It is located in SNNPRS 7^{0}29'N, 38^{0} 03 E' at an altitude of 1880m asl (EWNHS, 1996). It is a shallow and turbid lake surrounded by wetland (roughly the area in wet season is 140 ha) and shrinks to 80 ha in dry season. Annual rainfall is 1500 mm. It is an open lake that has two main inflows (Guder River and Wera River) and outflow (Merancho River). River Bilate drains the area along the southeast to join at an easterly point on the edge of the wetland (Yilma Delelegn, 1998; Hadis Tadele, 2018). This lake is part of the Bilate River basin that drains from the Gurage highlands and flows down southwards into Lake Abaya (EWNHS, 1996).

The surrounding highland areas especially those in the western and southern parts of the wetland are the major feeders or sources of flooding. The surrounding hills and mountains are intensively farmed, where deforestation rate is very high, increasing every year. Therefore, sediment load in the wetland from these highland mountainous areas is significantly high, making the wetland highly turbid (Hadis Tadele, 2018).

The climate around Lake Boyo is generally characterized by warm, wet rainy season (most of the rainfall occurring from June to September) and dry, cold and windy dry season (from December to March). Maximum temperature of the area reaches 27.4ºC during the warmest month, April and minimum of 13.6 ºC in the coldest month, December. As a result, the area can be characterized as a semi-arid climate with a long rainy season. The lake is surrounded by farmlands and human settlements. The map of Lake Boyo is shown in figure 3.1 below.

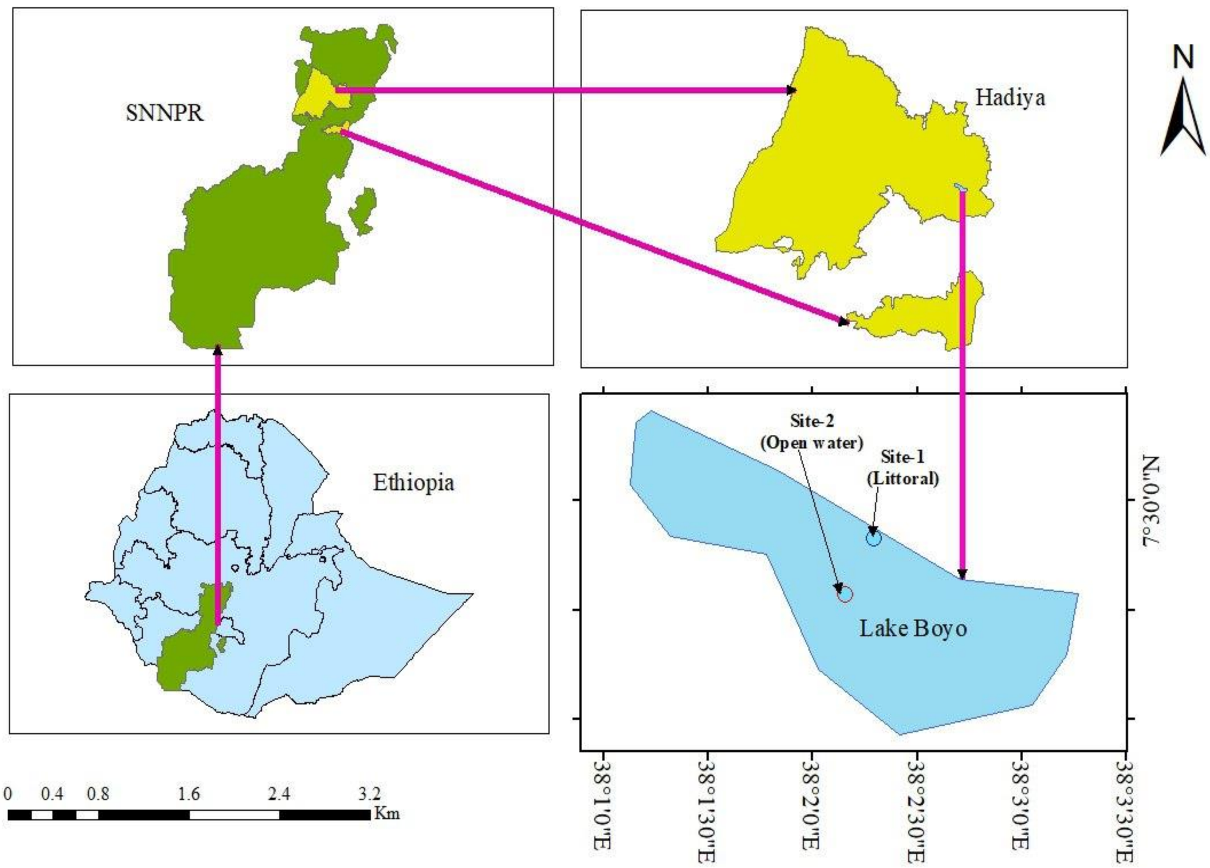

Figure 3.1 A map showing geographic location of Lake Boyo

During the wet season in August and September, the whole area of the wetland becomes flooded and the water level rises, causing huge area of farmlands and a number of houses submerged. Mostly, the farmland areas to the north, south and west of the wetland become submerged. During the peak dry season, a large part of the wetland dries out and changes to a vast area of grassland used for grazing by local communities living around the wetland. The lake is surrounded by hills and mountains; Bele Mountains to the north, northwest and west as well as Ambericho Mountain to the southwest. The small town of Doesha is located along the northeast and Bonosha town to the east. Cultivation and human settlements on the lower altitude are found along the four directions of the wetland.

Excessive land degradation, deforestation and irrigation resulted in vast sedimentation, and increase in soil salinity (Dagnachew Legesse and Tenalem Ayenew, 2006). Boyo wetland also suffers vast from human induced factors affecting its long-term survival. Rapidly growing human population is the main factor where people are increasing settlements to the surrounding wetland, especially people settling to the western and northern parts. The problem of soil erosion and siltation has also a substantial impact on the continuity of the wetland, where soil from the surrounding hills is being washed away to the wetland during the rainy season.

Fauna and flora

The wetland around Lake Boyo is surrounded by farmlands, human settlements and scattered patches of plantations of *Eucalyptus globulus*. In the surrounding farmlands, there are scattered trees of *Ficus vasta* and *Acacia spp*. The wetland is dominated by *Eriochloa fatmensis* and *Eriochloa meyeriana* grasses, which are important for cattle grazing, and *Typha angustifolia*, which is used for thatching of huts. *Aeschynomene elaphroxylon* is also present in the wetland, which local people use as firewood. In terms of fauna, the area was known to harbor a large number of Hippopotamus (*Hippopotamus amphibius*).

Boyo wetland is known as one of the 69 important bird areas of Ethiopia (Yilma Delelegn, 1998; Hadis Tadele, 2018). It supports a high concentration of water birds estimated to exceed 20,000. The wetland is one of the best wintering areas for wattled cranes (*Bugeranus carunculatus*), Common cranes (*Grus grus*), Black crowned cranes (*Pavonina pavonina ceciliae*), Egyptian geese

(*Alopochen aegyptiacus*) and Spur-winged geese (*Plectropterus gambensis*). In addition, this wetland is known as breeding ground for Black crowned cranes (*Pavonina pavonina ceciliae*) and Egyptian geese (*Alopochen aegyptiacus*) Ethiopia (Yilma Delelegn, 1998; Hadis Tadele, 2018).

Human population

Lake Boyo is bordered by more than 10 Kebeles (farmer associations). People from these Kebeles directly or indirectly use the wetland to graze their cattle, to cut grass either for traditional house construction or for their cattle as fodder, collect firewood and fetch water for their household use. According to the data from the district office, the wetland is surrounded by a population of more than 42,014 individuals (22,079 males and 19,935 females). Surrounding the wetland, more than 99% of the people are farmers, where they depend on subsistence agriculture (crop farming and cattle rearing). Major crops grown around the wetland are maize (*Zea mays*), wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*), teff (*Eragrostis tef*) and green chilli (*Nahuati chilli*).

3.2 Fish species selection and sampling

The fish species for this study were selected after setting the gill nets and the beache-seine several times in the lake in different sites to collect the fish species. The lake being with no fishery activity and no study conducted before, it was very difficult even to know which fish species were harboring in the lake. Furtunately, the three fish species (*O. niloticus*, *E. paludinosus* and *G. quadrimaculata*) were caught by the fishing gears in the sampling sites of the lake after several time efforts, and then after the identification of the fish species took place.

Samples of the three fish species were collected from the eastern part of the lake, from the littoral and open lake sites for 13 months from May 2021 to May 2022 using gill nets of 6, 8, and 10 cm mesh size and a beach seine of 6 mm mesh size. A total of 379, 513, and 290 specimens of *O. niloticus*, *E. paludinosus*, and *G. quadrimaculata,* respectively were collected from the lake. Total length (TL), fork length (FL) and standard length (SL) of each fish sample was measured using a measuring board to the nearest millimeter. Total weight (TW) of all fish samples was also measured to the nearest 0.1 g using Scaltec Digital balance. Then, the fish samples were dissected and sex and sexual maturity stages of each fish were determined by visual examination of the gonads and by using a five-point maturity scale (Holden and Raitt, 1974). The fish were categorized as immature (I), developing virgin or recovering spent (II), ripening (III), ripe (IV) and spent (V) based on the characteristic features of the gonad stages. Soon after the collection, the specimens of ripe female gonads were measured to the nearest 0.1 g using Scaltec digital balance. Ripe female ovaries were preserved in 5% formalin solution for further fecundity estimation.

3.3 Methods for studying reproductive biology of fish species

3.3.1 Breeding season determination

The breeding season of the fish species *(O. niloticus, E. paludinosus and G. quadrimaculata)* was determined following the five point gonad maturity stages developed by Holden and Raitt (1974) and Nagelkerke (1997). The monthly frequency of the various gonad stages was plotted by month to determine breeding periods.

Descriptive statistical procedures (percentages and mean) were used to describe and summarize the data obtained from sex ratio, size at first maturity and fecundity of *O. niloticus, E. paludinosus* and *G. quadrimaculata*. Tables and figures were used to illustrate the data obtained through analysis. Chisqure test was carried out to compare the indices of the relative importance of the parameters included in the study. Regression analysis was used to determine the relationship between total length and fork length and total length and standard lengths of the fish species. The relationships between total length and toal weight and the relationship between fecundity and some morphometric measurements of the fish (total length and total weight) were also determined using regression analysis.

3.3.2 Method for estimation of length at first maturity (L_m50)

The length at first maturity was estimated as the total length class at which 50% of all the individuals were sexually mature following Njiru, *et al.*, (2006) procedures. The fish samples in the maturity stage I and II were therefore considered immature and those in stages III, IV and V considered mature for the purpose of calculating L_m50 (Njiru *et al.*, 2006). The L_m50 was determined by grouping the ripe stage III, IV and V males and females separately into 2 cm length class interval. The resulting cumulative frequency was subjected to logistic curve function (the S-shape curve) and the length where 50% of the individuals fall was determined for both males and females. The average L_m50 of both sexes of the fish species was determined from the percentages of mature fish that are grouped in a 2-cm size classes as described by the logistic function (Echeveria, 1987).

$$P = 1/ (1+ e^{(\alpha+\beta L)})$$

Where P = estimated proportion of mature fish, L= total length in centimeters, and α and β are coefficients. Equation (1) can be transformed into logarithmic form as indicated below:

$$Ln\ (1-P/P) = \alpha - \beta L \qquad (2)$$

From the above linear regression relationship, the size at first sexual maturity (Lm50) of both sexes was estimated as $Lm50 = -\alpha/\beta$.

3.3.3 Determination of fecundity

The actual number of mature eggs in the ovaries was counted to determine the fecundity of the fish species. Fecundity was estimated from total counts of eggs in the ovaries of fish in the most advanced state of development (Njiru *et al.*, 2006). Ripe ovaries of stage IV were used for the fecundity estimation. Accordingly, total fecundity of *O. niloticus* was determined by counting all the eggs in the ovaries by using the total count method whereas fecundity of *E. paludinosus* was determined by using gravimetric method by counting a known weight of ovary (1 gram) and extrapolating the absolute fecundity by multiplying by the total ovary weight. The relationship between fecundity and some morphometric measurements was determined by relating to gonad weight (GW), total length (TL) and total weight (TW) total fecundity (F) to TL) and TW using the following formulae as of Crim and Glebe, 1990:

$$F = a \times GW^b \qquad (3)$$

$$F = a \times TL^b \qquad (4)$$

$$F = a \times TW^b \qquad (5)$$

Where *a* and *b* are parameters of the fitted line.

3.3.4 Determination of sex ratio

The actual number of fish whose sexes were successfully determined was considered for sex ratio. The sex ratio was expressed as the ratio of number of males to females. Sex ratio of the fish species was determined by calculating male to female ratio at different months of the year and at different sizes of the fish dividing the number of female fishes by that of male fishes (Vazzoler, 1996). The significant deviations from the hypothetical 1:1 ratio were determined using Chi-square test at $P < 0.05$ significance level.

3.4 Determination of food and feeding habits of fish

Stomach content analysis was conducted in the Fishery Laboratory of the Department of Aquatic Sciences, Fisheries and Aquaculture, Hawassa University. In the laboratory, the stomach contents were emptied into a petri dish to identify each prey (food) item. Food items were identified using a dissecting microscope (Leica, MS5, magnification-10x) and a compound microscope (Leica DME, magnification-100x). The relative importance of each food item was determined using frequency of occurrence and volumetric analysis methods (Hyslop, 1980; Bowen, 1983). In frequency of occurrence, the number of stomach (gut) samples containing one or more of a given food item was expressed as a percentage of all non-empty stomachs (guts) examined. The proportion of the population that fed on certain food items was estimated by this method. Frequency of occurrence of the different food categories during the dry and wet seasons were compared using a Chisquare test. Since *E. paludinosus and G. quadrimaculata* have no distinct stomachs, contents of the gut up to the first bend were taken and the gut contents were examined and prey items were identified under a dissecting (LEICA MS5) and compound (LEICA DME) microscopes.

In volumetric method of analysis, the volume of the food items that were found in the stomach was sorted into different categories and the volume of food items was measured using a partially graduated cylinder (Bowen, 1983).

The FCF was used to determine the condition of fish in their respective habitats. The individual total lengths and total weights recorded were used to determine the condition factor of *O. niloticus, E. paludinosus* and *G. quadrimaculata*. Condition factor (K) was calculated from the formula $K = W/L^3 X 100$, where W = weight of an individual fish specimen, L = total length of fish.

3.5 Methods for determination of physico-chemical characteristics of lake water

3.5.1 Water sampling site selection and sampling

For the analysis of physico-chemical characteristics of the lake, routine water sample collections were carried out in dry and wet seasons from the two sampling sites. Site 1 was littoral (Allage Gimbichu) where high human impact was expected, as it is close to the edge of the lake and site 2 was in the open water site (Woldaya), a relatively protected from direct human impacts. The waste from domestic animals and household disposals, and other related agricultural by-products cannot easily reach the center of the lake especially in the dry season where no flood carries the waste matter from the watershed. Water samples were collected from the lake from June to September (wet season) and October to December (dry season), 2022. Measurements were taken during the morning hours between 8:00 and 11:00 am from the two study sites from the lake surface with the depth of 10-20 cm. Water samples for the analysis of water physico-chemical chacteristics in the laboratory were carried in opaque 1L plastic bottles and chilled in the icebox on site and transported to the Water Quality Laboratory of Hadiya Zone Water, Minerals and Energy Office for chemical analysis.

3.5.2 *In-situ* measurement

In-situ measurements of temperature, electrical conductivity, and pH were carried out using a portable multimeter (Model HQ 40d Multi Hach Lange) at different depths within the euphotic area. TDS was calculated from the relationship of electrical conductivity for compatibility using the formula TDS=0.6 EC (Glenn, 2005). Turbidity of the lake water was measured using a portable digital turbidimeter (Model Oakton: T-100). EEPA (2003) Guideline Ambient Environment Standard for Ethiopia was used to determine the physico-chemical characteristics of the lake water.

3.5.3 Laboratory measurements and analysis methods

In the Laboratory, total alkalinity was determined from 100 ml of the unfiltered water sample taken from the surface by titration with 0.1N HCl with bromocresol green used as endpoint indicator (Wetzel and Likens, 2000). The major dissolved inorganic nutrients (nitrate-NO_3^-, and phosphate- $PO4^{3-}$) were determined using the standard method of APHA (1995).

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CHAPTER 4. REPRODUCTIVE BIOLOGY AND FEEDING HABITS OF THE NILE TILAPIA *Oreochromis niloticus* Linnaeus, 1758 (PISCES: CICHLIDAE) IN LAKE BOYO

Abstract

The Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758) is one of the most economically important fish species in the inland water bodies of Ethiopia. The objective of this study was to obtain baseline scientific information on its reproduction and feeding habits of the fish from Lake Boyo, Ethiopia. Monthly samplings were conducted in the lake, from May, 2021 to May, 2022. A total of 379 (197 males and 182 females) samples of *O. niloticus* were collected from the lake using gill nets of 6, 8, and 10 cm mesh size and beach seine of 6 mm mesh size to collect data on reproductive biology and feeding habits of the fish. The sex ratio (Male: Female) was 1: 0.92; ($p > 0.05$). Length at first sexual maturity (L_m50) was 10.0 cm (TL) for males and 7.7 cm (TL) for females. Fecundity ranged from 216 to 1,157 eggs per fish. *O. niloticus* breeds throughout the year with two breeding peaks the main in February to March and the main being from July to September. The slope of the length weight relationship (LWR) for males was $TW = 0.0153TL^{3.0491}$, $R^2 = 0.987$, for females was $TW = 0.0116TL^{3.1819}$, $R^2 = 0.991$ and for combined sexes was $TW = 0.0131TL^{3.127}$, $R^2 = 0.9911$ showed slight positive allometric growth pattern. The stomach contents were analysed using frequency of occurrence and volumetric method. Detritus, macrophytes, phytoplankton, insects and zooplankton occurred in 99.18%, 77.14%, 42.45%, 11.02%, 4.89% of fish stomachs examined and volumetrically they constituted 73.2%, 11.7%, 13.28%, 1.15%, 0.15% of the food consumed, respectively. From these results it was concluded that *O. niloticus* is an omnivorous fish in its feeding habits. Further research should be carried out on the fishery production and trophic status of the lake.

Key words: Condition factor**;** feeding habits; Lake Boyo; *O. niloticus*; reproduction biology

4.1 Introduction

O. niloticus is the most important fish among the members of the family Cichlidae in the ecology and fisheries of tropical African inland waters (Lowe Mc-Connell, 1982). The species is the most important fish in tropical and subtropical freshwaters, often forming a basis of commercial fisheries in many African countries (Mohammed and Uraguchi, 2013). *O. niloticus* is becoming increasingly well-known in fresh water aquaculture in many regions of the world, and is among the most studied in African waters due to its economic importance. It is also widely distributed in Ethiopian lakes, rivers and reservoirs (Abebe Getahun, 2017), and is the most important fish that contributes nearly 50% of the capture fishery in Ethiopia (Gashaw Tesfaye and Wolf, 2014).

O. niloticus is widely found in the Ethiopian Rift Valley lakes, Abay, Awash, Baro-Akobo, Omo-Gibe, Tekeze and Wabishebele-Genale River basins and in some other Ethiopian highland lakes and rivers (Golubtsov and Mina, 2003). The fish constitutes the bulk of the capture fishery and the commercial inland fish catch (Tsegay Teame *et al.*, 2018; Degsera Aemro *et al.*, 2020). *O. niloticus* is the most edible fish species in Ethiopia (Assefa Mitike, 2014). It also constitutes an irreplaceable piece of the food chain for local populations residing around lakes (Degsera Aemro *et al.,* 2020) and supports substantial populations of fish-eating birds in East African saline-alkaline lakes (Kavembe *et al.,* 2016).

High tolerance to environmental conditions and its ability to accept formulated and natural feeds make *O. niloticus* economically viable culture fish (Adeyemi, 2009). The advantages for *O. niloticus* are its extended breeding seasons and reproductive biology characterized by short generation time (Coward and Little, 2001). The herbivorous nature and its mouth-brooding habits are other advantages of the fish (Penda-Mendoza *et al.,* 2005).

The breeding season and maturity size of *O. niloticus* in some lakes in Ethiopia have been studied by several investigators where the species breeds continuously throughout the year. The breeding activity is intensive during the periods from December to March in Lake Ziway, from January to April and July to September in Lake Hawassa (Demeke Admasu, 1996), and from April to August (peaking in June and July) in Lake Tana that seems to have longer breeding season unlike the Rift Valley lakes. The main breeding activity of fish species in tropical waters has been associated with factors such as light intensity, temperature, rainfall and water level or seasonal flooding. Abundance of food has also been considered as an important factor in timing of breeding in some species (Zenebe Tadesse, 1997).

Many researchers reported that *O. niloticus* feeds on a variety of food items including phytoplankton, zooplankton, insects, detritus, macrophytes, fish parts and nematodes (Alemayehu Negasa and Prabhu, 2008; Filipos Engidaw *et al.*, 2013). The studies carried out in some Rift Valley Lakes, Koka Reservoir, some high land lakes, and River Omo indicated that phytoplankton are the most consumed food type by *O. niloticus* (Alemayehu Negasa and Prabhu, 2008; Filipos Engidaw *et al.*, 2013; Workiye Worie and Abebe Getahun, 2015; Mulugeta Wakjira, 2016). In addition to phytoplankton, high contribution of detritus was also reported from Lake Koka. The occurrences of macrophytes were also found in the diet of *O. niloticus* in some of the Ethiopian rift valley lakes (Alemayehu Negasa and Prabhu, 2008; Filipos Engdaw *et al.*, 2013).

The occurrence of zooplankton in the diet of *O. niloticus* was high in some of the Ethiopian lakes (Alemayehu Negasa and Prabhu, 2008 and Workiye Worie and Abebe Getahun, 2015). Studies conducted in different water bodies of Ethiopia indicated that phytoplankton was the most important food item consumed in dry season. In wet season, however, the high contribution of both plant origin (macrophytes and detritus) and animal origin (zooplankton and aquatic insects) were reported in most of the water bodies (Alemayehu Negasa and Prabhu, 2008; Filipos Engdaw *et al.*, 2013).

The high abundance of macrophytes and insects in the diet of *O. niloticus* in wet season is associated with rainy season of Ethiopia. Fish movements to shallow parts of the lake for reproduction could explain the increase of ingested macrophytes in the wet season. The high dietary proportion of detritus in the diet of the fish in wet season might also have emerged from plant materials flooding in during the rainy season (Workiye Worie and Abebe Getahun, 2015). There was neither fishery activity nor fishery research done yet in Lake Boyo, hence it necessitated to carry out this study. Therefore, this research was conducted to fill the gap by providing information on the reproductive biology and feeding habits of the fish in Lake Boyo.

4.1.1 Objectives of the study

4.1.1.1 General objective

The general objective of this study was to study some aspects of the reproductive biology and feeding habis of *O. niloticus in Lake Boyo.*

4.1.1.2 Specific objectives

1. To study the reproductive biology of *O. niloticus* such as breeding season, size at first maturity, fecundity, and sex ratio, in Lake Boyo.
2. To investigate the diet composition and seasonal variation on the feeding habits of *O. niloticus* in Lake Boyo.
3. To determine the length-weight relationships and condition factor of *O. niloticus* in Lake Boyo.

4.2 Materials and methods

4.2.1 Sampling

Samples of *O. niloticus* were collected from the littoral and open lake sites as described in chapter 3, materials and methods section 3.2.

4.2.2 Reproductive biology

Methods for studying reproductive biology (determination of sex ratio, Lm50, breeding season and fecundity) of *O. niloticus* were described in the materials and methods in chapter 3, under section 3.3 (sub sections 3.3.1 – 3.3.4).

4.2.3 Food and feeding habits

The stomach content analysis of *O. niloticus* was carried out according to the materials and methods mentioned in chapter 3, section 3.4.

4.3 Results and discussion

4.3.1 Reproductive biology of *O. niloticus*

4.3.1.1 Breeding season

The result of gonad maturity stages in this study showed that *O. niloticus* breeds throughout the year and had two peak breeding season that occured from May to September and in January and February (Figure 4.1).

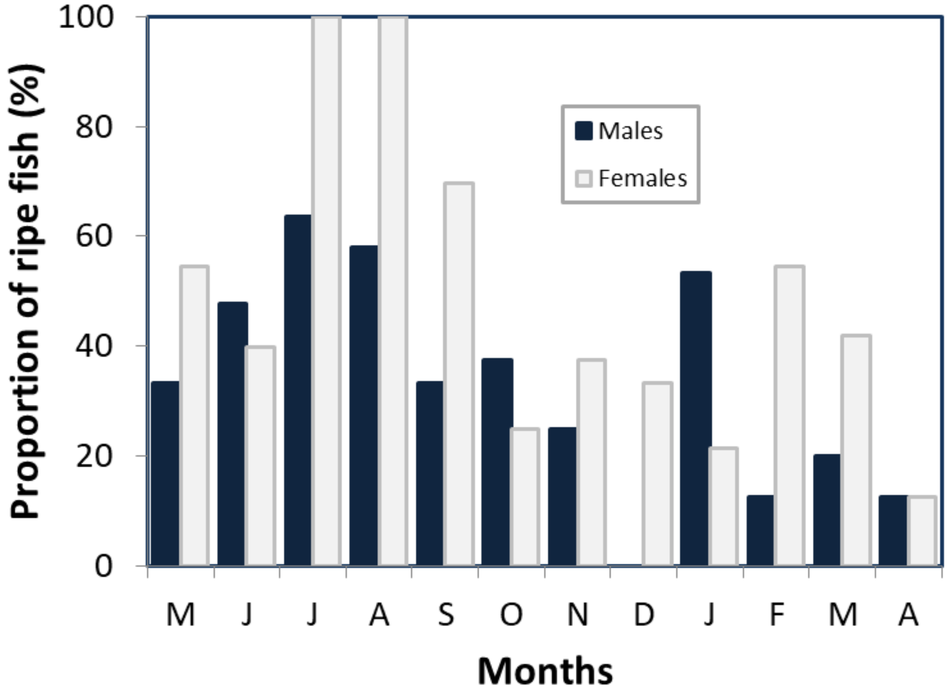

Figure 4.1 Breeding of *O. niloticus* in different months in Lake Boyo

This result was similar with *O. niloticus* in Lake Hawassa in that it had two breeding seasons (Demeke Admassu, 1996)

4.3.1.2 Length at first maturity ($_{Lm50}$)

The L_{m50} (Figure 4.2) of *O. niloticus* in this study was 10.0 and 7.7 cm TL for males and females, respectively. The result revealed that *O. niloticus* reached sexual maturity at small size.

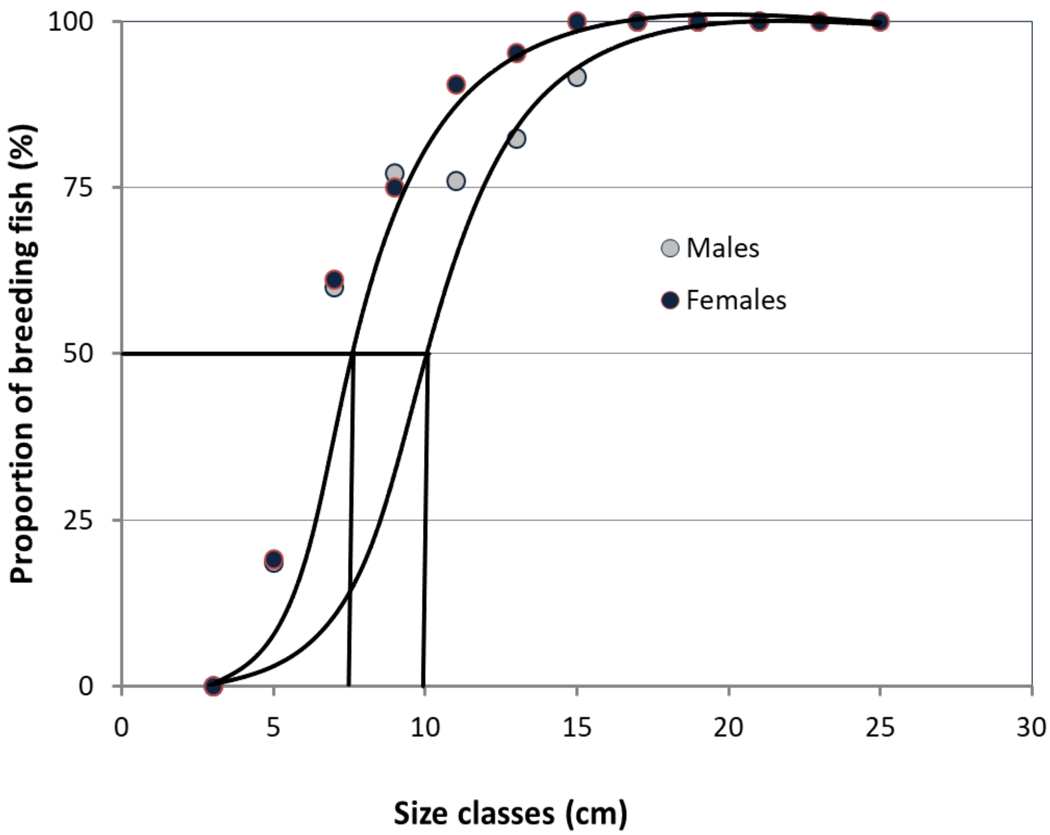

Figure 4.2 L_{m50} of *O. niloticus* in Lake Boyo

4.3.1.3 Fecundity

The number of eggs counted from ripe ovaries ranged from 216 to 1,157 eggs fish^{-1}. The relationships of fecundity with total length and total weight of the fish were linear and increased with increasing fish length and body weight (Figure 4.3a, b). Fecundity increased with body length and the relationship is described by the equation: F = 67.493TL - 408.12, R^2 = 0.7454 (Figure 4.3a), and the correlation was significant. The relationship of fecundity with TW of *O. niloticus* was also linear (R^2= 0.75, p<0.05) and increased with increasing fish weight. It was expressed by the linear equation: (F=4.0847TW + 311.78, R^2 = 0.75) and the correlation was significant.

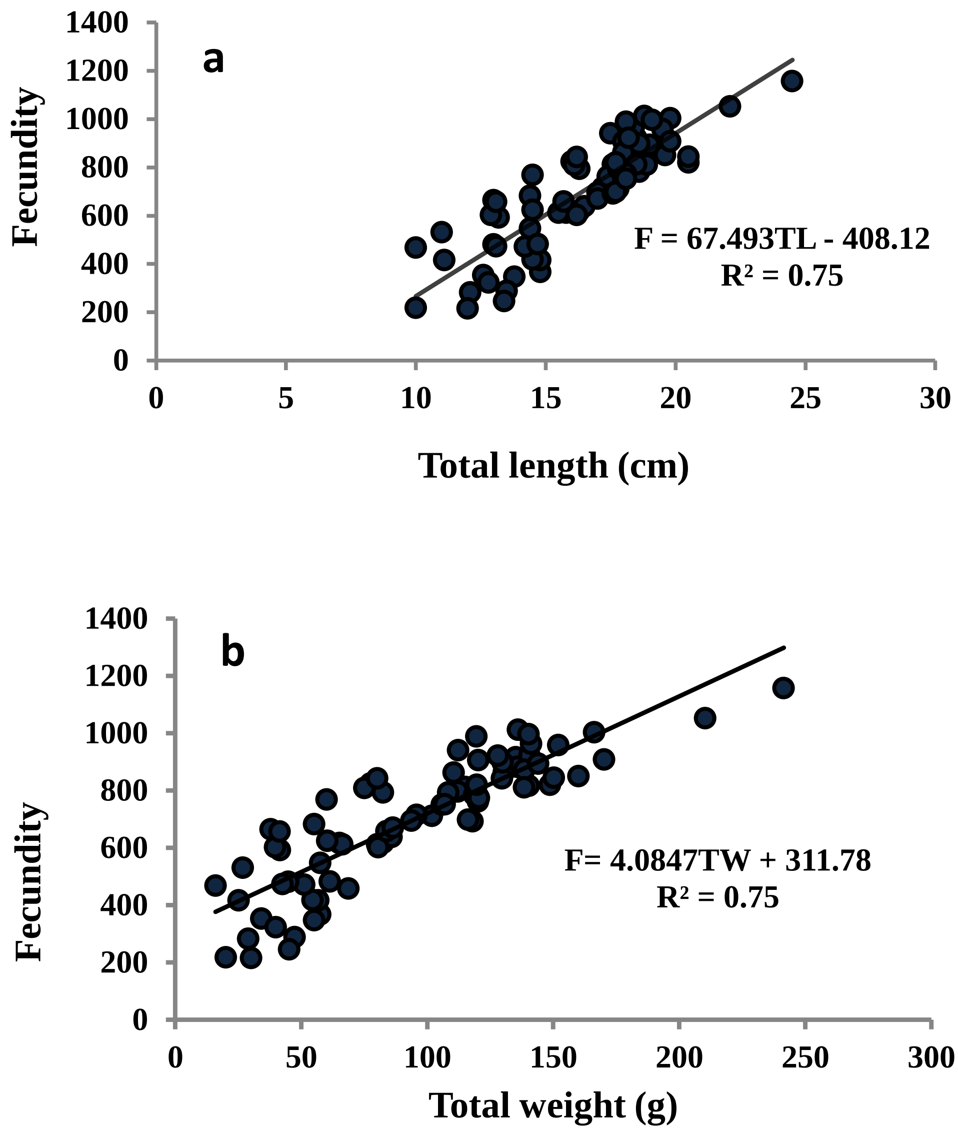

Figure 4.3 The relationship between fecundity and total length (a) and total weight (b) of *O. niloticus* in Lake Boyo

Fecundity obtained for *O. niloticus* in this study was comparable with the findings from Lake Hawassa (304 to 967 eggs ovary^{-1}) (Demeke Admasu, 1994) and Lake Tana (495 to 1,243 eggs ovary^{-1}) (Zenebe Tadesse, 1997). However, it was lower than the fecundity of same species in Lake Chamo (1,047 to 4,590 eggs ovary^{-1}) (Yirgaw Teferi *et al.*, 2001).

4.3.1.4 Sex ratio

Three hundred and seventy nine samples of *O. niloticus* (Table 5.1) were examined for sex ratio determination. Out of these, 197 (52%) were males and 182 (48%) were females. The overall sex ratio (male: female) was 1:0.92 which was not significantly different from the hypothetical 1:1 sex ratio ($p > 0.05$). The result also showed that there were more males than females in the sampling month of December, while females dominated in the months of July and September. For the rest of the months (January -April), male and female *O. niloticus* were represented with almost equal proportion (Table 4.1).

Table 4.1 Male to female sex ratio of *O. niloticus* sampled in different months of the year in Lake Boyo.

Sampling month	Male	Female	Sex ratio (M:F)	Chi-square
May, 2021	15	11	1:0.73	0.62
June	22	13	1:0.6	2.31
July	26	32	1:1.23	0.62
August	28	27	1:0.96	0.02
September	25	36	1:1.44	1.98
October	8	5	1:0.63	1.23
November	12	9	1:0.75	0.29
December	15	5	1:0.33	5.0*
January, 2022	17	17	1:1	0.0
February	13	11	1:0.85	0.17
March	6	7	1:1.17	0.08
April	10	9	1:0.9	0.05
Total	**197**	**182**	**1:0.92**	**0.6**

* indicates significant difference ($p<0.05$)

The result on the analysis of sex ratio at different size classes of *O. niloticus* showed that there were significantly more males than females for the size classes 7.0- 8.9 and 9.0 -10.9 cm TL, while for the size class 17.0-18.9 cm TL, females were more represented than males. However, for the other size classes, there was no significant difference at 5% level of significance (Table 4.2).

Table 4.2 Male to female sex ratio of different size classes of *O. niloticus* in Lake Boyo

Size class	Male	Female	M:F Sex ratio	Chi-square
3.0- 4.9	10	6	1: 0.6	1
5.0- 6.9	35	26	1: 0.74	1.33
7.0- 8.9	43	23	1: 0.53	6.1*
9.0- 10.9	51	18	1: 0.4	15.8**
11.0- 12.9	15	23	1: 1.5	1.7
13.0- 14.9	17	23	1: 1.4	0.9
15.0- 16.9	12	14	1: 1.2	0.2
17.0- 18.9	8	35	1: 4.4	17.0**
19.0- 20.9	4	10	1: 2.5	2.6
21.0- 22.9	1	2	1: 2	0.33
23.0- 24.9	1	1	1: 1	0
25.0- 26.9	1	1	1: 1	0
Total	**197**	**182**	**0.92**	**0.6**

* indicates significant difference ($p<0.05$)

The results of the present study is in agreement with other studies reported for *O. niloticus* in Lake Nyamusingiri and Kyasanduka, Uganda (Bwanika *et al.,* 2004), and in Itapaji Dam, Nigeria (Omotayo *et al.,* 2019) in that the sex ratio was not significantly different from the hypothetical 1:1 ratio. However, the dominance of female *O. niloticus* was reported from other water bodies including Ethiopian lakes and reservoirs including Lake Hawassa (Demeke Admasu, 1996), Lake Beseka (Lemma Abera, 2013), Lake Hayq (Workiye Worie and Abebe Getahun, 2014), Tekeze Reservoir (Tsegay Teame *et al.,* 2018) Albert Nile, and Uganda (Nyakuni, 2009). On the other hand, the dominance of male *O. niloticus* population over females was reported in Lake Tana (Zenebe Tadesse, 1997), Lake Victoria (Njiru *et al.,* 2006) and Lake Babogaya (Lemma Abera, 2012).

The sex ratio shows significant variation for the same species in different water bodies, but usually it is close to one, and predominance of one sex over the other may differ due to sexual segregation during spawning period, difference in habitat preference, behavioural variations between the sexes, vulnerability to fishing gear type and fishing site (Tsegay Teame *et al.,* 2018). In general, the unbalanced ratio between males and females could be due to the behavioral difference between sexes, which makes one sex to be more vulnerable to the fishing gear than the other or the difference in refuge preference due to deviation in sexual maturity stages during the spawning season (Demeke Admasu, 1994).

4.3.1.5 Length-length relationship

The relationship between TL and SL (Figure 4.4) of *O. niloticus* was linear (n= 379; R^2= 0.993, $p<0.05$) and it is expressed by the equation: SL = 0.791TL + 0.013.

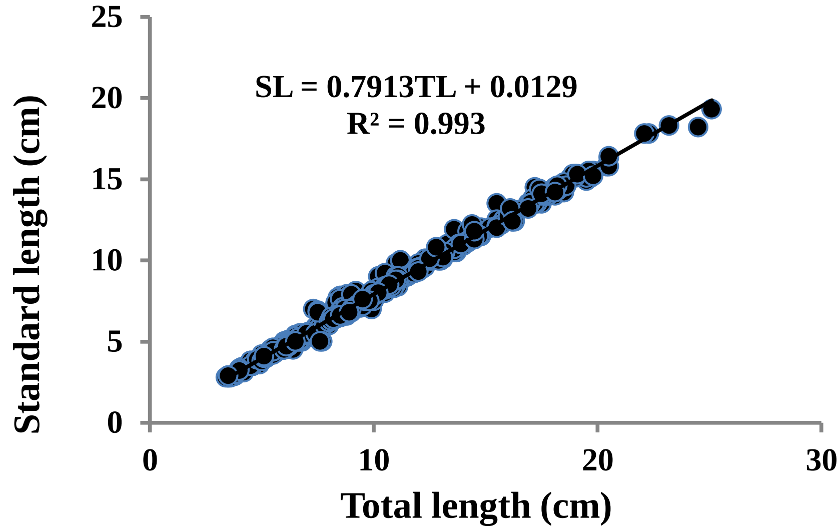

Figure 4.4 The relationship between total length and standard length of *O. niloticus* in Lake Boyo

4.3.1.6 Length-weight relationship

The length-weight relationship (Figure 4.5) of male *O. niloticus* was curvilinear and the regression equation is expressed as $TW = 0.0153TL^{3.0491}$, $R^2 = 0.987$.

The LWR of female *O. niloticus* was curvilinear and the regression equation is as $TW = 0.0116TL^{3.1819}$, $R^2 = 0.991$. The result of LWR for combined sexes showed that it was curvilinear and expressed by the following regression equation: $TW = 0.0131TL^{3.127}$, $R^2 = 0.991$. The slope of the relationship (b) for the combined sexes was greater than 3.

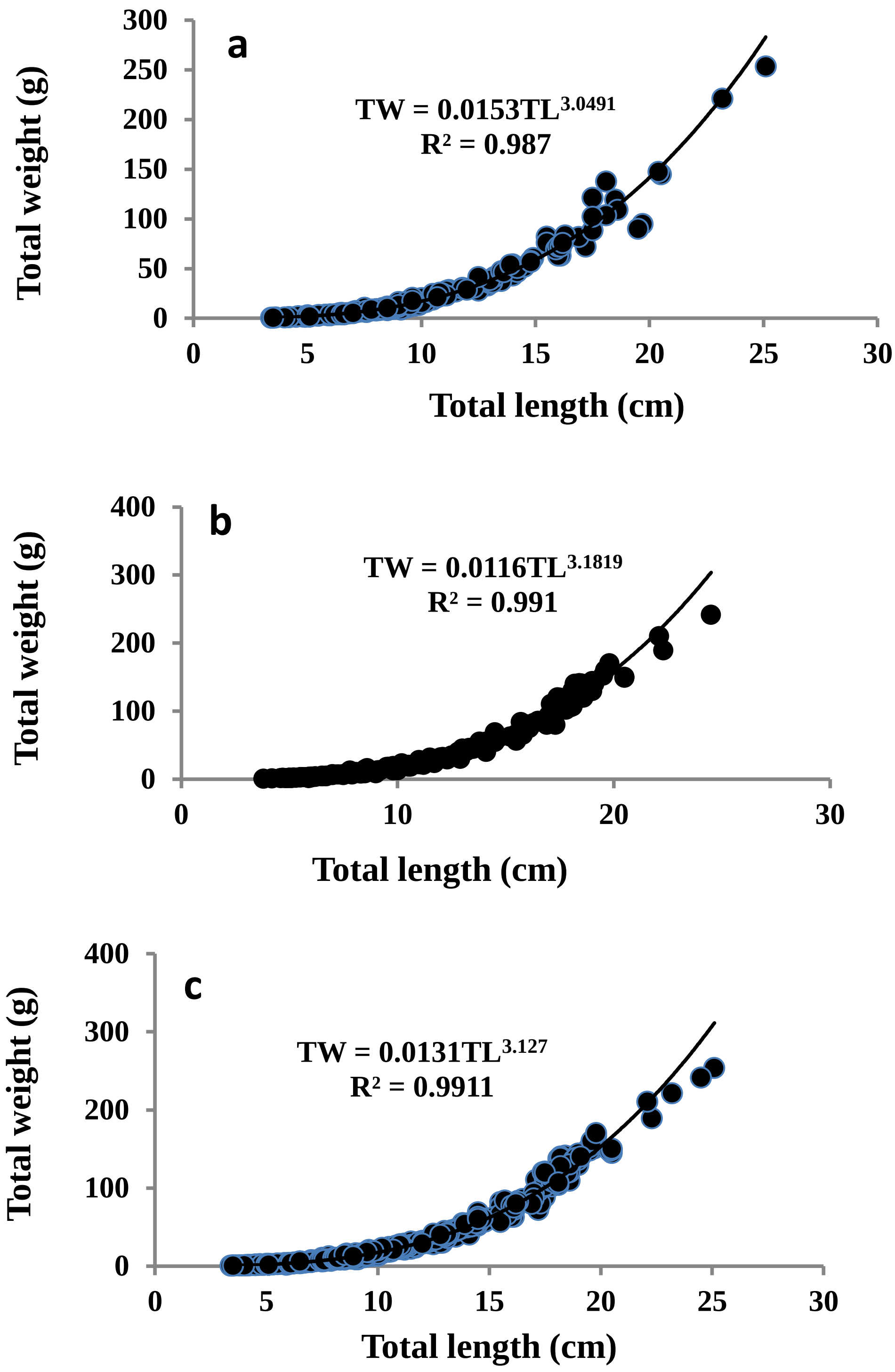

Figure 4.5 The length weight relationship of male (a) female (b) and male and female combined (c) of *O. niloticus* in Lake Boyo.

The length-weight relationship of *O. niloticus* in this study with the value of regression co-efficient or b= 3.05, 3.18 and 3.13 for males, females and combined sexes, respectively exhibited slight positive allometric growth pattern. The results in this study were in agreement with the results reported by Njiru *et al.,* (2006) from Lake Victoria (b=3.20). The "b" value of this study was greater for the same fish species in Lake Beseka (b= 2.69) (Lemma Abera, 2013).

4.3.1.7 Fulton`s condition factor

Monthly mean FCF values (Figure 4.6) ranged from 1.55 to 1.91 and 1.50 to 2.0 for males and females, respectively. The overall FCF values for males and females were 1.73 and 1.77, respectively. The average FCF value (1.77) of female *O. niloticus* in this study was lower than the values reported for the same fish species from Lake Hawassa (2.03) (Eyualem Abebe and Getachew Teferra, 1992) and Chamo (2.35) (Yirgaw Teferi *et al.*, 2001). The variation in the FCF value could be due to changes in the environmental conditions of the lake and thereby changes in the nutritional status of the fish. For instance, there are different agricultural activities taking place around the lake and these activities might disturb and break the available food chain for the fish. Variations in the condition factor of many fishes is believed to be related to their reproductive cycle (Narejo *et al.,* 2002), feeding rhythms, physiochemical factors of lake environment, age, physiological state of fish or some other unknown factors (Dar *et al.,* 2012). In general, the FCF values of females were higher than that of males in some of the studied period and it might be due to the higher gonad weight of females that result in higher total body weight as well as mobilization of energy for building and guarding of nests which might reduce total body weight in males.

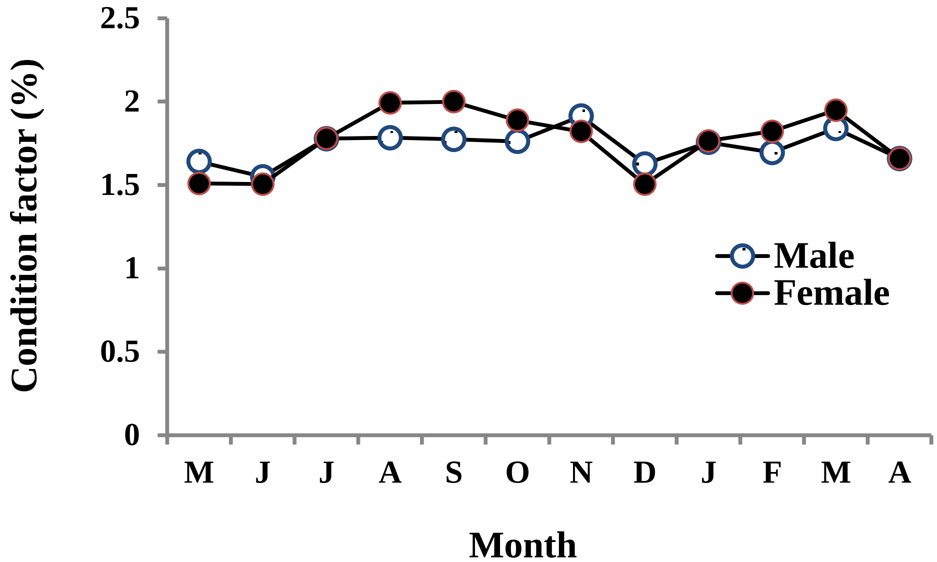

Figure 4.6 FCF of male and female *O. niloticus* in Lake Boyo

4.3.2 Food and feeding habits of *O. niloticus*

To determine the feeding habits of *O. niloticus*, 315 stomach specimens were analysed of which 70 (22.5%) were empty stomachs while 245 (77.8%) had food items in their stomachs. The stomach content analysis indicated that *O. niloticus* fed on a variety of food categories in the lake including food of plant and animal origins. Five taxonomic categories were identified and categorized as detritus, macrophytes, insects, zooplankton and phytoplankton. Detritus, macrophytes and phytoplankton occurred in 99.18%, 77.14% and 42.45% of the fish diet, respectively and volumetrically constituted 73.6%, 11.7% and 13.36% of the food items, respectively. The frequencies of occurrence of insects and zooplankton is low comprising only 11.02% and 4.89% of fish stomachs, respectively, and volumetrically they constituted 1.17% and 0.15% of the food items, respectively (Table 4.3). Detritus, macrophytes and phytoplankton were the dominant food items while insects and zooplankton were less significant in their contribution to the diet of *O. niloticus*. Detritus was the most commonly consumed food item, followed by macrophytes and phytoplankton.

The result of this study was in agreement with the findings of many scholars in that *O. niloticus* feeds on a variety of food items including phytoplankton, zooplankton, insects, detritus, macrophytes, fish parts and nematodes (Alemayehu Negasa and Prabhu, 2008; Filipos Engdaw *et al.,* 2013). The contribution of detritus in this study was highest. This is in agreement with the report from Koka Reservoir (Filipos Engdaw *et al.*, 2013) in that the contribution of detritus was high in addition to phytoplankton. The occurrences of macrophytes were also found slightly higher in the diet of *O. niloticus* than other food items, and it is in agreement with some of the Rift Valley lakes (Alemayehu Negasa and Prabhu, 2008; Filipos Engdaw *et al.,* 2013; Mathewos Temesgen, 2017). The less occurrence of zooplankton in the diet of *O. niloticus* in this study is in contrary to the findings from Lake Ziway (Alemayehu Negasa and Prabhu, 2008); Lake Hayq (Workiye Worie and Abebe Getahun, 2015) and Lake Langano (Mathewos Temesgen, 2017).

The results of the present study generally showed that there were seasonal variations in the food composition of *O. niloticus*. It was found that in the wet season (Table 4.4) detritus, macrophytes and phytoplankton occurred in 100%, 84.55% and 27.64% fish diet, respectively, and volumetrically they contained 72.96%, 13.94% and 12.98% of food items. The contribution of insects and zooplankton was low and occurred in 1.62% and 2.43% in the fish's diet and volumetrically constituted 0.07% and 0.05% of food items.

Table 4.3. Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *O. niloticus* in Lake Boyo (n=245).

Food items	**Frequency of occurrence**		**Volumetric contribution**	
	Frequency	**Percent**	**Volume (ml)**	**Percent**
Detritus	**243**	**99.18**	**99.81**	**73.6**
Macrophytes	**189**	**77.14**	**15.91**	**11.7**
Insects	**27**	**11.02**	**1.58**	**1.17**
Zooplankton	**12**	**4.89**	**0.20**	**0.15**
Phytoplankton	**104**	**42.45**	**18.12**	**13.36**
Diatoms	98	40.00	13.70	10.1
Green algae	35	14.29	2.80	2.06
Bluegreen algae	14	5.71	1.24	0.92
Euglenoids	2	0.82	0.38	0.28

Detritus and macrophytes were the main food items during the wet season. Similar results of high contribution of both plant and animal origin (macrophytes and detritus) were reported in most of the water bodies (Alemayehu Negasa and Prabhu, 2008; Filipos Engdaw *et al.*, 2013; Workiye Worie and Abebe Getahun, 2015). The high abundance of macrophytes in the diet of *O. niloticus* in wet season is associated with the rainy season. Fish movements to shallow parts of the lake for reproduction could explain the increase of ingested macrophytes in the wet season (Workiye Worie and Abebe Getahun, 2015).

Table 4.4 Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *O. niloticus* in wet season in Lake Boyo (n=123).

Food items	**Frequency of occurrence**		**Volumetric contribution**	
	Frequency	**Percent**	**Volume (ml)**	**Percent (%)**
Detritus	**123**	**100**	**39.42**	**72.96**
Macrophytes	**104**	**84.55**	**7.53**	**13.94**
Insect	**2**	**1.62**	**0.04**	**0.07**
Zooplankton	**3**	**2.43**	**0.03**	**0.05**
Phytoplankton	**34**	**27.64**	**7.02**	**12.98**
Diatoms	31	25.20	4.95	9.17
Green algae	12	9.76	1.32	2.44
Bluegreen algae	6	4.88	0.74	1.37

In the dry season (Table 4.5) detritus, macrophytes and phytoplankton occurred in 98.36%, 69.67% and 57.38% fish diet, respectively and volumetrically constituted 74.01%, 10.27% and 13.61% of food items, while the contribution of insects and zooplankton was less and occurred in 20.49% and 7.38% of the fish diet, respectively, and volumetrically constituted 1.89% and 0.22% of food items, respectively. Detritus, macrophytes and phytoplankton were the dominant food categories in dry season. This result is in agreement with the studies made in different water bodies indicating that phytoplankton is the most important food item consumed in dry season in Lake Ziway (Alemayehu Negasa and Prabhu, 2008), in Lake Koka (Filipos Engdaw *et al.*, 2013), in Lake Hayq (Workiye Worie and Abebe Getahun, 2015) and in Omo River (Mulugeta Wakjira, 2016).

Table 4.5 Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *O. niloticus* in dry season in Lake Boyo (n=122).

Food items	Frequency of occurrence		Volumetric contribution	
	Frequency	Percent	Volume (ml)	Percent
Detritus	120	98.36	60.39	74.01
Macrophytes	85	69.67	8.38	10.27
Insect	25	20.49	1.541	1.89
Zooplankton	9	7.38	0.10	0.22
Phytoplankton	70	57.38	11.10	13.61

4.4 Conclusions

The overall sex ratio (Male: Female) of *O. niloticus* in Lake Boyo indicated that the overall male to female sex ratio was not significantly different from the hypothetical 1:1 sex ratio ($p > 0.05$). *O. niloticus* breeds throughout the year and the breeding season of the fish had two peaks (the first peak from February to March and the second peak from July to September). The fecundity of the fish increased with the increase in the fish length and weight. The L_{m50} indicated that *O. niloticus* exhibited early maturation. *O. niloticus* in the lake exhibited a slight positive allometric growth pattern. The FCF of male and female indicated that *O. niloticus* in Lake Boyo was not in good condition throughout the study period. *O. niloticus* in Lake Boyo was characterized by omnivorous feeding habits and showed seasonal variation in the food composition. Detritus and macrophytes were the main food items during the wet season, while detritus, macrophytes and phytoplankton were the dominant food items in dry season. The existence of high amount of detritus and low amount of phytoplankton in the wet season and lower condition factor of the fish with reference to other lakes indicate that the productivity of Lake Boyo is low.

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CHAPTER 5: REPRODUCTIVE BIOLOGY AND FEEDING HABITS OF THE STRAIGHTFIN BARB *ENTEROMIUS PALUDINOSUS* (PETERS, 1852) IN LAKE BOYO, ETHIOPIA

Abstract

The straightfin barb *Enteromius paludinosus* (peters, 1852) is widely distributed in Africa ranging from Ethiopia in the north, through to the east and central Africa. The purpose of this study was to investigate the reproductive biology and feeding habits of the straight-fin barb *E. paludinosus* (Peters, 1852) (Pisces: Cyprinidae) in Lake Boyo. A total of 513 fish samples were collected from the lake between May 2021 and May 2022 using beach seine of 6 mm stretched mesh. The sex ratio of male to female was almost equal (1:1.03) ($p>0.05$). Length at first maturity (L_m50) was 5.5 and 4.3 cm TL for males and females, respectively. The fecundity of the fish ranged from 1,078 to 9,683 eggs per fish. *E. paludinosus* breeds throughout the year in the lake, and two breeding peaks the main from October to January and the minor occurs in March and April. The length weight relationship (LWR) $TW = 0.0082TL^{3.18}$, $R^2 = 0.984$ for males, $TW = 0.0132TL^{2.98}$, $R^2 = 0.979$ for females and $TW = 0.0098TL^{3.1}$ $R^2 = 0.981$ for combined sexes showed a slightly positive allometric growth pattern for males and combined sexes, while a slightly negative isometric growth pattern for females. Detritus, macrophytes, phytoplankton, insects, and zooplankton were found in 98.22%, 75.6%, 39.44%, 19.08%, and 6.62% of the fish diets and volumetrically constituted 64.12%, 22.1%, 10.31%, 2.50%, and 0.40% of the food items consumed. Further research is recommended on the fishery production and trophic status of the lake.

Key words: *E. paludinosus*; fecundity; feeding habits; Fulton`s condition factor; Lake Boyo; Reproductive biology

5.1 Introduction

The family Cyprinidae consists of the carps, the true minnows, the barbs and barbels. It is the largest family of freshwater fish, with over 2,400 species in about 220 genera (Nelson, 2006). The genus *Enteromius* in the family Cyprinidae consists of more than 800 species from East Asia to South Africa and is divided as small and large barbs and also most members of the genera have a pair of barbels on their mouths, which they can use to search food at the bottom of the water (Berrebi and Valishok, 1998).

The straight fin barb *E. paludinosus* is widely distributed in Africa ranging from Ethiopia in the north, through to the east and central Africa. In southern Africa, its distribution extends from Vungus, KwazuluNatal, and the southern Congo tributaries to the Quanza Angola and the Orange River (Skelton and Cambray, 1981; Skelton, 2001).

In some parts of Africa, the species is economically important having significant contribution to the commercial landings. The estimated maximum economic yield of *E. paludinosus* in Lake Chilwa (Southern Malawi) is US$3.4 million (Njaya, 2001). *E. paludinosus,* which is consumed whole, is a good source of calcium - one of the principal micronutrients required by the human body (Effiong and Fakunle, 2011; Jiang *et al.,* 2015). *E. paludinosus* is one of the three most harvested commercial fish species in Lake Chilwa (Chiwaula *et al.,* 2012). The study of nutritional quality of *E. paludinosus* from Lake Chilwa suggests that it is a highly nutritious fish with crude protein content of 60.5% in freshly caught fish (Lipato and Kapute, 2017). Moreover, the fish serves as a prey for other commercially important fish species and fish eating birds. The findings of Zerihun Desta *et al.*, (2006) revealed the importance of *E. paludinosus* as prey fish for the African big barb and the African catfish in Lake Hawassa, Ethiopia. In other parts of Africa, the species is preyed upon by the African catfish, tigerfish, large-mouth bream and birds (Skeleton, 1993).

E. paludinosus is not of any commercial importance in the fisheries of Ethiopia in general, but it is ecologically important because it is used as a prey fish for some commercially important fish species such as *Clarias gariepinus* and *Labeobarbus intermedius in* Lake Hawassa (Zerihun Desta *et al.*, 2006, 2007).

Enteromius spp. spawns several times in a year, with breeding fish making several spawning runs throughout the year (Macuiane *et al.*, 2009). Breeding in more than one occasion in an unstable and stressful environment will contribute to reproductive success of *Enteromius* (Msiska, 2001). The main reproductive period for *E. paludinosus* is between October and January, with a second and less pronounced reproductive period between March and April, followed by a reproductively quiescent period between May and August (Messias *et al.*, 2009).

Cyprinids are stomach-less fish with toothless jaws but the food can be effectively chewed by the pharyngeal teeth as the fish makes chewing motions by pressing the food between the pharyngeal teeth and the chewing plate (Nelson, 2006). These groups of fishes are known to be opportunistic feeders and also have protrudable upper jaws and a fleshy palatal organ, opposing the branchial sieve, which can be used for food sorting and transport (Sibbing, 1991). Cyprinids are not well equipped for piscivorous feeding habits because of lack of distinct stomach, cellulase and oral teeth (Hofer, 1991).

E. paludinosus is an omnivorous species able to utilize a wide range of food items including micro-crustaceans, insects, gastropods, algae, and detritus (Cambray, 1983; Brummett and Katambalika, 1996; Skelton, 2001). In addition, it also feeds on macrophytes, zooplankton and invertebrates in African inland waters (Skelton, 1993; Mattson, 1999).

5.1.1 Objectives of the study

5.1.1.1 General objective

The general objective of this study was to study some aspects of the reproductive biology and feeding habis of *E*. *paludinosus* in Lake Boyo.

5.1.1.2. Specific objectives

1. To study the reproductive biology of *E*. *paludinosus* such as breeding season, length at first maturity, fecundity, and sex ratio, in Lake Boyo.
2. To investigate the diet composition and seasonal variation on the feeding habits of *E*. *paludinosus* in Lake Boyo.
3. To determine the length-weight relationships and condition factor of *E*. *paludinosus* in Lake Boyo.

5.2 Materials and methods

5.2.1 Sampling

Samples of *E. paludinosus* were collected from the littoral and open lake sites as indicated in chapter 3 materials and methods section 3.2.

5.2.2 Reproductive biology of *E. paludinosus*

Methods for studying reproductive biology (determination of sex ratio, Lm50, breeding season and fecundity) of *E. paludinosus* were described in the materials and methods in chapter 3, under section 3.3 (sub sections 3.3.1 – 3.3.4).

5.2.3 Food and feeding habits

The gut content analysis of *E. paludinosus* was carried out according to the materials and methods section in the general materials and methods in chapter 3 section 3.4.

5.3. Results and discussion

5.3.1 Reproductive biology of *E. paludinosus*

5.3.1.1 Breeding season

E. paludinosus reproduced throughout the sampling period. The peak breeding time for *E. paludinosus* in this study was between May and July (Figure 5.1).

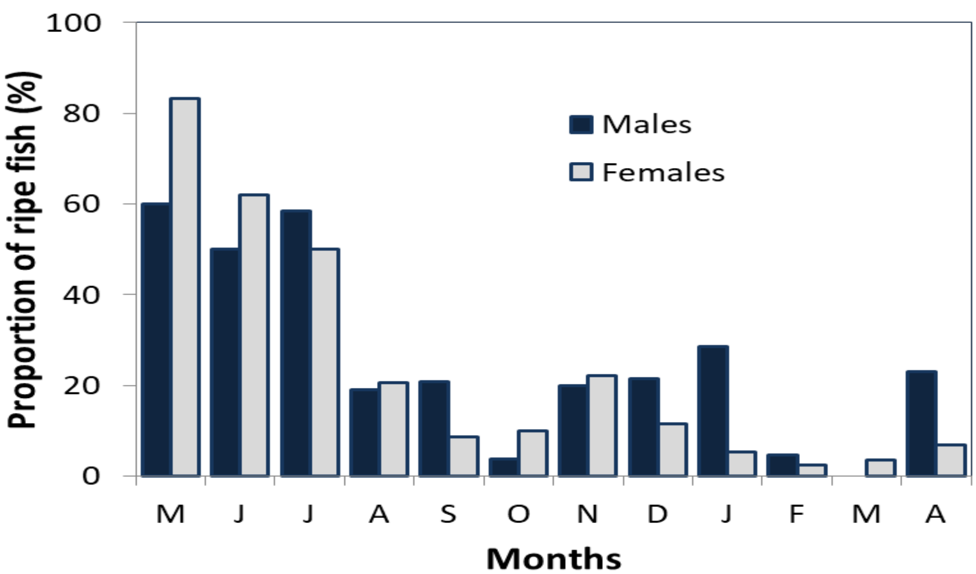


Figure 5.1 Breeding season of *E. paludinosus* in Lake Boyo

The breeding season of *E. paludinosus* in this study was contrary to the findings of Furse (1979) in Lake Chilwa and the Domasi and Likangala rivers. The result was also in contrast with the findings of Messias *et al.* (2009) in that the main reproductive period for *E. paludinosus* in Lake Chilwa, Malawi was between October and January, with a second and less pronounced reproductive period between March and April. In the present study *E. paludinosus* reproduced throughout the year in Lake Boyo as that reported by Macuiane *et al.*, (2009) from Lake Chiliwa, Malawi. In an unstable and stressful environment (Msiska, 2001), breeding on more than one occasion will contribute to reproductive success of *Enteromius*.

5.3.1.2 Length at first maturity (L_m50)

The L_m50 obtained for *E. paludinosus* in this study (Lake Boyo) was 5.5 and 4.3 cm TL for males and females, respectively (Figure 5.2). The L_m50 obtained for *E. paludinosus* in this study was smaller than that reported from Lake Chilwa, Malawi (6.5 cm TL for females and 5.8 cm TL for males) (Macuiane *et al.*, 2009). It was also lower than that reported from Lake Chilwa, Malawi (7.4 cm) (Howard-Williams *et al.*, 1972). This might be due to inadequate resources in the lake.

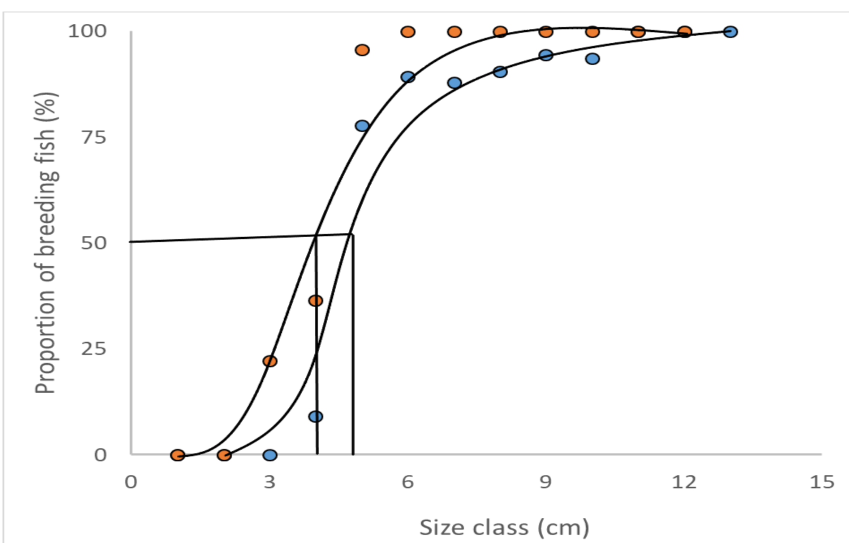
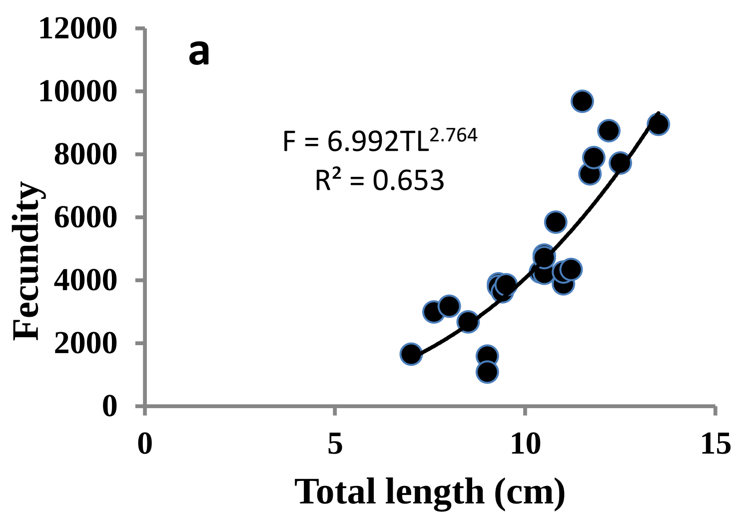


Figure 5.2 L_m50 of male and female *E. paludinosus* in Lake Boyo.

5.3.1.3 Fecundity

The number of eggs in the examined ripe ovaries ranged from 1,078 to 9,683 eggs/fish. The relationship of fecundity with TL of *E. paludinosus* was found to be curveilinear (R^2= 0.72, $p<0.05$) and increased with increasing fish weight. It is expressed by the equation: $F= 6.9923TL^{2.764}$ (Figure 5.3a). The relationship of fecundity with TW of *E. paludinosus* was found to be linear (R^2= 0.773, $p<0.05$) and increased with increasing fish length. It is expressed by the equation: $F = 362.19TW - 116.3$ (Figure 5.3b). Fecundity obtained for *E. paludinosus* in this study was lower than fecundity of other cyprinds. For instance, it was lower than fecundity of *Barbus grypus* (16000–235784 oocytes) (Oymak *et al.,* 2008), and *Labeo senegalensis* (12948–74832 oocytes) (Montchowui *et al.*, 2010),



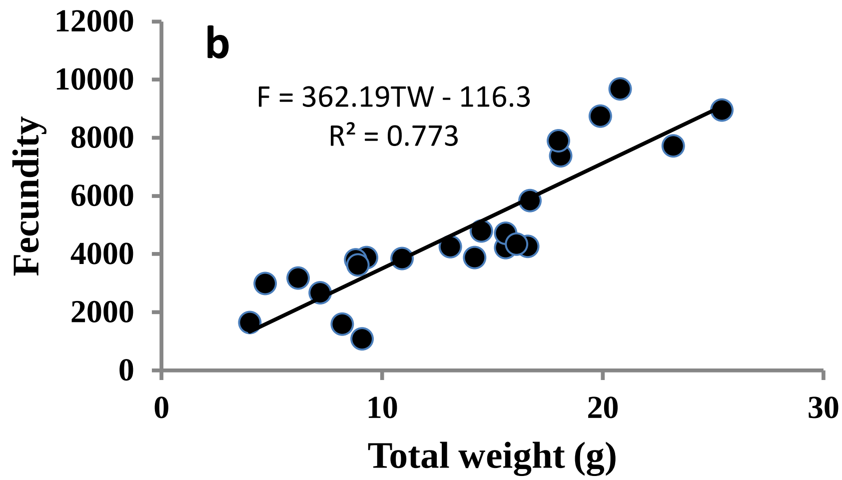


Figure 5.3 Relationships between fecundity and TL (a) and fecundity and TW (b) of *E. paludinosus* in Lake Boyo.

5.3.1.4 Sex ratio

Five hundred and thirteen fish samples of *E. paludinosus* were examined for sex determination. Out of these, 253 (49.3%) were males and 260 (50.7%) were females. The overall sex ratio (male: female) was 1:1.03 which was not significantly different from the hypothetical 1:1 sex ratio ($p > 0.05$). However the sex ratio varied significantly in fish sampled in May and November. The result also showed that there were more females than males in the sampling month of May. On the other hand, males dominated over females in November. For the rest of the months, there was no significant difference at 5% level of significance (Table 5.1).

Table 5.1 Male to female sex ratio of *E. paludinosus* in different months of the year from Lake Boyo.

Sampling Month	Male	Female	M:F Sex ratio	Chi-Square
May, 2021	5	17	1: 3.4	6.5*
June	14	21	1: 1.5	0.01
July	24	16	1:0.7	1.6
August	21	35	1:1.6	3.5
September	24	36	1:1.5	2.4
October	27	20	1:0.7	1.04
November	46	16	1:0.3	14.52***
December	28	26	1:0.9	0.07
January, 2022	14	13	1:0.9	0.02
February	7	13	1:1.9	1.8
March	12	12	1:1	0
April	31	35	1:1.1	0.2
Total	**253**	**260**	**1:1.03**	**0.09**

* indicates significant differences (p<0.05)

The sex ratio in different size classes of *E. paludinosus* showed that there were significantly more males than females for the size classes 7.0-8.9 cm whereas more females than males for the size classes 9.0-10.9 cm TL. However, for the smaller (3.0 through 6.9 cm) and larger (11.0 through 14.9 cm) size classes, there was no significant difference (P>0.05) between sexes (Table 5.2). The overall sex ratio (male: female) of *E. paludinosus* in this study was not significantly different from the hypothetical 1:1 ratio (Table 5.2). This result is contrary to the finding reported in Lake

Chilwa, Malawi that reveals 1:3 (male: female) sex ratio indicating the abundance of more females than males (Messias *et al.*, 2009). The findings of Ngesa *et al.*, (2019) in Lake Naivasha (1:1.981 sex ratio), Mutia *et al.,* (2010) in Lake Naivasha, and Mathewos Temesgen (2018) in Lake Langeno (1:1.24 sex ratio) also reveal the dominance of females over males.

Table 5.2 Male to female sex ratio of *E. paludinosus* at different size classes in Lake Boyo

Size class	**Male**	**Female**	**M:F Sex ratio**	**Chi-Square**
3.0-4.9	7	5	1: 0.71	0.33
5.0-6.9	42	26	1: 0.62	3.8
7.0-8.9	108	77	1: 0.72	5.2*
9.0-10.9	55	88	1: 1.6	7.62*
11.0-12.9	34	50	1: 1.5	3.95
13.0-14.9	7	14	1: 2	2.33
Total	**253**	**260**	**1: 1.03**	**0.09**

* indicates significant differences (p<0.05)

5.3.2 Total length-standard length relationship

The relationship between TL and SL (Figure 5.4) of *E. paludinosus* collected from Lake Boyo was linear (n= 513; R^2= 0.9825, $p<0.05$) and it is expressed by the equation: SL = 0.8287TL + 0.0007.

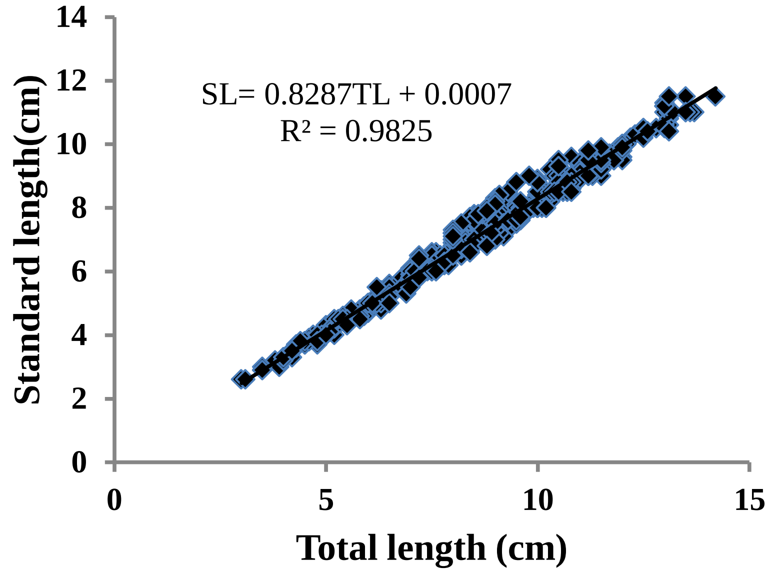


Figure 5.4 Relationship between TL and SL of *E. paludinosus* from Lake Boyo

5.3.3 Length weight relationship of *E. paludinosus*

The LWR of *E. paludinosus* in this study (Figure 5.5a, b and c) with the “b” value of 3.18, 2.98 and 3.1 for males, females and combined sexes, respectively revealed slight positive allometric growth pattern for males and combined sexes while slight nearly isometric growth pattern for female fishes.

The length weight relationship of *E. paludinosus* in this study (Figure 5.5a, b and c) was within the range of 2 - 4 recommended by (Bagenal and Tesch 1978) as ideal for fresh water fishes. This result was also lower than other *Enteromius* species. For instance, in Lake Abaya, Ethiopia (b=3.260) (Elias *et al.,* 2014) for *Barbus bynni* and Atatruk Dam Lake, South Eastern Anatolia (b=3.34) (Bastwta and Cicec, 2006) for *Ceraso barbus luteus*. But higher than *Enteronius luteus* (b=2.97) (Bastwta and Cicec, 2006) in Atatruk Dam Lake, South Eastern Anatolia.

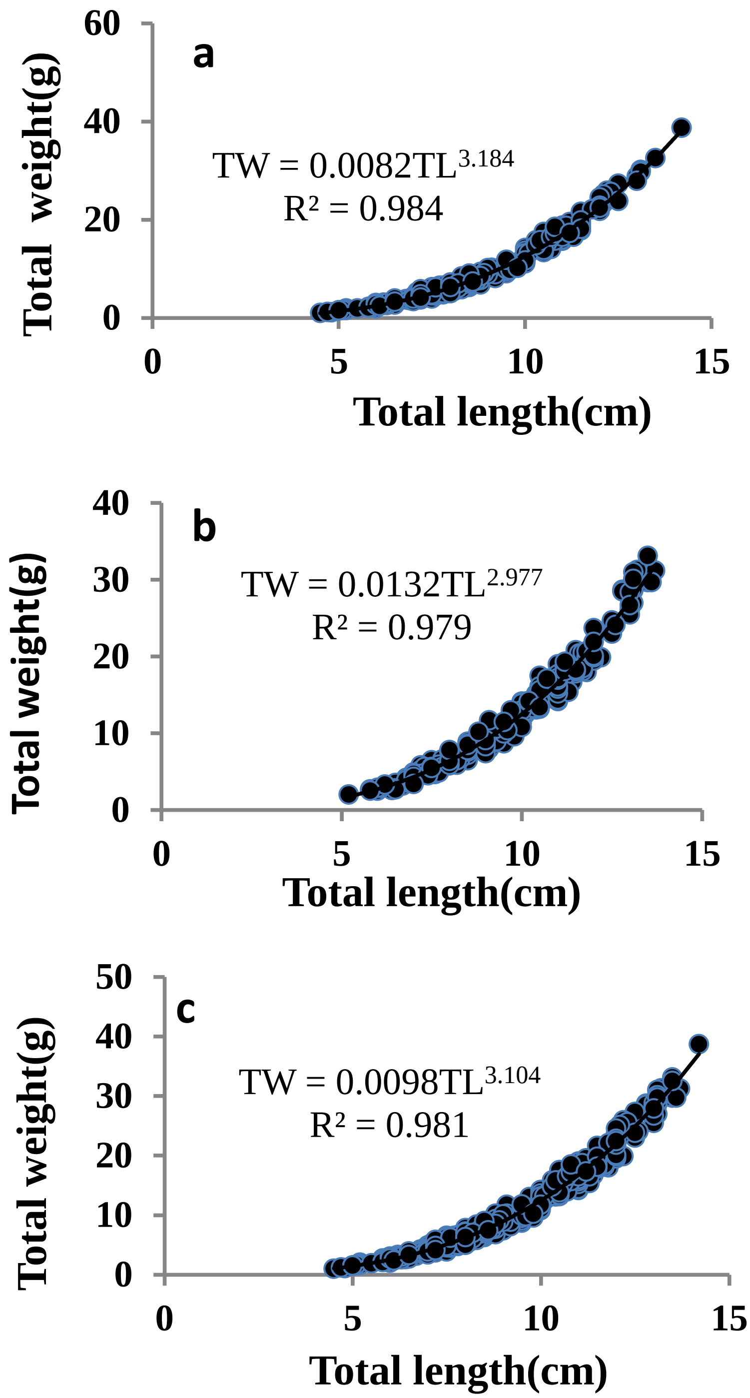


Figure 5.5 Length weight relationship of male (a) female (b) and combined sex (c) of *E. paludinosus* from Lake Boyo.

5.3.4 Fulton`s condition factor (FCF)

In this study (Figure 5.6), the average FCF of *E. paludinosus* was 1.21 and 1.27, for males and females, respectively. There was a significant difference between the FCF of the males and females ($P < 0.05$). But there was no significant difference in the months October, November, December and August. The result also showed that the average FCF value of females was higher than that of males and females were in a good condition than males in some months of the year (for instance, June, July, August and January).

The FCF values obtained in this study was higher than the values reported from Lake Baringo (1.0) (Elijah *et al.*, 2014) and in Lake Naivasha (0.5981 and 0.5729 for males, respectively) (Ngesa *et al.*, 2019).

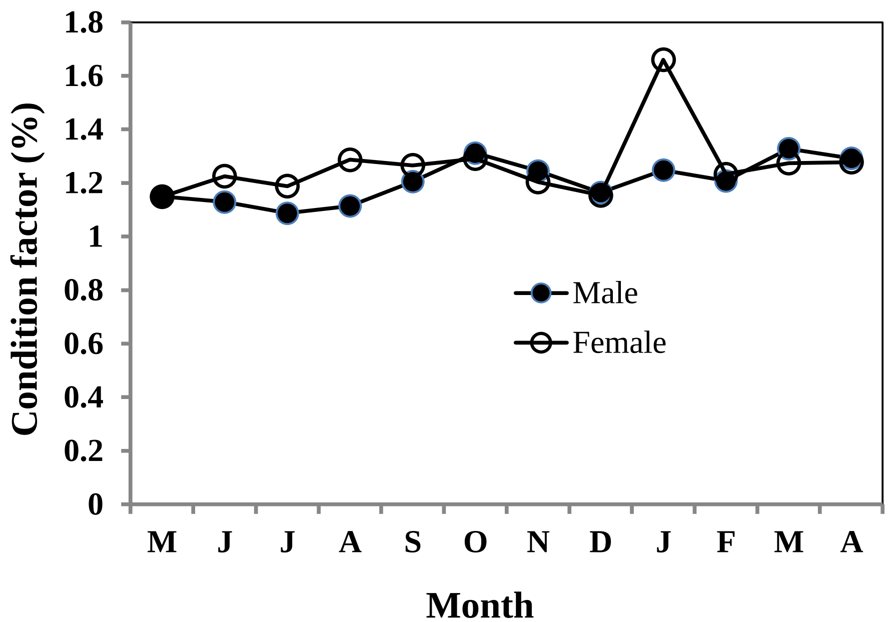


Figure 5.6 Monthly Fulton`s condition factor of male and female *E. paludinosus* in Lake Boyo

5.3.5 Food and feeding habits

The gut contents of 513 samples of *E. paludinosus* samples were analysed to examine diet composition and feeding habits of the fish in Lake Boyo. From these 120 (23.4%) were empty guts whereas 393 (76.6%) contained some food items in their guts. The food items were catagorized under five taxonomic groups including detritus, macrophytes, insects, zooplankton and phytoplankton. Detritus, macrophytes and phytoplankton occurred in 98.22%, 75.6% and 39.44% of the fish guts, respectively, and volumetrically constituted 64.12%, 22.1% and 10.31% of the food items, respectively. The contribution of insects and zooplankton was less and they occurred in 19.08% and 6.62% fish guts and volumetrically constituted 2.50% and 0.40% of the food items, respectively (Table 5.3).

From the results, detritus, macrophytes and phytoplankton were the dominant food items while insects and zooplankton were less important in their contribution to the diet of *E. paludinosus.* Elias Dadebo *et al.*, (2013) reported six food categories namely insects, detritus, macrophytes, phytoplankton, zooplankton and ostrcods consumed by *E. paludinosus* in Lake Ziway. According to the above authors insects and detritus were the dominant food categories while macrophytes, phytoplankton, zooplankton and ostracods were relatively of minor importance. Ostracods that were of relatively low importance in the study of Elias Dadebo *et al.,* (2013) were not found at all in the present study. Other food categories, albeit in different proportions, were observed in the guts of *E. paludinosus* in both environments. On the other hand Zerihun Desta *et al.,* (2007) reported only four food categories namely, ostracods, aquatic insects, gastropods a small cyprinidont fish (*Aplocheilichthys antinorii*).

In the wet season detritus, macrophytes and phytoplankton occurred in 100%, 69.83% and 15.09% fish guts and volumetrically constituted 75.03%, 21.35% and 1.04% of the food items, respectively. The contribution of insects and zooplankton was less and occurred in 7.76% and 3.88% fish guts and volumetrically constituted 0.98% and 0.11% of the food items, respectively (Table 5.4). In the dry season detritus, macrophytes and phytoplankton occurred in 95.65%, 83.85% and 75.53% fish guts and volumetrically constituted 57.2%, 22.6% and 16.4% of the food items, respectively. The contribution of insects and zooplankton was also less and occurred in 33.54% and 11.8% fish guts and volumetrically constituted 3.13% and 0.7% of the food items respectively (Table 5.5).

Table 5.3 Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *E. paludinosus* in Lake Boyo (n=393).

Food items	**Frequency of occurrence**		**Volumetric contribution**	
	Frequency	**Percent**	**Volume (ml)**	**Percent**
Detritus	**386**	**98.22**	**19.49**	**64.12**
Macrophytes	**297**	**75.6**	**6.72**	**22.10**
Insect	**75**	**19.08**	**0.7**	**2.5**
Zooplankton	**26**	**6.62**	**0.12**	**0.4**
Phytoplankton	**155**	**39.44**	**3.13**	**10.31**
Diatoms	137	34.9	2.42	7.96
Green algae	54	13.74	0.424	1.4
Bluegreen algae	56	14.25	0.23	0.92
Euglenoids	2	0.51	0.011	0.03

Some differences were noted in the proportion of certain food items between the dry and wet periods. The proportion of insects and phytoplankton was higher during the dry months than wet months while the proportion of detritus and macrophytes was high during the wet months than dry months. The reason for this difference could be the difference in the availability and abundance of various food items in the environment during the two seasons. The factors likely responsible for the differences could be runoff from the catchement areas.

Table 5.4 Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *E. paludinosus* in wet season in Lake Boyo (n=232).

Food items	**Frequency of occurrence**		**Volumetric contribution**	
	Frequency	**Percent**	**Volume (ml)**	**Percent**
Detritus	**232**	**100**	**8.99**	**75.03**
Macrophytes	**162**	**69.83**	**2.58**	**21.35**
Insect	**18**	**7.76**	**0.12**	**0.98**
Zooplankton	**9**	**3.88**	**0.013**	**0.11**
Phytoplankton	**35**	**15.09**	**0.124**	**1.04**
Diatoms	25	10.78	0.09	0.74
Green algae	15	6.5	0.017	0.14
Bluegreen algae	11	4.74	0.002	0.015

Large quantities of detritus may drain into Lake Boyo with run-off during the rainy season from the catchment area which increases the proportion of decomposed plant and animal materials in the diet of *E. paludinosus*. Since the proportion of food items and their abundance change at different times of the year, the fish often shows seasonal diet shifts (Kariman *et al.*, 2009).

The feeding habits of *E. paludinosus* in Lake Boyo could be classified as an omnivorous species as the diet includes a wide spectrum of food items including phytoplankton, zooplnanktons, invertebrates and macrophytes.

Table 5.5 Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *E. paludinosus* in dry season in Lake Boyo (n=161).

Food items	**Frequency of occurrence**		**Volumetric contribution**	
	Frequency	**Percent**	**Volume (ml)**	**Percent**
Detritus	**154**	**95.65**	**15.5**	**57.2**
Macrophytes	**135**	**83.85**	**4.16**	**22.6**
Insect	**54**	**33.54**	**0.58**	**3.1**
Zooplankton	**19**	**11.8**	**0.13**	**0.7**
Phytoplankton	**120**	**75.53**	**3.01**	**16.4**
Diatoms	112	69.57	2.3	12.69
Green algae	39	24.23	0.41	2.22
Bluegreen algae	45	27.95	0.26	1.42
Euglenoids	2	1.24	0.011	0.06

The results of this study agreed with the report of Nagelkerke and Sibbing (2000) which grouped small *Enteromius* species under omnivorous feeding guild. It is also in agreement with the findings of Zerihun Desta *et al.*, (2008) on the omnivorous feeding habits of *Enteromius* species in Lake Hawassa. No fish prey was found in the gut contents of *E. paludinosus* in Lake Boyo. The reason for the absence of fish prey in the present study might be due to the absence of suitable-sized fish prey in the lake Boyo. In contrast to the findings of Elias Dadebo *et al.*, (2013) the present study showed variations in the proportion of food categories consumed by *E. paludinosus* during the dry and wet months. The most notable variation was the contribution of phytoplankton (16.4% by volume) during the dry season in the present study the dry season in lake Ziway (4.9% by volume) (Elias Dadebo *et al.,* 2013).

5.4 Conclusions

The reproductive biology and feeding habits of *E. paludinosus* was studiedbased on monthly samples collected from Lake Boyo. The overall sex ratio (Male: Female) for *E. paludinosus* in Lake Boyo indicated that males and females are nearly equal in numbers. *E. paludinosus* in Lake Boyo breeds throughout the year and the breeding season of the fish had two peaks (the first peak was between October and January and the second reproductive period between March and April). The fecundity of the fish increased with the increase in the fish length and it was correlated with the fish length and weight. The L_m50 indicated that *E. paludinosus* in Lake Boyo exhibited early maturation. *E. paludinosus* in Lake Boyo showed a slight positive allometric growth pattern for males and combined sexes while nearly isometric growth pattern for females. The values of FCF of males and females indicates that *E. paludinosus* in Lake Boyo was in a moderate condition. *E. paludinosus* in Lake Boyo was characterized by omnivorous feeding habits and showed a seasonal variation of food composition. Detritus and macrophytes were the main food items during the wet season, while detritus, macrophytes and phytoplankton were the dominant food items in dry season. The high amount of detritus and low amount of phytoplankton in the dry season and lower condition factor of the fish with reference to other lakes indicates that productivity of Lake Boyo is low. Further research should be carried out on fisheries production potential, phytoplankton and macrophytes of the lake.

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CHAPTER 6: FEEDING HABITS, SIZE AT FIRST MATURITY, BREEDING SEASON AND SEX RATIO OF LAPPING MINNOW *GARRA QUDRIMACULATA* IN LAKE BOYO, ETHIOPIA

Abstract

The lapping minnow *G. quadrimaculata* is mainly found in the Arabian Peninsula (Saudi Arabia and Yemen), south-eastern Eritrea, south-eastern Ethiopia, and possibly also in Somalia. This study aimed to investigate the reproductive biology and feeding habits of the lapping minnow *G. qudrimaculatain* in Lake Boyo. A total of 290 fish samples were collected from the lake between May 2021 and May 2022 using a beach seine. The sex ratio of males to females was significantly different (1:0.73, $p<0.05$) from theoretical 1:1 ratio. Size at first maturity (L_m50) of *G. quadrimaculata* was 5.0 and 4.2 cm TL for males and females, respectively. *G. quadrimaculata* in Lake Boyo breeds throughout the year with two peak breeding seasons: the first peak from June to September and the second peak from January to February. The slope of the length weight relationship (LWR) for males was $TW= 0.0113TL^{2.9851}$, $R^2 = 0.9756$, for females was $TW = 0.0151TL^{2.8619}$, $R^2 = 0.9711$ and for combined sexes was $TW = 0.0117TL^{2.977}$, $R^2 = 0.9766$ showed nearly slight negative isometric growth pattern. The average FCF values for males and females were 1.1 and 1.2, respectively indicating that both sexes have similar mean FCF values. Detritus, macrophytes and phytoplankton were the dominant food items. *G. quadrimaculata* showed a seasonal variation of food composition. Further research is recommended on fishery production, macrophyte, phytoplankton and zooplankton composition, biomass and productivity of Lake Boyo.

Key words: Breeding season; *E. paludinosus*; fecundity; feeding habits; Fulton`s condition factor; Lake Boyo

6.1 Introduction

The genus *Garra* is widely distributed in Ethiopia and contains about 12 species of small barbs that belong to the family Cyprinidae (Froeser and Pauly, 2000; Stiassny and Abebe Getahun, 2007). The minnow *G. quadrimaculata* is mainly found in the Arabian Peninsula (Saudi Arabia and Yemen), south-eastern Eritrea, south-eastern Ethiopia, and possibly also in Somalia (Froeser and Pauly, 2000; Yosef Tekle-Giorgis *et al.,* 2016). The species is indigenous and it is found in many of the Ethiopian Rift Valley lakes and in many of the Ethiopian water bodies, for instance in Gilgel Gibe reservoir (Stiassny and Abebe Getahun, 2007; Mulugeta Wakjira and Abebe Getahun, 2017). Some *Garra* species are abundantly found in the country's water bodies. For example, a recent report from Ethiopia on fish diversity in the River Debbis showed that *G. quadrimaculata* and *G. chebera* are the most dominant species (Urga *et al.*, 2017).

G. quadrimaculata is a benthic, non-migratory, freshwater fish that thrives in tropical climate (Froeser and Pauly, 2000; Yosef Teklegiorgis *et al.,* 2016). It is a small fish that grows to a maximum total length of 15 cm and a weight of 40 g (Yosef Teklegiorgis *et al.,* 2016). These species have not been evaluated for their food value yet (Stiassny and Abebe Getahun, 2007). However, the genus has ecological importance in fisheries, since it is used as a prey fish for African catfish (*Clarias gariepinus*) and Labeobarbus (*Labeobarbus intermedius*), which are commercially important fish species in the country (Elias Dadebo, 2000). The numerous species of the genus *Garra* in the country have been overlooked, although they could play a role in aquatic food production in the country.

G. quadrimaculata feeds on different types of food items including phytoplankton, detritus, sand grains and zooplankton. The study of Bacha Temesgen *et al.,* (2023) shows that most of the guts examined contained a variety of food items including the decomposed materials like plant fragments mixed with periphyton, diatoms and green algae. *G. quadrimaculata* in different water bodies in Ethiopia fed on different types of food items including phytoplankton, detritus, sand grains and zooplankton (Alemayehu Eshete, 2009; Yosef Teklegiorgis *et al.*, 2016; Urga *et al.*, 2017).

6.1.1 Objectives of the study

6.1.1.1 General objective

The general objective of this study was to study some aspects of the reproductive biology and feeding habis of *G. quadrimaculata* in Lake Boyo.

6.1.1.2 Specific objectives

1. To study the reproductive biology of *G. quadrimaculata* such as breeding season, size at first maturity, fecundity, and sex ratio, in Lake Boyo.
2. To investigate the diet composition and seasonal variation on the feeding habits of *G. quadrimaculata* in Lake Boyo.
3. To determine the length-weight relationships and condition factor of *G. quadrimaculata* in Lake Boyo.

6.2 Materials and methods

6.2.1 Sampling

Samples of *G. quadrimaculata* were collected from the littoral and open lake sites as indicated in chapter 3 materials and methods section 3.2

6.2.2 Reproductive biology

Methods for studying reproductive biology (determination of sex ratio, Lm50, breeding season and fecundity) of *G. quadrimaculata* were described in the materials and methods in chapter 3, under section 3.3 (sub sections 3.3.1 – 3.3.4).

6.2.3 Food and feeding habits of *G. quadrimaculata*

The gut content analysis of *G.quadrimaculata* was carried out according to the general materials and methods in chapter 3 section 3.4.

6.3 Results and discussion

6.3.1 Reproductive biology of *G. quadrimaculata*

6.3.1.1 Breeding season

The result of gonad maturity stages in this study (Figure 6.1) showed that *G. quadrimaculata* in Lake Boyo breeds throughout the year and it had two peak breeding seasons: the major peak from May to August and the second peak in the months of October and February. This result is in agreement with Mizra and Javed, (1988) in that, in general, the breeding season of *G. quadrimaculata* occurs from June to August.

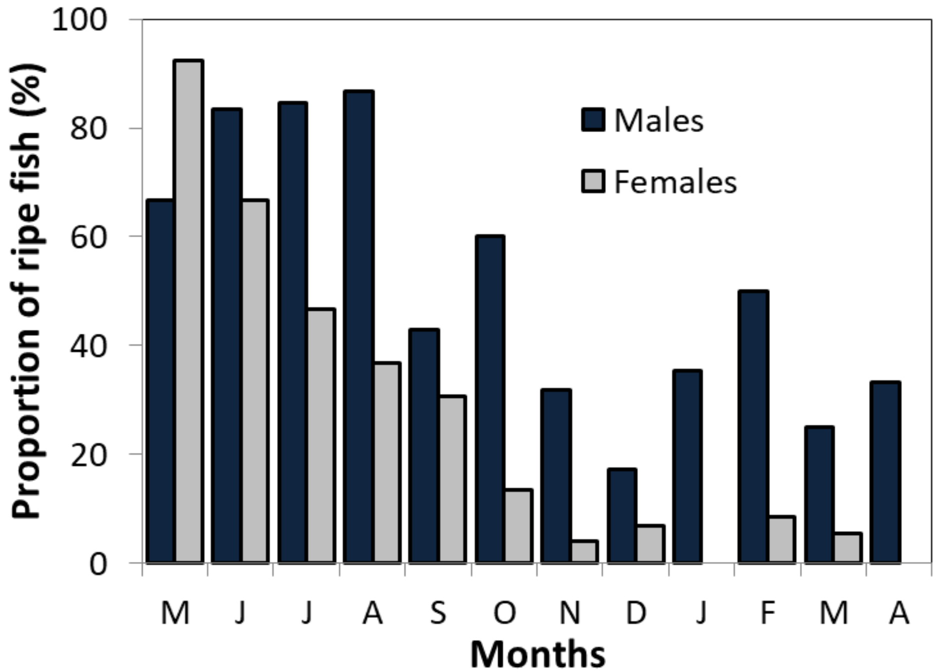

Figure 6.1 Breeding season of *G. quadrimaculata* in Lake Boyo

6.3.1.2 Length at first maturity (L_m50)

The L_m50 obtained for *G. quadrimaculata* in this study (Figure 6.2) was 5.0 cm and 4.2 cm TL for males and females, respectively.

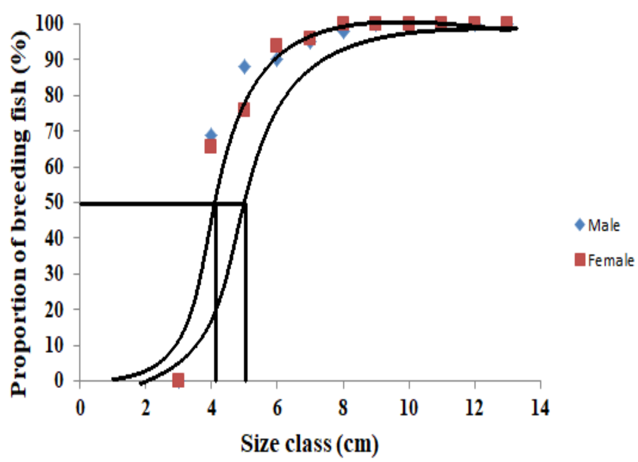

Figure 6.2 L_m50 of male *Garra quadrimaculata* from Lake Boyo

The L_m50 (Figure 6.2) shows that females *G. quadrimaculata* appeared to attain sexual maturity at smaller size than males. It is in agreement with the findings of Bacha Temesgen *et al.*, (2023) from upper Awash river, Ethiopia and Garomsa (2017) from Cholle Stream of Guder tributary for the same species.

6.3.1.3 Sex ratio

The size of sampled males ranged from 3.8 to 12.8 cm in TL, and in weigh between 0.6 to 20g. The TL and TW of females ranged from 3.9 to 12.4 cm and 0.9 to 16.1 g, respectively. 290 fish samples were examined for sex determination. Out of these, 168 were males (57.9%) and 122 were females (42.1%). The overall sex ratio (male: female) was 1:0.73 which was significantly different from the hypothetical 1:1 sex ratio ($p < 0.05$) (Table 6.1).

Table 6.1 Male to female sex ratio of *G. quadrimaculata* sampled in different months of the year in Lake Boyo.

Sampling Month	Male	Female	M:F Sex ratio	Chi-square
May	7	2	1:0.29	2.77
June	6	3	1:0.5	1
July	13	15	1:1.15	0.14
August	15	7	1:0.46	2.91
September	14	13	1:0.93	0.04
October	25	7	1:0.29	10.12*
November	6	5	1:0.8	0.09
December	31	20	1:0.65	2.37
January	17	9	1:0.53	2.46
February	12	9	1:0.75	0.39
March	10	13	1:1.3	0.39
April	12	19	1:1.58	1.58
Total	**168**	**122**	**1:0.73**	**7.45***

* indicates significant differences ($p<0.05$)

The result on the analysis of sex ratio at different size classes of *G.quadrimaculata* showed that, there were significantly more males than females for the size classes 7.0-8.9 cm, whereas more females than males for the size class 5.0-6.9 cm TL (Table 6.2). However, for the smaller (3.0 - 4.9 cm TL) and larger (11.0-12.9 cm TL) size classes, there was nearly equal distribution. But for the medium size class (7.0-10.9 cm TL), there was no significant difference at 5% level of significance.

Table 6.2 Male to female sex ratio of *G. quadrimaculata* in different size classes of Lake Boyo

Size class (cm)	Male	Female	Sex ratio	Chi-square
3.0-4.9	4	5	1: 1.25	0.11
5.0-6.9	53	18	1: 0.34	17.25**
7.0-8.9	89	67	1: 0.75	3.10
9.0-10.9	18	27	1: 1.5	1.8
11.0-12.9	4	5	1: 1.25	0.11
Total	**168**	**122**	**1: 0.73**	**7.29***

* indicates significant differences (p<0.05)

The sex ratio (Table 6.1) obtained for *G. quadrimaculata* in this study showed the dominance of females over males. This result is in agreement with the report of Garomsa (2017) in Cholle stream and Bacha Temesgen *et al.* (2023) in Upper Awash River which showed the dominance of females of *G. quadrimaculata* over males.

6.3.2 Length-length relationships

6.3.2.1 TL and FL

The relationship between TL and FL (Figure 6.3) of *G. quadrimaculata* was linear (n= 290; R^2= 0.9923, $p<0.05$) and it is expressed by the equation: FL = 0.9461TL - 0.2713.

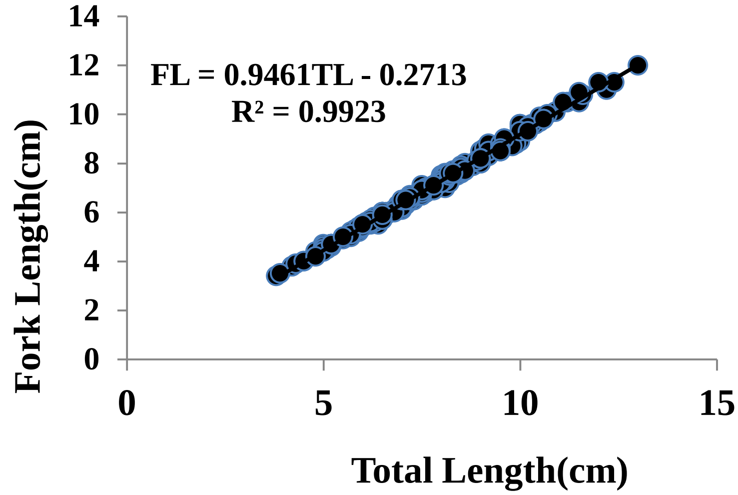

Figure 6.3 Relationship of TL and FL of *G. quadrimaculata*

6.3.2.2 TL and SL

The relationship between TL and FL (Figure 6.4) of *G. quadrimaculata* was linear (n= 283; R^2 = 0.9851, p<0.05) and it is expressed by the equation: SL = 0.7994TL + 0.0242.

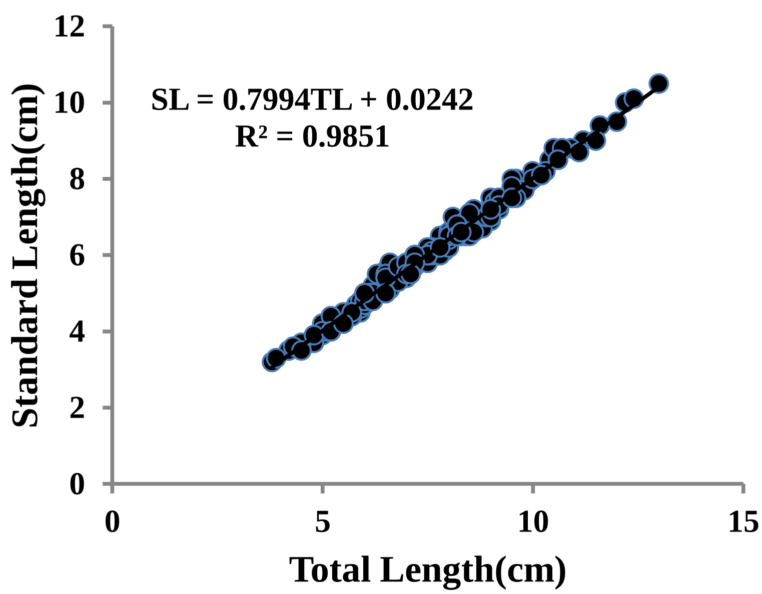

Figure 6.4 Relationship of TL with SL of *G. quadrimaculata*

6.3.3 Length weight relationship (LWR)

The relationship between TL and TW (Figure 6.5a) of male *G. quadrimaculata* from Lake Boyo was curvilinear (n= 168; R^2 = 0.9756, $p<0.05$) and it is expressed by the equation: $TW = 0.0113TL^{2.9851}$. The relationship between TL and TW (Figure 6.5b) of female *G. quadrimaculata* was also curvilinear (n= 122; R^2 = 0.9711, $p<0.05$) and it is expressed by the equation: $TW = 0.0151TL^{2.8619}$. The relationship between TL and TW (Figure 6.5c) of combined sexes of *G. quadrimaculata* was curvilinear (n= 290; R^2 = 0.9766, $p<0.05$) and it is expressed by the equation: $TW = 0.0117TL^{2.977}$.

The LWR of *G.quadrimaculata* in this study (Figure 6.5a, b and c) showed strong correlation (R^2= 0.9756, 0.9711 and 0.9766 for males, females and combined sexes, respectively) and the "b" value (2.9851, 2.8619 and 2.977 for males, female and combined sexes, respectively) showed slight negative allometric growth pattern for the females while males and combined sexes showed isometric growth pattern. This allometric growth pattern of the females is inline with the findings of other researchers in different water bodies. For example, in the upper Awash River (b=2.74) (Bacha Temesgen *et al.,* 2023) and Debbis River (b=2.614) (Urga *et al.,* 2017). The difference could probably be because of the differences in food availability, gonad development and spawning period of the fish species (Bagenal and Tesch, 1978).

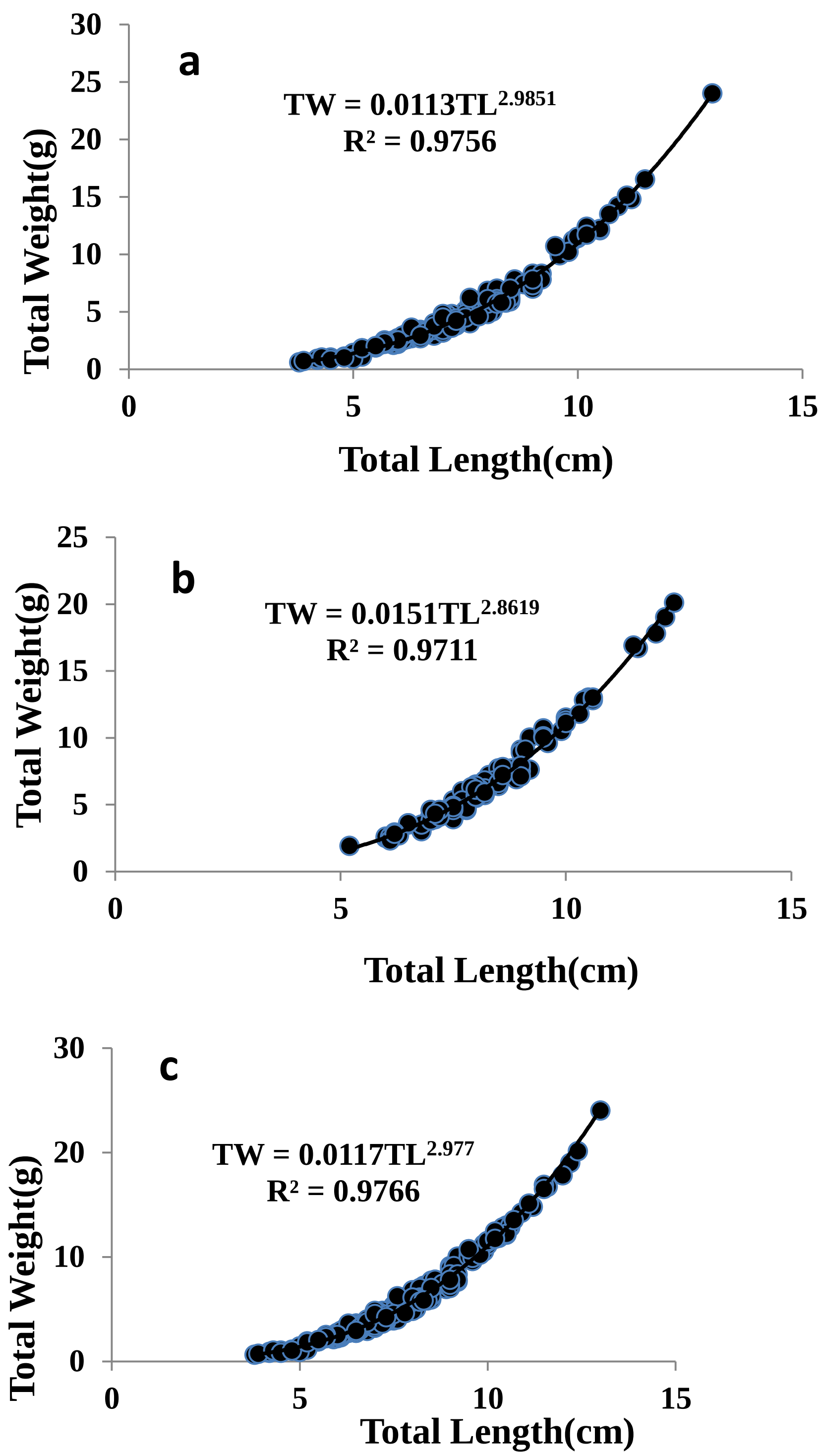

Figure 6.5 Length weight relationship of male (a) female (b) and combined sex (c) of *G. quadrimaculata* in Lake Boyo

6.3.4 Fulton`s condition factor (FCF)

Monthly mean FCF values ranged from 1.0 to 1.2 and 0.9 to 1.2 for males and females respectively (Figure 6.6). The average FCF value for male and female was 1.1 and 1.12, respectively.

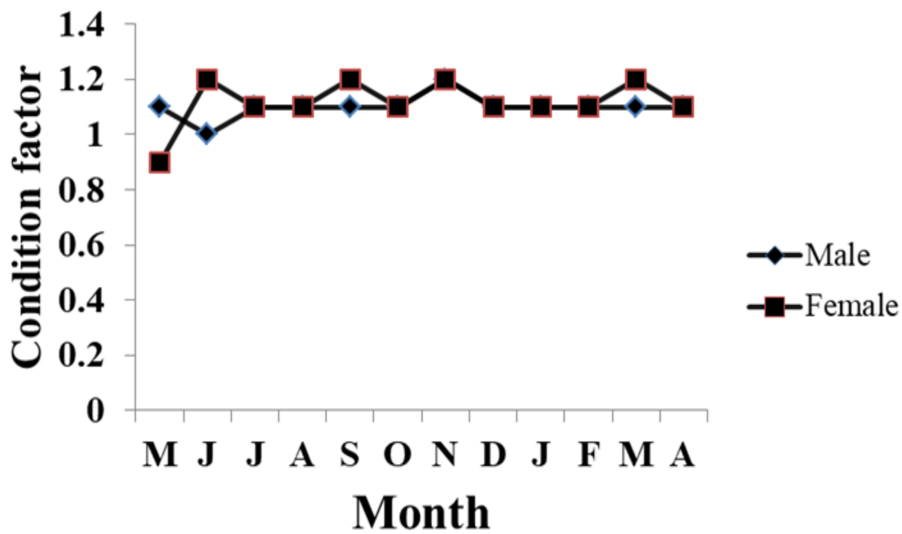

Figure 6.6 Fulton`s condition factor of male and female *G. quadrimaculata* in Lake Boyo

The condition factor of *G. quadrimaculata* (Figure 6.6) showed slight variation between the two sexes. It also depicted that female *G. quadrimaculata* has slightly higher mean FCF than males in nearly all sampling months. The result also showed that FCF in Lake Boyo was lower than reported for the same species in different water bodies. For instance, higher FCF values of Garra spp were reported in the upper Awash River (1.31-1.36 and 1.23-1.27 for females and males, respectively) (Bacha *et al.*, 2023), in Debbis River (1.2-1.23 and 1.14-1.31 for females and males, respectively) (Urga *et al.*, 2017), and in Cholle Stream (tributaries of Guder River) (1.12-1.18) (Garomsa F, 2017). But it was comparable with *G. dembecha*, in Lake Hayq (0.8-1.73 and 0.82-1.84 for females and males, respectively (Alemayehu Eshete, 2009).

6.3.5 Food and feeding habits

Gut content analysis (Table 6.3) of *G. quadrimaculata* showed the presence of five categories of food items categorized as detritus, macrophytes, insects, sand particles, zooplankton and phytoplankton. Detritus, macrophytes and phytoplankton were the dominant food items while the contribution of insects and zooplankton was less significant in the diet of *G. quadrimaculata*.

Table 6.3 Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *G. quadrimaculata* in Lake Boyo (n=245).

Food items	Frequency of occurrence		Volumetric contribution	
	Frequency	Percent	Volume (ml)	Percent
Detritus	**222**	**90.61**	**6.756**	**74.01**
Macrophytes	**168**	**68.57**	**1.2645**	**13.85**
Insect	**23**	**9.39**	**0.0315**	**0.35**
Zooplankton	**7**	**2.86**	**0.0215**	**0.24**
Phytoplankton	**85**	**34.69**	**1.0545**	**11.55**
Diatoms	78	31.84	0.767	8.4
Green algae	39	15.92	0.1875	2.05
Bluegreen algae	18	7.35	0.095	1.04
Euglenoids	1	0.41	0.005	0.05

Detritus, macrophytes and phytoplankton occurred in 90.61%, 68.57% and 34.69% fish guts, and volumetrically constituted 74.01%, 13.85% and 11.55% of the food items respectively. The contribution of insects and zooplankton was less and they occurred in 9.39% and 2.86% of fish guts and volumetrically constituted 0.35% and 0.24% of the food items, respectively (Table 6.3).

In the wet season (Table 6.4) detritus and macrophytes occurred in 74.8% and 50.41% fish gut respectively and volumetrically make up 87.39%, 12.4% of food items, while the contribution of zooplankton and phytoplankton was less and occurred in 2.44% and 0.81% fish gut and volumetrically constituted 0.15% and 0.06% of food items.

Table 6.4 Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *G. quadrimaculata* in wet season in Lake Boyo (n=123).

Food items	Frequency of occurrence		Volumetric contribution	
	Frequency	Percent	Volume (ml)	Percent
Detritus	92	74.8	1.4285	87.39
Macrophytes	64	50.41	0.2025	12.4
Zooplankton	3	2.44	0.0025	0.15
Phytoplankton	1	0.81	0.001	0.06

In the dry season (Table 6.5) detritus, macrophytes and phytoplankton occurred in 98.36%, 85.25% and 68.85% fish gut respectively, and volumetrically constituted 71.1%, 14.17% and 18.85% of food items, while the contribution of insects and zooplankton was less and occurred in 18.85% and 3.28% fish gut and volumetrically constituted 0.42% and 0.25% of food items.

Table 6.5 Percentage frequency of occurrence and volumetric contribution of the different food items consumed by *G. quadrimaculata* in dry season in Lake Boyo (n=122).

Food items	Frequency of occurrence		Volumetric contribution	
	Frequency	Percent	Volume (ml)	Percent
Detritus	120	98.36	5.328	71.1
Macrophytes	104	85.25	1.062	14.17
Insects	23	18.85	0.0315	0.42
Zooplankton	4	3.28	0.019	0.25
Phytoplankton	84	68.85	1.0535	14.06

The results of the analyses (Table 6.3) indicated that *G. quadrimaculata* in Lake Boyo fed on a variety of food items including, phytoplankton, detritus, macrophytes, insects and zooplankton. Since there was no published work available on the food and feeding habits of *G. quadrimaculata* in Lake Boyo, the present result is compared with other related species in different water bodies.This result was similar with the results reported from different water bodies in Ethiopia, for instance, (Alemayehu Eshete, 2009) in Lake Hawassa (Yosef Teklegiorgis *et al.*, 2016) in that the fish in Lake Hawassa fed on a variety of food items including, phytoplankton, detritus, macrophytes, insects, fish eggs and zooplankton. Urga *et al.*, (2017) and Garomsa (2017) also reported similar results from Debbis and Guder River, respectively.

Presence of large amounts of detritus in the fish guts indicates that *G. quadrimaculata* is bottom feeder and the presence of various food items plant and animal origin showed the omnivorous feeding habit of the fish (Ayotunde *et al.*, 2007; Ayoade, 2011). When compared with other *Garra* species in other water bodies, for instance, the food item of *G. rufa* in Asi River and its tributaries

(Turkey) is dominated by benthic algae (Cyanobacteria, Chrysophyta and Chlorophyta, with Chrysophyta being the most common), as well as rotifers and protozoans (Yalçin-Özdilek and Ekmekçi, 2006). Similarly, *G. flavatra* in Rakhine State is herbivorous and mainly feeds on algae and detritus (Yalçin-Özdilek and Ekmekçi, 2006). Thus unlike the results of Yalçin-Özdilek and Ekmekçi (2006), the present findings clearly indicated that *G. quadrimaculata* in Lake Boyo is an omnivorous species, although the quanitity of foods of animal origin are relatively low. Seasonal variation has great effect on the contributions of different food items. The most important food items that constituted the bulk of the fish diet during dry season were detritus and macrophytes. The ventrally positioned (ventro-terminal) mouth of *G. quadrimaculata* is particularly suited for feeding on the bottom of the lake. Many bottom feeding fish living in mud showed showed the presence of high percentage of detritus in their guts (Oso *et al.*, 2006).

The contribution of insects and zooplankton was insignificant to the bulk of food consumed in both seasons. During the wet season (Table 6.4), detritus and macrophytes were the most dominant food items. Compared to the dry season, the contribution of detritus was high during the wet season, but the contribution of macrophytes was higher in dry season (Table 6.5) than the wet season.

6.4 Conclusions

The overall sex ratio (male: female) of *G. quadrimaculata* in Lake Boyo was significantly different from the hypothetical 1:1 sex ratio ($p < 0.05$) in that males were more abundant than females. The L_m50 indicated that *G. quadrimaculata* exhibited early sexual maturity. *G. quadrimaculata* in the lake exhibited slight negative allometric growth pattern. The FCF of male and female indicated that *G. quadrimaculata* in Lake Boyo was not in a good condition throughout the study period. *G. quadrimaculata* in Lake Boyo shows bottom feeding behavior because of high presence of detritus in the gut and was also characterized by omnivorous feeding habits and showed a seasonal variation of food composition. Detritus and macrophytes were the main food items during the wet season, while detritus, macrophytes and phytoplankton were the dominant food prey in dry season.

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CHAPTER 7. ASSESSMENT ON SOME PHYSICO-CHEMICAL CHARACTERISTICS OF WATER IN LAKE BOYO

Abstract

The physico-chemical characteristics of water greatly influence the production, distribution and richness of biota. The objective of this study was to assess the physico-chemical characteristics of Lake Boyo is suitable for fish production. Water samples were taken from the littoral and open lake sites in the dry and wet seasons in the year 2022. *In-situ* measurements were carried out immediately in the lake whereas laboratory studies were carried out in the water quality laboratory of Hadiya Zone Water, Minerals and Energy Office. Mean range of the physico-chemical parameters were: temperature 22.9-23.7°C, pH 8.7-9.2, electric conductivity 104.1-113.7 µS /cm, turbidity 200-235 NTU, TDS 52.03-56.9 mg/L, nitrate (NO_3^-) 4.3815-5.6938 mg/L, and phosphate (PO_4^{3-}) 3.3-6.6 mg/L. The lake water was slightly warm, alkaline, contained more TDS and EC, very turbid and with high inorganic nutrients (NO_3^- and PO_4^{3-}). The temperature and pH fall within the normal range of natural tropical waters and thus the lake water is considered favorable for fish survival and production. The electric conductivity of Lake Boyo was also in the optimum level for the fish species in the study lake. The turbidity level was above the optimum range for the fish species in the lake. The nitrate level was in the suitable range for the fish species inhabiting the study lake whereas the phosphate level was above the suitable level for the fish. Generally, based on the results of the nutrient condition, it is concluded that Lake Boyo is low productive inland freshwater ecosystem in the Ethiopian Rift Valley basin. Further research is recommended on dissolved oxygen of Lake Boyo.

Key words: *In-situ*; Lake Boyo; pH; physico-chemical; temperature; total dissolved solids; turbidity

7.1 Introduction

The productivity of water bodies can be obtained only when the physical and chemical parameters are present at optimum level. Water quality deals with the physical, chemical, and biological characteristics in relation to all other hydrological properties (Aminu *et al.,* 2017). The quality of water in any ecosystem provides significant information about the available resources for supporting life in that ecosystem and it provides the basis for judging the suitability of water for its designated uses and to improve existing conditions (Shined *et al.,* 2011).

The physical and chemical properties of water greatly influence the distribution and richness of biota (Zinabu Gebremariam, 1994). A property such as high dissolved oxygen in water is an essential pre-requisite for satisfactory aquatic life (Yezbie Kassa, 2016). The techniques of analyzing physical and chemical properties to assess water bodies are essential. They also reveal the concentrations of known environmental contaminants which could reduce such water unfit for human consumption and other purposes (Venkatesharaju *et al.*, 2010).

Water quality parameters such as temperature, turbidity, nutrients, hardness, alkalinity, dissolved oxygen, etc. are some of the important factors that determine the growth of living organisms in the water body including fish (Smitha, 2013). Fish populations are highly dependent upon the physicochemical characteristics of their aquatic habitat which supports their biological functions (Furhan *et al.,* 2004; Ojutiku and Kolo, 2011; Mushahida-Al-Noor and Kamruzzaman, 2013). Marshall and Elliot (1998), noted significant correlations between a number of individual fish species and water temperature, salinity, dissolved oxygen and depth. These factors are responsible for distribution of organisms in different fresh water habitats which allow them to survive in a specific habitat (Jeffries and Mills, 1990). Temperature plays an important role for controlling the physico-chemical and biological parameters of water and considered as one of the most important factors in the aquatic environment particularly for freshwater (Singh and Mathur, 2005).

Nutrients supplement from the lake watershed may influence the water quality and trophic status of lake water. Excessive inputs of nutrients (compounds of nitrogen and phosphorous) to the water body leads to the increased growth of algal biomass, and therefore causes reduction in dissolved oxygen, water transparency, resulting in decline in water quality and subsequent adverse effects on human and lake ecosystem (Kane *et al.*, 2014; Wilkinson, 2017).

The input and accumulation of nitrogen and phosphorus have been reported as the most important sources of eutrophication (Paerl, 2009). There is a preliminary consensus that phosphorus dominates primary production in freshwater lakes, while nitrogen controls the productivity of marine systems (Anderson *et al.,* 2002; Paerl, 2009).

Water quality assessment involves the analysis of physico-chemical, biological and microbiological parameters that reflect the biotic and abiotic status of the ecosystem (Verma *et al.,* 2012). Hence, it has become obligatory to analyze at least the important water quality parameters when ecological studies on aquatic ecosystems are carried out (Zinabu Gebremariam *et al.*, 2002).

The aim of this study was to determine some physicochemical characteristics of Lake Boyo in relation to the potential of the lake for fish production.

7.1.1 General objective

- ❖ To determine some physicochemical parameters of the water in Lake Boyo.

7.1.1.1 Specific objectives

- ❖ To examine some physical characteristics of the lake water such as pH, temperature.
- ❖ To determine the level of nitrate and phosphate in the lake water for fish production.
- ❖ To analyse major nutrients such as nitrate and phosphate levels in reference to lake productivity.

7.2 Materials and methods

7.2.1 Water sampling site selection and sampling

Sampling water from the determined littoral and open water sampling sites of the lake were carried out based on the materials and methods mentioned in chapter 3 section 3.5 (sub section 3.5.1)

7.2.2 Sampling protocol

For the analysis of various physical and chemical parameters, routine water sample collections were carried out in dry and wet seasons from two predefined sampling sites based on the materials methods mentioned in chapter 3 section 3.5 (sub-section 3.5.1).

7.2.3 *In-situ* and laboratory measurements

In-situ measurements of temperature, electrical conductivity, and pH were carried out using a portable multimeter (Model HQ 40d Multi Hach Lange) at different depths within the euphotic area following the materials and methods mentioned in chapter 3 section 3.5 (sub section 3.5.2-3.5.3).

7.3 Results and discussion

7.3.1 Temperature

The surface water temperature in Lake Boyo ranged from 18.2^0C to 27.5^0C at the littoral site, while 18.5^0C to 28.9^0C at the open site of the lake. The minimum temperature was recorded in wet period (June to September) and dry period (October to December) were 18.2^0C and 27.5^0C, respectively, while the maximum value of temperature observed in wet period (June to September) and dry period (October to December) were 18.5 ^{0}C and 28.9^0C, respectively.

The surface water temperature of Lake Boyo recorded during this study (18.2-28.9^oC mean= 23.55 ^{o}C) (Table 7.1) is comparable with the water temperature reported from some rift valley lakes of Ethiopia. For instane, it is closer to the fresh water lakes like Lake Ziway (Lemma Abera, 2016), Lake Langeno (23.54 ^{o}C) (Mathewos Temesgen, 2018), Lake Hawassa (Begashaw Abate *et al.*, 2015), Lake Hawassa (20.5-28.4^0C) (Demke Kifle, 1985), Lake Ziway (18.5-27.5^0C) (Girma Tilahun, 1988), Lake Langano (18-27^0C) (Kassahun Wodajo, 1982), and Lake Chamo (23-30^0C) (Eyasu Shumbulo, 2004) and the saline Lake Abijata (18-27^0C) (Kassahun Wodajo, 1982). But it was less than those reported from Lake Chamo (Adane Fenta and Almaz Kidanemariam, 2016) and Tekeze Reservoir (Dereje Tewabe *et al.,* 2010). This could be attributed to the difference in temperature of the area, for instance, Lake Chamo is located in the hottest humid area (Adane Fenta and Almaz Kidanemariam 2016). The variation in water temperature can influence metabolic activities of fish, which results in the variation of fish growth, body condition and species distribution (Langland and Cronin, 2003; Adane Fenta and Almaz Kidanemariam 2016).

Table 7.1 *In situ* determinations of some physicochemical parameters at littoral and open site during wet and dry reason in Lake Boyo.

Physical characteristics	**Season**	**Shore site (Allage Gimbichu)**	**Open water (Woldaya)**
Temperature (^{o}C)	Dry	27.5	28.9
	Wet	18.2	18.5
	Mean	22.9	23.7
pH	Dry	9.1	9.5
	Wet	8.3	8.8
	Mean	8.7	9.2
Electric conductivity (µS/cm)	Dry	87.4	84.1
	Wet	140	124
	Mean	113.7	104.1

The highest temperature recorded in dry season was 28.9°C and could be due to high solar radiation, low water level, clear atmosphere and high atmosphere temperature. The lowest temperature reported during wet season was 18.2°C and this could due to cold low ambient temperature and shorter photoperiod.

The temperature of 25-30^{o}C is a normal temperature range of natural tropical water for the survival of aquatic life (Eyo *et al.*, 2008). Temperature below 14°C and above 39.5°C is harmful to fish particularly to tropical species (Hossain *et al.,* 2012). Studies have shown that for *O. niloticus* temperatures between 25-30^{o}C are considered ideal for spawning and egg development in *O. niloticus* (El-Sayed, 2006). *E. paludinosus* displays optimal feeding rates at tempertures ranging from 22-26^{o}C, where their metabolic processes are most efficient for nutrient assimilation and growth (Froese and Pauly, 2021). Optimal reproductive performance of *E. paludinosus* is typically observed within a temperature range of 24-28^{o}C. *G. qudrimaculata* exhibit increased feeding activity at temperatures between 20-25^{o}C, which corresponds to their metabolic requirements for growth and maintenance (Froese and Pauly, 2021). Reseach by Liu *et al.*, (2014) suggests that *G. qudrimaculata* exhibit successful spawning and egg development within a temperature range of 22-28^{o}C. The determined water temperature range in this study is with in the range of that supports different vital activities of the fish speacies in Lake Boyo. Therefore, it can be concluded that the lake water is considered suitable for the fish species in the lake.

7.3.2 pH

The pH of Lake Boyo ranged from 8.3 to 9.1 at the littoral site and from 8.8 to 9.5 at the open site of the lake. This indicates that Lake Boyo is an alkaline lake. The pH recorded in Lake Boyo in this study (8.7-9.2) (Table 7.1) was lower than the mean pH recorded in Lake Langeno (9.45) (Mathewos Temesgen, 2018). However, it is higher from the report made from Koka Reservoir (8.11-8.6) (Elizabeth Kebede, 1996), Lake Abaya (7.85-9.0) (Zinabu Gebremariam *et al.*, 2002), Lake Langeno (8.91) (Zinabu Gebremariam *et al.*, 2002), Lake Ziway (8.84-8.96) (Girma Tilahun and Ahlgren, 2010), Lake Tana (6.69- 7.48) (Shewit Gebremedhin *et al.*, 2014), Lake Hawassa (6.98-7.59) (Begashaw Abate *et al.*, 2015), and Lake Chamo (8.45- 9.02) (Adane Fenta and Almaz Kidanemariam, 2016). Yet, it is less than that reported by Zinabu Gebremariam *et al.*, (2002) from Lakes Abijata (9.5-10.3) and Shalla (9.4-10.2).

The high value of pH shows the high consumption of free CO_2 by algae, which results in H^+ concentration and influences the distribution of the aquatic organisms (Adane Fenta and Almaz Kidanemariam, 2016). The minimum pH values (i.e., pH= 8.8 at the open-water site and 8.3 at littoral site) in Lake Boyo are within the maximum permissible limits (WHO, 2006) for fish production and for the survival of other aquatic life (6.5-8.5 or 9.0). The increase in pH values in aquatic systems such as Lake Boyo could be associated with the daily cycle of photosynthetic activity, where by day the peak hours of solar radiation enhances photosynthesis followed by a rise in pH, leading to a more alkaline situation than in the morning. The decrease in pH during the period of the main rainy season might be due to dilution caused by the rainwater that may result from the production of CO_2 from biological oxidation process (Tadesse Ogato, 2007) and may have contributed to the reduction of pH.

The present study revealed that the pH range (8.7-9.2) determined for Lake Boyo (Table 7.1) is suitable for the fish species as the standard of EPA, (2001), in that fish generally thrive in neutral to slightly alkaline conditions with the standard range of pHvalue 6.5 to 9.0. El-Sayed (2006), also indicated the optimum pH range, for instance, for *O. niloticus* it is typically between 6.5 and 9.0 and the fish species performed best in terms of growth and reproduction at a pH range of 7.0-8.5. Similarly, for *E. paludinosus* it is generally between 6.0 and 8.0. In the case of *G. quadrimaculata*, the optimum pH range is typically between 6.5 and 8.0 and the fish species exhibited optimal growth and reproduction at a pH range of 7.0-7.5 (Vishwanath and Shanta Kumar, 2010). The pH value of Lake Boyo was within the permissible limit (6.5- 9.0) for aquatic life (EEPA, 2003). Accordingly, the pH value recorded throughout the study time in Lake Boyo is favorable for the fish species since the optimum pH value falls within this range for most of freshwater fish species.

7.3.3 Electrical conductivity (EC)

The electrical conductivity of surface water in Lake Boyo varied from 87.4 µS/cm to 140 µS/cm at the littoral site and 84.1 µS/cm to 124 µS/cm in the open water. The highest electrical conductivity observed during dry season was 87.4 µS/cm, while in the wet season it was 140 µS/cm (Table 7.1).

The mean EC recorded in the present study was within the suitable standard according to Environment Canada (2001) in that the standard range for EC is 50 - 1500 µS/cm for most freshwater fish. The EC of Lake Boyo was in the optimum level for the fish species in the study lake in that, *O. niloticus* can tolerate electric conductivity levels ranging from 100 to 800 µS/cm for optimal feeding and reproduction (El-Sayed, 2006), *E. paludinosus* is generally recommended to maintain electric conductivity levels below 500 µS/cm to support the feeding and reproduction in freshwater bodies (IUCN, 2021). Electric conductivity for *G. quadrimaculata* is also generally advisable to keep levels below 800 µS/cm to ensure optimal feeding and reproduction condition (Kottelat and Freyhof, 2007).

The result for EC is much lower than values reported for Lake Langeno by Zinabu Gebremariam *et al.*, (2002) (1632.0 µS cm^{-1}) and Mathewos Temesgen, (2018) (the mean EC 1782.1 µS cm^{-1}). It was also lower than values reported from Lake Ziway (Lemma Abera, 2016), Lake Hawassa (Admasu Woldesenbet, 2015) and Koka Reservoir (Zinabu Gebremariam *et al.*, 2002), upper Awash River basin (187.65 ± 1.84 to 495.39 ± 1.02 µS/cm) (Bacha Temesgen *et al.*, 2021), Guder River (326 ± 7.54 to 608.67 ± 168.62 µs/cm) (Garomsa F, 2017), Modjo River (910 ± 186.6 µS/cm) (Sitotaw B, 2006), Debbis River (922 ± 12.29 µS/cm) (Urga *et al.*, 2017) and Lake Hayq (900.6 µS/cm) (Alemayehu Eshete, 2009). The variation in EC of inland waters depends on many factors like concentration, charge and mobility of ions in the water, which is directly affected by water temperature, TDS and salinity (Miller *et al.*, 1988).

Table 7.2 Laboratory determinations of some physicochemical parameters at littoral and open site during wet and dry reason in Lake Boyo.

Physical characteristics	**Season**	**Shore site (Allage Gimbichu)**	**Open water (Woldaya)**
Turbidity (NTU)	Dry	180	160
	Wet	290	240
	Mean	235	200
Total dissolved solid (mg/L)	Dry	43.7	42.05
	Wet	70	62
	Mean	56.9	52.03
Nitrate (NO_3^-) (mg/L)	Dry	1.628	2.1736
	Wet	7.135	9.214
	Mean	4.3815	5.6938
Phosphate (PO_4^{2-}) (mg/L)	Dry	3.3	6.6
	Wet	12.4	18.5
	Mean	7.85	12.55

7.3.4 Turbidity

The result depicted that Lake Boyo is very turbid lake with turbidity ranging from 180 to 290 NTU and 160 to 240 NTU at the littoral and open sites of the lake, respectively. Lake Boyo was highly turbid throughout the year. Turbidity significantly varied seasonally with high values during the wet season. Comparatively, low turbidity was observed in the dry season.

The turbidity level of Lake Boyo was above the optimum range for the fish species based on the New Zealand Ministry for the Environment (2001) standard range in thatturbidity <5NTU for optimal conditions; >25 NTU can be harmful for aquatic life. The optimum turbidity for *O. niloticus* generally falls 10-100 NTU and but it can adapt to a wide range of turbidity levels (El-

Sayed, 2006). The optimum turbidity range for *E. paludinosus* is usually between 5-30 NTU. The optimum range of turbidity for *G. quadrimaculata* is typically between 10-50 NTU. A study by Vishwanth and Shanta (2010) also found that *G. quadrimaculta* prefer moderately clear waters for feeding and reproduction.

7.3.5 Total dissolved solids (TDS)

Comparatively higher TDS with high values were observed in the wet period (April to September) than dry period (January to March). The result of TDS in this study (56.9 and 52.03 mg/L in littoral and open sites, respectively with the mean value of 54.5 mg/L) (Table 4.1) is lower than the report of Berhanu Rabo (2008) from Lake Zeway (270.0 mg/L), Admasu Woldesenbet (2015) from Lake Hawassa (455.6 mg/L), Adane Fenta and Almaz Kidanemariam (2016) from Lake Chamo (656.0 mg/L) and Mathewos Temesgen, (2018) from Lake Langeno (1512.9 mg/L). The maximum limit for TDS as suggested by WHO is 500 mg/L.

The TDS value of Lake Boyo is low with regard to the fish species in the lake since WHO (2011), the standard range of TDS is 100 to 500 mg/L for most freshwater species; levels above 1000 mg/L can be harmful. High TDS can indicate pollution and affect aquatic life through osmotic stress. The optimum TDS range for *O. niloticus* is being generally 200-1000 mg/L(El-Sayed (2006), *O. niloticus* can tolerate a wide range of TDS levels but perform best within this range. The optimum TDS range for *E. paludinosus* is typically 100-300 mg/L. The optimum range of TDS for *G. quadrimaculata* can vary, but generally falls between 100-500 mg/L. Accordingly, Lake Boyo contains low TDS level which is suitable for fish production. The TDS value of Lake Boyo is within the permissible limit for aquatic life (EEPA, 2003).

7.3.6 Nitrate (NO_3^-) and Phosphate (PO_4^{3-})

In the present study, high amount of nitrate was recorded during wet season (mean= 8.2 mg/L) that could be due to the influx of nitrogen rich flood water into the lake water from the catchment area. The lowest amount of nitrate in the lake water was recorded during dry season (mean= 1.9 mg/L) (Table 7.1) and could be due to the utilization by plankton and aquatic plants for metabolic activities. The result also showed high amount of phosphate (mean= 15.5 mg/L) during wet season, while the lowest amount was recorded during dry season (2.1736 mg/L). Both NO_3-N and PO_4-P were lower during the dry months (1.628-2.1736 and 3.3-6.6 mg/L, respectively) than during the wet months (7.135- 9.214 and 12.4-15.5 mg/L). The concentration of NO_3^- and PO_4^{3-} were 4.3815 and 7.85 mg/L at the shore site and 5.6938 mg/L and 12.55 mg/L in the open lake site, respectively.

Nitrate and phosphate are essential nutrients for aquatic organisms, but excessive levels can lead to water quality issues and negatively impact fish health and reproduction. *O. niloticus* requires adequate levels of nitrate and phosphate for optimal growth and reproduction. Studies have shown that nitrate levels between 0.5 to 10 mg/L and phosphate levels of 0.05 to 0.5 mg/L are considered suitable for Nile tilapia aquaculture (FAO, 2011). *E. paludinosus* is also sensitive to nitrate and phosphate levels. It is generally recommended to maintain nitrate levels below 10 mg/L and phosphate level below 0.5 mg/L to support the feeding and reproduction of *E. paludinosus* in freshwater bodies. *G. quadrimaculata* requires balanced nutrient levels for optimal health and reproduction. It is advisable to keep nitrate levels below 10 mg/L and phosphate level below 0.5 mg/L to ensure a suitable environment for *G. quadrimaculata*. From the above results it can be concluded that the nitrate level of Lake Boyo during the study period was in the suitable range for the fish species inhabiting the study lake whereas the phosphate level was above the suitable level

(1 mg/L) for the fish species (EEPA, 2003). The nitrate value of Lake Boyo is within the permissible limit 10 mg/L for aquatic life (EEPA, 2003) and EPA (2013), in that the standard range for nitrate is <10 mg/L for protection of aquatic life.

The phosphate value of Lake Boyo is above the standard for aquatic life **a**ccording to Canadian Council of Ministers of the Environment (CCME, 2004), in that the standard range for phosphate is <0.1mg/L for protection of aquatic ecosystems; higher concentrations can lead to eutrophication.

7.4 Conclusions

The physical and chemical features of Lake Boyo were discussed and generalized that the lake water was slightly warm, alkaline, contained more TDS and EC, very turbid and with relatively high inorganic nutrients (NO_3^- and $PO4^{2-}$) which support most of the aquatic life. During the rainy period, electrical conductivity, turbidity, total dissolved solids, nitrate ions and phosphate ions were high.

The result obtained from the physico-chemical analysis also indicates that most of the parametrs such as turbidity, total dissolved solids, pH, alkalinity and phosphate contents in the lake water are within the suitable range for the fish species. Generally, based on the results of the nutrient condition, it is concluded that Lake Boyo is low productive inland freshwater ecosystem in the Ethiopian Rift Valley basin. To sustain the ecology and aquatic life in the lake, researches should be carried out on lake ecosystem managent.

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CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The results of this study on reproductive biology and feeding habits revealed that the distribution of the fish species was in the hypothetical 1:1 male to female ratio (for *O. niloticus* and *E. paludinosus*) except for *G. quadrimaculata* (significantly different, $p < 0.05$). The L_m50 of the fish species depicted early maturity for all three fish species studied, which could be the result of anthropogenic and environmental stresses. The three fish species breed through out the year with their own peak periods and showed overlap on their breeding times. *O. niloticus* showed mouth brooding strategy in the lake since fertilized eggs were found in the mouthof the fish.

The FCF of the fish species was relatively low with reference to other lakes. The LWR for the three fish species generally showed slight positive allometric growth pattern for *O. niloticus*, nearly isometric growth pattern for *E. paludinosus*, and slightly negative allometric growth pattern for *G. quadrimaculata*. The results of food and feeding habits of the fish species in this study showed that the fish species were ominivourous in their feeding habits. The role of insects and zooplankton to the fish diet was low. The food and feeding habits of all the three fish species showed seasonal variation in diet composition. The three fish species also showed diet overlap, in which detritus was their main food item in the lake.

The results of the physical and chemical features of the lake showed that the lake water is slightly warm, alkaline, contained low TDS, and EC, turbid and with relatively high inorganic nutrients (NO^{3-} and $PO4^{3-}$) which support most of the aquatic life. Generally, based on the results it could be concluded that Lake Boyo is inland freshwater ecosystem in the Ethiopian Rift Valley basin.

8.2 Recommendations

- ✓ This work first and foremost laid down the basic information on the reproductive and feeding biology of the three fish spcies and determined water physico-chemical characteristics of Lake Boyo.
- ✓ Lake Boyo has no buffer zone all around it. The shoreline of the lake was modified by the inflow of domestic wastes from the villages in the watershed. Therefore, shoreline development should be applied.
- ✓ Restoration of riparian vegetation and conservation of the existing macrophytes should be a vital aspect for the maintenance and protection of the degraded Lake Boyo and its environments.
- ✓ Monitoring and management options should be taken for minimizing and reducing further reduction of the water quality of the Lake Boyo including the different agricultural activities.
- ✓ Continuous monitoring of the lake water to protect from any further possible pollutions and contamination of the lake water.
- ✓ Empowering local communities should be done to manage and conserve Lake Boyo
- ✓ Awareness creation should be done on the utilization importance of fishery resource to improve the livelihood of the local community.
- ✓ Researches should be done on lakeecosystem conservation, trophic status of the lake, phytopalankton productivity and abundance.

Appendices

Appendix I: Sample colletion

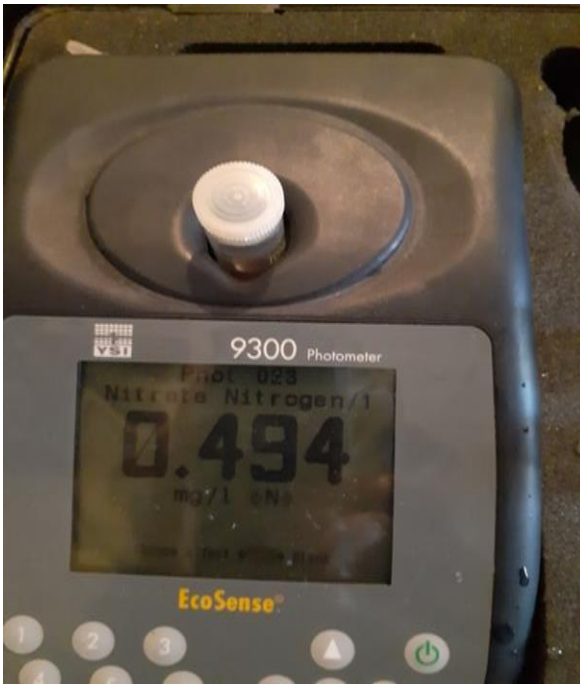
Appendix II: Fish sample measurements

Appendix III: Fecundity estimation of the fish

Appendix IV: Stomach/gut content analysis

Appendix V: *In situ* analysis of water physical and chemical parameters

Appendix VI: Laboratory analysis of nitrate (NO_3^{2-})



Appendix VII: Laboratory analysis of phosphate (PO_4^{3-})