Effect of water quality, common carp (*Cyprinus carpio*) invasion, and fishing activities on the population of Nile tilapia (*Oreochromis niloticus*) in Lake Hayq, Ethiopia

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Chair of the Department of Graduate Program Coordinator

Dedication

This dissertation is dedicated to my beloved Wife, Meaza Wuhib who helped me a lot in taking care of my daughter and my son during my stay in the field and laboratory for data collection. I also dedicated my work to the fishermen of Lake Hayq who are very humble and supportive.

Statement of the author

I hereby affirm that this Dissertation " Effect of water quality, common carp (*Cyprinus carpio*) invasion, and fishing activities on the population of Nile tilapia (*Oreochromis niloticus*) in Lake Hayq, Ethiopia" is the product of my own research, and no part of the Dissertation has been copied from any published source; except the references, standard mathematical equations and protocols. This dissertation has been submitted in partial fulfillment for the requirements of the Doctor of Philosophy in Biology (Aquatic Sciences, Fisheries, and Aquaculture) at Addis Ababa University (AAU), Ethiopia. I declare that this Dissertation is not submitted to any other institution for the award of any academic degree, diploma, or certificate. The paper is permitted to be deposited at the University Library to be available to borrowers under the rules of the library. Brief quotations from this dissertation are allowable without special permission provided with accurate acknowledgments of the source is made. Requests of permission for extended quotation or reproduction of this Dissertation in whole or in part for academic purpose may be granted by the Head of the Department or the Dean of the College and Director of Postgraduate Studies of AAU. In all other instances, however, permission must be obtained from the author. Finally, all sources of materials used in this Dissertation have been duly acknowledged.

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Date of submission: _______________________

Abstract

Ethiopia is endowed with a number of lakes located across the country in different ecological regions. However, most lakes are found clustered in the Ethiopian Rift valley but there are also few lakes located in the Ethiopian highlands (>1800 m a.s.l.). Lake Hayq is one of the highland lakes located in the north central highlands of the country. The lake fishery provides economic and ecosystem services to the local community. However, since 2010, the fishery production of the lake in general and the population of Nile tilapia, in particular, have been reduced. In addition to this, the growth of Nile tilapia has been stunted. There is limited information on factors that might have contributed to the low population and stunted growth of Nile tilapia in Lake Hayq. Therefore, this study aimed at assessing possible internal and external factors that could have contributed to the decline of Nile tilapia fish growth and the fishery. To realize these objectives, I determined physicochemical water quality, plankton community structure, fish diversity, relative abundance and some biological aspects of common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) and assessed the effect of fishing activities on *O. niloticus* between January and December, 2018 using standard methodology. Though significant difference (ANOVA, $P < 0.05$) was observed in Dissolved Oxygen (DO) and water temperature between dry and wet seasons, variability in most of the physicochemical parameters was low in Lake Hayq. The low variability in physicochemical parameters could be associated with less climatic variability (rainfall and water temperature) and higher depth of the lake. The depth profile data showed that the physicochemical parameters including DO and temperature variation were less between the surface and the deeper portion of the lake. Hence, the lake was not stratified during our sampling period. In this study, the reduction in the concentration of total phosphorus (TP) and Chlorophyll-*a* (Chl-*a*) and increment in Secchi disk depth (SD) was observed. Thus, the change in these parameters contributed for the change in the trophic state of the lake from eutrophic to mesotrophic state. A total of 44 phytoplankton taxa grouped under six divisions: Chlorophyta, Bacillariophyta, Cyanophyta, Euglenophyta, Dinophyta, and Cryptophyta were identified in Lake Hayq. Chlorophyta and Bacillariophyta were the major groups in terms of species composition. *Peridinium* (Dinophyta) was the most numerically abundant species in most of the sampling seasons and sites and formed blooms. Currently, a total of 28 zooplankton taxa were identified from Lake Hayq. The number of both phytoplankton and zooplankton taxa was higher in this study which could be associated with a higher number of sampling sites and two of them were from the shore of the lake which might have used as refuging and feeding sites. A total of 1980 fish specimens belonging to three species, *Cyprinus carpio* (1055), *Oreochromis niloticus* (892), and *Clarias gariepinus* (33) were collected. The dominant fish species in abundance were *C. carpio* (53.28 %), followed by *O. niloticus* (45.05 %). The length and weight relationships showed nearly isometric growth in both female and male *C. carpio.* Males (596) were more numerous than females (459) which showed a significant deviation from the 1:1 hypothetical sex ratio in *C. carpio.* The length at first sexual maturity (L_{50}) of female and male *C. carpio* were 21.5 and 17.5 cm, respectively. The length and weight relationships in *O. niloticus* showed negative allometric growth in both female and males. Male *O. niloticus* were more numerous (553) than female (339) which was deviated from a hypothetical 1:1 sex ratio (Females: Males). The size at first sexual maturity (L_{50}) of females and males *O. niloticus* were 12.8 and 12.9 cm, respectively. Both *C. carpio* and *O. niloticus* have similar peak breeding season between February and April. In Lake Hayq, diet overlap was observed at a smaller size (< 12 cm for *O. niloticus* and < 16 cm for *C. carpio*). Fishing activities in Lake Hayq were fully illegal, fishermen have been used monofilaments of mesh s sizes of 4- 6 cm (below the recommended mesh size, > 8 cm). In addition to this, the selective fishing pressure on *O. niloticus* was higher for Nile tilapia. The change in trophic state from eutrophic to mesotrophic (low food availability), presence of similar breeding season, diet overlap, and fishing pressure (overfishing) especially on *O. niloticus* might have contributed for stunted growth of *O. niloticus* in Lake Hayq. Therefore, monitoring the limnological variables, restocking *O. niloticus* fingerlings, and closing the lake at least for two consecutive years should be done to improve the fishery of Lake Hayq in general and *O. niloticus* in particular.

Keywords/ Keyphrases: Chl-*a*, diet overlap, mesotrophic, nutrients, overfishing, reproductive potential

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Chapter 1: General Introduction

1. 1. Background and justification

Ethiopia has many lakes and rivers harboring about 200 fish species (Abebe Getahun, 2017) which have both ecological and economical importance to the country. Though the contribution of the fishery to the GDP is negligible, the sector is being used as means of livelihoods for many people involved from production to marketing (Global Fish Alliance, 2010; FAO, 2012). Lake Hayq is one of the highland lakes located in northeastern Ethiopia (Molla Demlie *et al*., 2007) that has remarkable ecosystem services like fishery, recreation, transportation, source of water for drinking, livestock watering and irrigation (Tadesse Fetahi *et al*., 2011; Zuriash Seid, 2016).

Lake Hayq was reported as oligotrophic by earlier Italian visitors considering the Secchi depth and chlorophyll-a concentration (Zanon, 1941; Cannicci and Almagia, 1947; Baxter and Golobitsch, 1970). Boxter and Golobitsch (1970) have reported very high Secchi depth (9 m) and low algal biomass (< 1.23 µg L^{-1}) and the presence of oxygen up to 40 m depth. However, about 20 years later Elzabeth Kebede *et al*. (1992) reported that the lake as eutrophic considering the nutrient to volume ratio and the introduction of Nile tilapia (planktivorous fish) which has a cascading effect on the food chain of Lake Hayq. They reported algal biomass of 13-23 µg L^{-1} and 1.2 m Secchi depth and the absence of oxygen below 15 m. Two decades later, Vijverberg *et al*. (2014) based on their snapshot survey have reported the lake as mesotrophic while Tadesse Fetahi *et al*., (2014) , the same year reported the lake as eutrophic with their detailed study on the food webs, energy flows, and the associated limnological variables.

In addition to limnological studies conducted in Lake Hayq, other studies were done on physicochemical parameters (Zinabu Gebremariam, 2002, Aregawi Teklay and Meareg Amare, 2015; Ruchi *et al*., 2016), land use land cover change (Hassen Mohammed *et al*., 2013; Dagnachew Melaku and Abate Shiferaw, 2014), invasive macrophytes (Girum Tamire *et al*., 2016), the socioeconomic survey of fishes (Assefa Tessema and Kelemework Geleta, 2013) and some biological aspects of Nile tilapia (Workiye Worie, 2009; Workiye Worie and Abebe Getahun, 2014; 2015).

Nile tilapia is one of the most important commercial fish and the most studied species in African waterbodies. In Ethiopia, Nile tilapia is the most important and widely preferred and consumed fish species. It is one of the most important fish in fisheries of almost all-Ethiopian inland waters due to its taste (Shibru Tedla, 1973; Felegeselam Yohannes, 2003). Nile tilapia of Lake Hayq introduced in to the lake with the intention to ehnhance fish production (Elizabeth Kebede *et al.*, 1992; Golubstove and Mina, 2003; Tadesse Fetahi *et al.*, 2011a).

Currently, the fisheries of Lake Hayq, especially Nile tilapia production and growth have been dramatically reduced. As a result, most of the fishermen abandoned fishery in which some of them are involved in agricultural activities around the lake and some of them have migrated to Arabian countries in search of jobs. There are many hypotheses for the stunted growth and low production of Nile tilapia in Lake Hayq. Some authors (Workie Worie and Abebe Getahun, 2014; Dereje Tewabe *et al*., 2015; Zuriash Seid, 2016) have reported destruction of breeding ground, overfishing, and illegal fishing activities as possible reasons for the stunted growth of Nile tilapia in Lake Hayq. Recently, the local fishermen have hinted that the accidentally introduced common carp might have competed and caused stunt growth of Nile tilapia in the lake. Common carp was sampled for the first time in 1994 (Fiseha Woldemariam, Personal communication) and has gradually dominated the catch since 2013 (Endalh Mekonen *et al*, 2019a).

Common carp was introduced to different lakes and reservoirs such as Koka, Ziway, Geray, Ardibo, Maybar, and Hashenge to enhance fish production. The introduction was successful and has become the source of livelihoods for thousands but its impact on native species was not studied well (LFDP, 1997; JERBE, 2008; Brehan Mohammed *et al*., 2016). Common carp is now one of the commercially important fish species in Lake Hayq, however, the negative impact of common carp on other fish species through its feeding competition, changing the water quality of the lake, and destruction of macrophytes were reported in other water bodies. (Chumchal *et al*., 2005; Driver *et al*., 2005; Weber and Brown, 2009; Bajer *et al*., 2009; Kloskowski, 2011).

Tadesse Fetahi *et al*. (2011a; 2014) have reported detailed information on limnological variables, phytoplankton biomass, zooplankton density, and productivity of Lake Hayq. They have reported mean chl-*a* of 12.9 µg L^{-1}, and more inorganic nutrients such as soluble reactive phosphorus

(SRP), total phosphorus (TP) and ammonium ion (NH_4^+). About 40 phytoplankton and 11 zooplankton taxa were reported and diatoms and copepods were the most dominant taxa represented phytoplankton and zooplankton, respectively. Based on Carlson productivity index value and higher zooplankton density, Tadesse Fetahi *et al.* (2011a; 2014) grouped the lake as eutrophic (higher algal biomass, organic matter, and zooplankton density). They justified nutrient to volume ratio and introduction of Nile tilapia (planktivorous fish) for the change of Lake Hayq from oligotrophic to eutrophic state.

However, the ecology of the lake might have changed in the last 10 years due to the anthropogenic and the aforementioned natural factors. Therefore, three hypotheses: 1. water quality change, 2: common carp invasion impact with feeding competition with Nile tilapia, and 3. fishing Pressure on Nile tilapia were formulated as possible factors on the current stunt growth of Nile tilapia. The first hypothesis was tested based on spatial and temporal studies of physicochemical water quality parameters, phytoplankton, and zooplankton of the lake. The second hypothesis was tested by analysis of food and feeding ecology of both common carp and Nile tilapia. The third hypothesis was tested using a formal and informal survey on fishing activities and socioeconomic importance of fishes of Lake Hayq.

1.1.1. Characteristics of Lake Hayq and its watershed

According to Hassen Mohammed *et al.* (2013), the watershed of Lake Hayq has undergone a dramatic change in land use and land cover over the past half-century and resulted in significant farmlands/settlements increment by 43.1% and a reduction of the lake by 7.6% in the same period of time (Figure 1.1 and Table 1.1).

Figure 1.1: Degraded catchment and buffer zone of Lake Hayq

Table 1.1: Lake Hayq basic hydrology data (From Hassen Mohammed *et al.,* 2013)

No.	Parameters	Morandini,1941	Hassen Mohammed *et al*, 2013
1	Drainage area in a hectare	-	6544.74
2	Lake surface area, hectare	2302	2245.65
3	Volume in km^3	-	1.01
4	Maximum depth in m	88.2	81.44
5	Mean depth in m	37.37	32.65
6	Watershed to lake surface area (Wa/La)	-	2.91
7	Maximum length (North-South) in Km	6.7	6.69
9	Maximum length (West to East) in Km	6	4.99
10	Water elevation, m, amsl (at lake Surface, zero depth)	-	1903

1.1.2. The climate of Lake Hayq area

Among the climate variables, only maximum and minimum temperature and rainfall of Lake Hayq were available at Kombolcha Meteorological Agency. In 2018, the average monthly maximum and minimum temperature around Lake Hayq was 25.9 and 9.9 ^{o}C, respectively. In addition to the main rainy season (July-September), more rainfall was recorded in April and June (Figure 1.2) indicating rainfall is bimodal around the lake. The annual total rainfall was 1200 mm in the same year. The annual rainfall and the temperature variability around Lake Hayq for the last 10 years (2009-2018) were very low (Figure 1.3). The average monthly minimum and maximum temperature and annual rainfall were 9.8 °C, 26.6 °C, and 1205.6 mm, respectively ((Ethiopian Meteorological Agency, 2018).

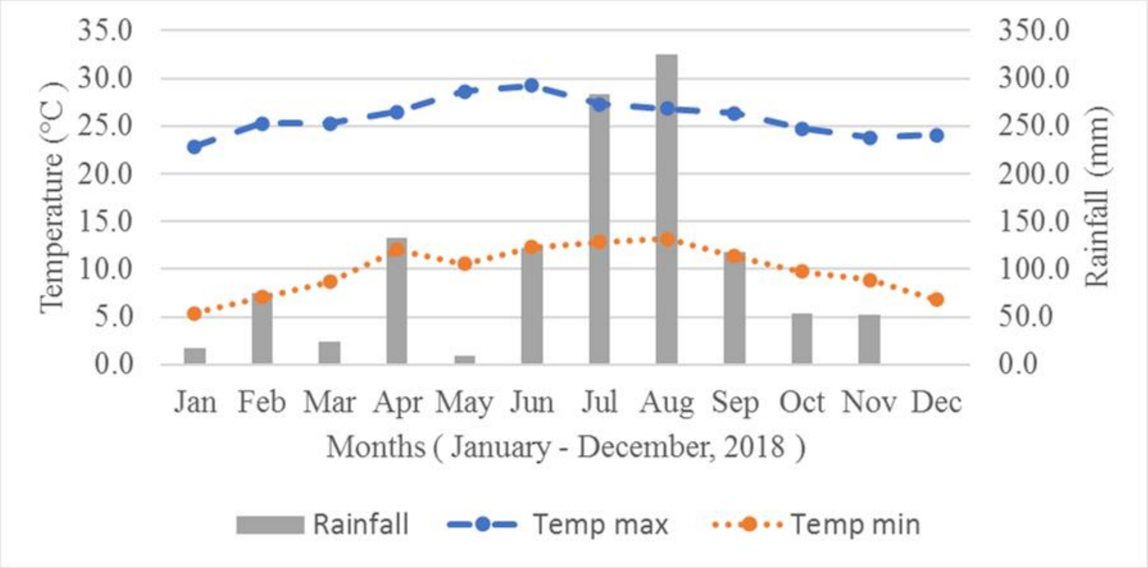

Figure 1.2: Monthly maximum and minimum temperature and rainfall variation of Lake Hayq in 2018

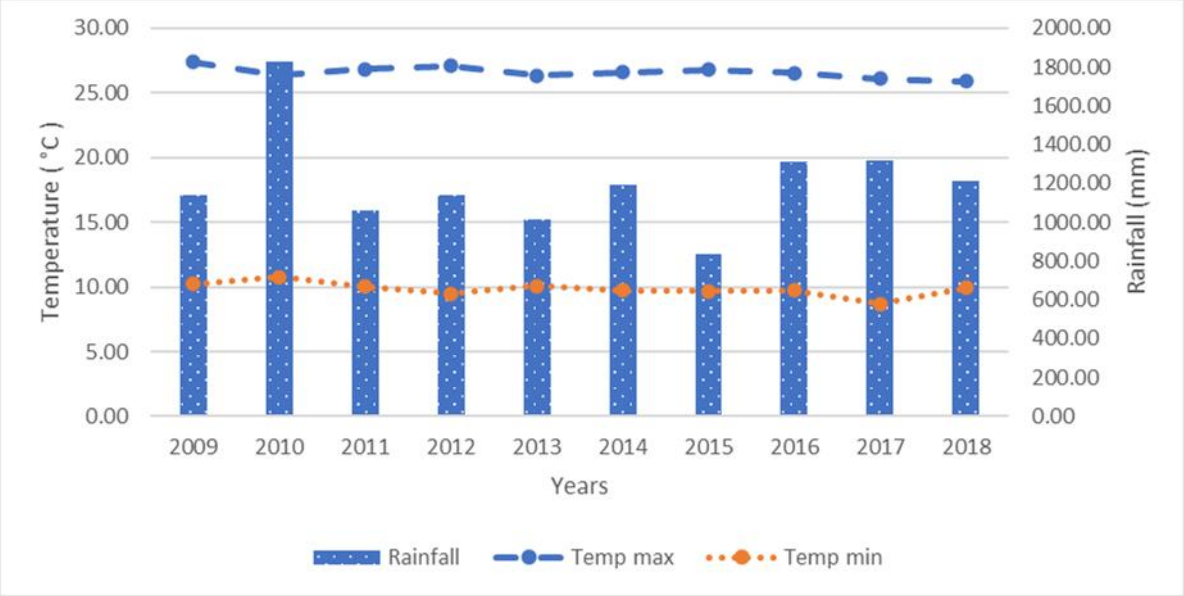

Figure 1.3: Temperature and rainfall variability (2009-2018) around Lake Hayq

1.1.3. Biodiversity of Lake Hayq

1.1.3.1. Plankton

Both phytoplankton and zooplankton species of Lake Hayq were studied by several researchers since the 1940s (Zanon, 1941; Baxter and Golobitsch, 1970; Elizabeth Kebede *et al*., 1994; Tadese Fetahi *et al*., 2011; 2014; Girum Tamire *et al*., 2016). A total of 40 phytoplankton and 11 zooplankton taxa were reported from Lake Hayq (Tadese Fetahi *et al*., 2011; 2014).

1.1.3 .2. Bird species

Though very limited information is available about bird species of Lake Hayq, the lake has many bird species around the Ankerkeha River. A total of 62 species of birds belonging to 12 orders and 29 families were recorded around Lake Hayq (Abeba Demeke and Mesele Yihune, 2019). Some of the birds like Marabou stork (Figure 1.4) are fish eaters and they scavenge on fish leftovers.

Figure 1.4: Marabou stork (*Leptoptilos crumeniferus*), a common bird species around Lake Hayq

1.1.3.2. Macrophytes

At the shores of Lake Hayq, there are three majorspecies of macrophytes namely, emergent (*Typha latifolia*, *Scirpus cyperinus,* and *Echinochloa pyramidalis*), floating (*Nymphaea lotus*) and submerged (*Ceratophyllum demersum* L., *Potamogeton pectinatus* L. *and Ceratophyllum submersum* L*)*. In Lake Hayq, coverage of the submerged types of macrpophytes (Table 1.2 and Fig. 1.5) has increased and is becoming a challenge for fishermen and boat drivers. Because, these macrophytes modified the habitat of the fish and reduced the lake water used for boat transportation. *Ceratophyllum submersum* L., especially, is affecting fishing activities in Lake Hayq due to its high coverage and spiny leaves hindering fish movement for feeding, reproduction, and nesting.

Table 1. 2: Invasive Aquatic weeds (macrophytes) of Lake Hayq

No	**Botanical Name**	**Family**
1	*Ceratophyllum demersum* L.	Ceratophyllaceae
2	*Potamogeton pectinatus* L.	Potamogetonaceae
3	*Ceratophyllum submersum* L.	Ceratophyllaceae

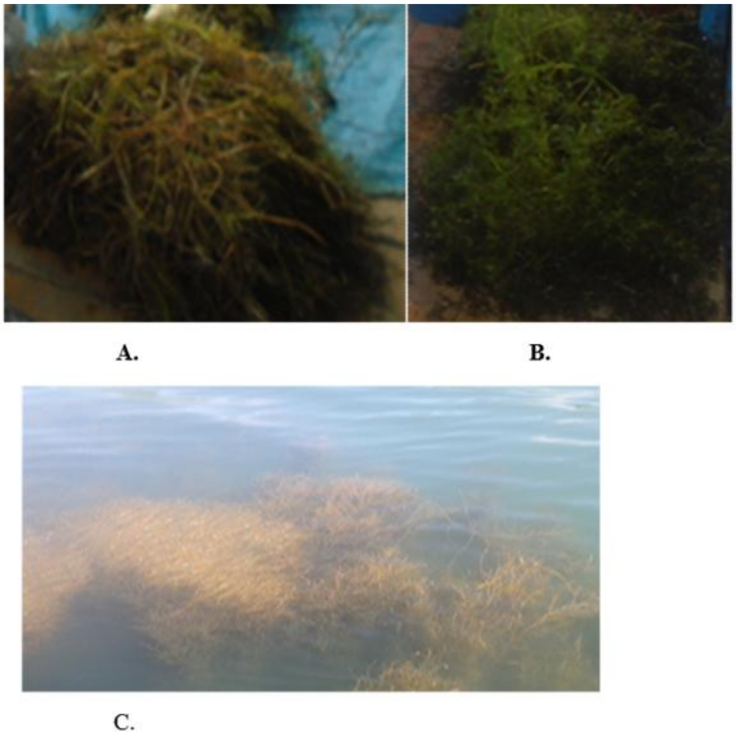

Figure 1. 5: Invasive Aquatic plants, *Ceratophyllum demersum* L (A), *Ceratophyllum submersum* L (B), and *Potamogeton pectinatus* L (C).

1.1.3. 4. Fish species

Lake Hayq harbors four fish species, one ecologically important fish species (*Garra dembecha*) and three commercially important fish species (*Clarias gariepinus*, *Oreochromis niloticus*, and *Cyprinus carpio*) (Figure 1.6). *Garra dembecha* and *C. gariepinus* are native fish species. Whereas, *O. niloticus* (introduced to enhance the fishery) and *C. carpio* was accidentally introduced through Ankerkeha River from the nearby Lake Ardibo.

Oreochromis niloticus *Cyprinus carpio*

Clarias gariepinus *Garra dembecha*

Figure 1.6: Fish species of Lake Hayq

1. 2. Statement of the problem

Lake Hayq is a very important highland lake that has significant ecosystem services such as, drinking water, fishery, tourism, irrigation, and livestock watering. Lake Hayq has been changed from oligotrophic to the eutrophic state after the introduction of *O. niloticus* in the 1970s (Elizabeth Kebede *et al*., 1992; Tadesse Fetahi *et al.*, 2011a). The four fish species available in the lake are *C. gariepinus*, *O. niloticus*, *G. dembecha*, and *C. carpio* (Tadesse Fetahi *et al*., 2011a; Zuriash Seid, 2016). However, Lake Hayq has been affected by anthropogenic and natural factors, invasive macrophytes (Girum Tamire *et al*., 2016), overfishing (Assefa Tessema and Kelemework Geleta, 2013; Dereje Tewabe *et al*., 2015; Zuriash Seid, 2016), pollution (Aregawi Teklay and Meareg Amare, 2015; Ruchi *et al.*, 2016), land use land cover change and reduction in water volume (Hassen Mohammed *et al*., 2013; Dagnachew Melaku and Abate

Shiferaw, 2014), siltation (Hassen Mohammed *et al*., 2013; Dagnachew Melaku and Abate Shiferaw, 2014) and rainfall variability and change in temperature (Dagnachew Melaku and Abate Shiferaw, 2014).

Though several studies were conducted on Lake Hayq's morphometry, water balance, water quality, plankton structure and biology of Nile tilapia, factors that may affect Nile tilapia were not studied considering the spatial and temporal variation of the lake's ecology. Therefore, this study aims to investigate the major factors that may affect the Nile tilapia in Lake Hayq and attempts to answers for the following major research questions:

1. 3. Research questions

1. Is there a change in physicochemical parameters of the water that may affect Nile tilapia?
2. Did the invasion of common carp affect plankton composition and biomass as well as the population of Nile tilapia?
3. What is the socio-economic importance of *O. niloticus* and *C. carpio* and the impact of the past and the current fishing activities on Nile tilapia in Lake Hayq?

1. 4. Objectives

1.4.1. General objective

The general objective of this study was to assess current water quality status of Lake Hayq, the biology of common carp and Nile tilapia, the impact of common carp invasion on Nile tilapia and the socioeconomic importance of common carp and Nile tilapia and impact of fishing activities on Nile tilapia and to set up a management system and sustainable utilization of the fish resources and recommend ways and means of conserving Lake Hayq.

1.4.2. Specific objectives

1. To assess physicochemical water quality parameters and determine the abundance and composition of phytoplankton and zooplankton taxa
2. To determine diversity and abundance of fish species
3. To determine the length-weight relationship and condition factor and reproductive potential of common carp and Nile tilapia
4. To study the feeding habits of common carp and Nile tilapia
5. To assess the socio-economic importance of common carp and Nile tilapia and the impact of fishing activities on the growth of Nile tilapia

1. 5. General description of the area

The study was conducted in Lake Hayq. Lake Hayq is located in the north central highlands of Ethiopia. Lake has different names, Logo, Lugo, Lego and Haik in literature. It is a typical example of highland lake of Ethiopia with volcanic origin. Geographically, it lies between 11^0 3' N to 11^0 18' N latitude and 39 ^{0} 41' E to 39^0 68' E longitude with an average elevation of 1911 meters above sea level. The lake has a closed drainage system and the total watershed area is about 77 km^2 of which 22.8 km^2 is occupied by the lake. According to Molla Demlie *et al*. (2007), the average depth of the lake is 37 m, and the maximum depth is 81 m.

Sampling site selection

Three sampling sites, Littoral and Ankerkeha (near the shore of the lake) and Pelagic (open water) were selected based on the level of impact from human and livestock activities (Table 1.3)

Table 1.3: Sampling site description

Sampling sites	**Characteristics**	**Depth (m)**	**Coordinate points (UTM)**	
			X	**Y**
Ankerkeha	Silt load	5.3	579715.383	1253117.123
Pelagic	Open water (less impact)	55.4	576688.51	1252693.02
Littoral	Near Lodges (more pressure)	6.3	575131.78	1252295.8

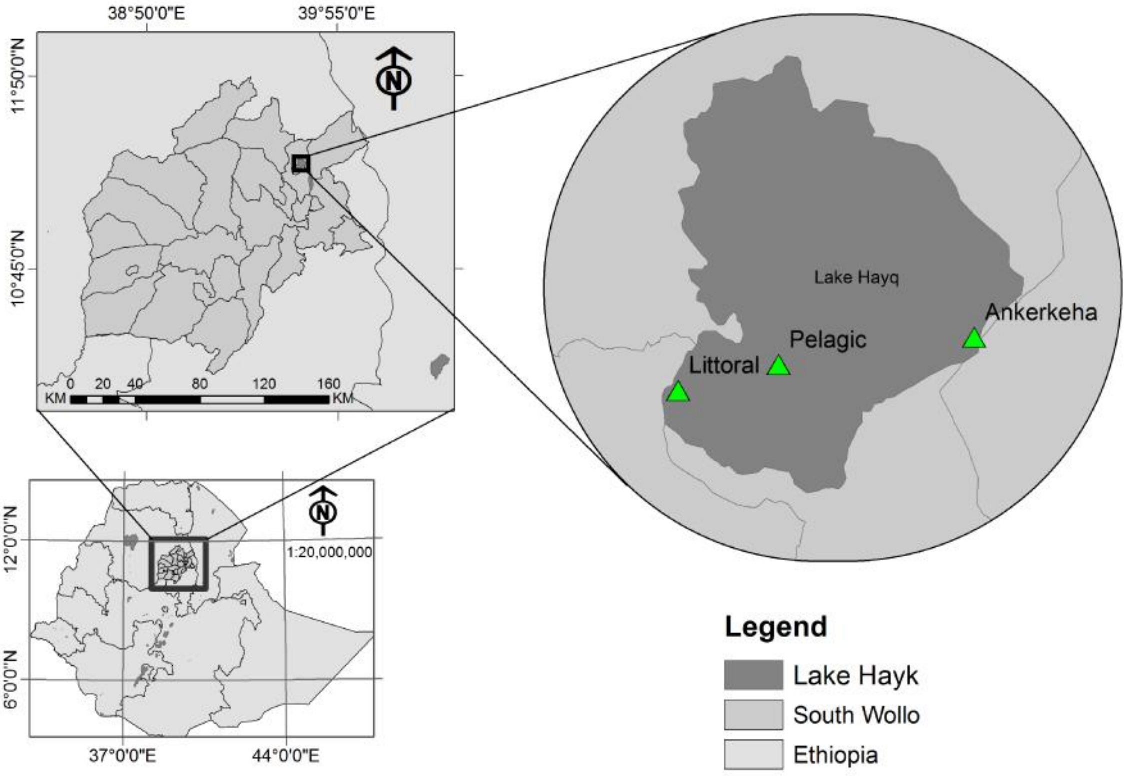

Figure 1. 7: Location of Lake Hayq in reference to Ethiopia and Amhara Regional State

1. 6. Structure of the dissertation

This dissertation is organized into seven principal chapters. **The first chapter** is an introduction part of the dissertation, which gives a brief outline on the background of the study, a short introduction of the study area, which includes characteristics of Lake Hayq and its watershed, climate and biodiversity of Lake Hayq, statements of the problem, research questions, and objectives of the study. **The second chapter** of this dissertation covers the physicochemical water quality parameters, phytoplankton, and zooplankton community structure of Lake Hayq. **The third chapter** deals with diversity, distribution, and relative abundance of fish species in Lake Hayq. **The fourth chapter** focuses on length-weight, condition factor, and some reproductive biology of common carp and Nile tilapia in Lake Hayq. **The fifth chapter** discusses food and feeding ecology of common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) in Lake Hayq. **The sixth chapter** deals with the impact of fishing activities on Nile tilapia (*Oreochromis niloticus*) in Lake Hayq. Finally, the **last chapter** includes the conclusion and recommendations of the study, which provides a summary and suggestions for future studies.

Chapter 2: Physicochemical water quality parameters, phytoplankton and zooplankton community structure of Lake Hayq

2.1. Introduction

The quality of water in every ecosystem provides major information about the available resources for sustaining life in that ecosystem. The healthy aquatic ecosystem depends on the abiotic and biotic characteristics of water. The interactions of physical and chemical properties of water play an important role in abundance, composition, distribution, diversity, growth, reproduction, and the movements of aquatic organisms. Therefore, monitoring of physicochemical parameters is necessary to recognize the magnitude and the source of any pollution load and identify the suitable environmental condition of organisms to design appropriate conservation strategies (Mayavan *et al.*, 2017).

Phytoplankton are important primary producers and are at the base of the food chain in aquatic ecosystem. They are also recognized as bio-indicator organisms in the aquatic environment due to their short generation time and fast response to changes in aquatic environments such as nutrient enrichment, and they can be used as early warning indicators for water pollution (Hassan *et al*., 2013; Agnieszka, 2016).

Phytoplankton composition, distribution, and density are a good indicator of trophy. Their composition, growth, abundance, and dynamics in lakes are collectively influenced by environmental variables (physical, chemical and biological properties of water), especially nutrient enrichment, water transparency, temperature and biotic interactions such as predation and competition (Ariyadej *et al*., 2004; Nowrouzi and Valavi, 2011; Ogbuagu *et al*., 2011; Dayala *et al.,* 2014; Patil *et al*., 2015; Addisu Fekadu and Solomon Chanie, 2017). Phytoplankton is the most sensitive aquatic community and any undesirable change in the aquatic ecosystem affects diversity as well as biomass of the community (Ayalew Wondie *et al*., 2007; Manjare, 2015)

Phytoplankton does not only produce oxygen and food but also uses ammonia produced by fish as a nitrogen source removing the potentially toxic substance from the system. Some species such as Cyanobacteria, on the other hand, can be harmful to human, and other animals by releasing toxic substances (hepatotoxins or neurotoxins, etc.) into the water (Carmichael, 2001; Kaihong *et al*., 2006; Malbrouck and Kestemont, 2006; Chapman and Ronberg, 2008; Hassan *et al*., 2013). Cyanoprokaryota dominates and forms bloom in eutrophic system disrupting the normal food web interactions and some species producing toxins to the system. Thus, knowledge of phytoplankton ecology is important for freshwater lake management. The relationship between phytoplankton biomass and nutrients in limnology has been studied extensively, as such a study providing insight into the relative importance of chemical, physical and biological constraints on phytoplankton biomass in water bodies (Kuo *et al*., 2007).

Algal biomass and productivity can be limited by nitrogen, phosphorus, or by physical factors such as light or temperature in lakes and reservoirs (Vörös and Pandisak, 1991). Nitrogen and phosphorus are generally described as driver variables of phytoplankton biomass and water transparency in lakes and reservoirs (Soballe and Kimmel, 1987).

Often phytoplankton communities of eutrophic tropical lakes are dominated by cyanobacteria due to excessive nutrient enrichment (Gragnani *et al*., 1999). However, this is not always true, for example, the tropical eutrophic highland Lake Hayq was mainly dominated by Bacillariophyta and Chlorophyta species (Tadess Fetahi *et al*., 2014). According to Gragnani *et al*. (1999) and Kaihong *et al*. (2006), filter-feeding zooplankton and fishes such as Nile tilapia and carp can have top-down control on cyanobacteria (*Microcystis Spp*.) and other algal population by up to 93 %. The importance of grazers (zooplankton and fish species) in controlling the phytoplankton population has been reported for Lake Hayq (Tadesse Fetahi *et al*., 2014). The trophic cascading effect has been observed in Lake Hayq revealing the interaction among phytoplankton, zooplankton, and fish.

Zooplankton plays a pivotal role in the aquatic food web, having the potential to affect water transparency, levels of suspended algae (phytoplankton), and the fishery. Many economically important fish depend on the zooplankton diet during some stage in their life cycle (Eshete Assefa, 2009). Zooplankton abundance has a positive correlation with fish production, which is higher in water bodies where zooplanktons are abundant (Xuelu *et al*., 2011; Waidi *et al*., 2016)

Zooplankton is a good bioindicator for lake ecology change as their composition and abundance vary with physicochemical and biological parameters as well as predation by fish and other zooplankton. They are highly sensitive and respond quickly to environmental variations because most species have short generation times. They have been used for monitoring eutrophication, pollution, and global warming (Bianchi *et al*., 2003; Molinero *et al*., 2005).

The diversity and population dynamics of zooplankton are regulated by several factors including environmental variables (temperature, dissolved oxygen, organic matter, and water transparency), trophic status, level of pollution and interaction among biotic communities (predation by fish and other zooplankton and change in phytoplankton communities in lake ecosystem) (Waya, 2004; Wang *et al.*, 2007; Omondi *et al*., 2011). Abundance and composition may also vary based on patchiness in resource distribution within the lake (Sousa *et al*., 2008). The abundance of zooplankton depends on habitat complexity, the more complex the habitat, the more abundant. Correspondingly, the shore of the lake which has a more complex habitat compared to the pelagic zone has more zooplankton abundance (Ngupula *et al*., 2010). Moderate pollution in lakes also enhance zooplankton abundance since it initiates the growth of green algae which are food for zooplankton (Edwine *et al*., 2017)

Thus, understanding the patterns of variability of phytoplankton and zooplanktons both temporally and spatially provides a good source of information on the processes affecting them. The physicochemical parameters and biotic factors have been reported as major sources of the variations in species composition, abundance, diversity, and distribution of the plankton (Imaobong, 2013).

Though some studies were conducted including land-use/ land cover change, water balance, and limnology related to Lake Hayq, there is limited information about the current water quality of the lake, phytoplankton, and zooplankton community structure. On the other hand, agriculture-based (that uses chemical fertilizer, pesticide, and herbicide) and degraded catchment might have changed the water quality and ecology of the lake system. Therefore, the study on the phytoplankton and zooplankton composition, biomass, and density were studied in relation to the physicochemical parameters of the lake. The current trophic status of the lake was also determined.

2. 2. Materials and methods

2.2.1. Sampling sites and sampling protocol

Three sampling sites, littoral (close to lodges and intensive humans and livestock activities), Pelagic (open water, relatively less pressure from direct human activities), and Ankerkeha River Mouth (the Largest river that brings siltation to the lake) were selected (Table 1.2).

2. 2. 2. Sampling protocol and analytical methods

Seasonal sampling and in situ measurements were carried out between January and December 2018 at Littoral (close to lodges, intensive pressure), pelagic (open water, less pressure) and Ankerkeha (River mouth, with more silt load) sites that had a mean depth of 5.3, 55.4 and 6.3 m respectively. Temperature, conductivity, pH and dissolved oxygen were measured in situ using a portable multiprobe (Model HQ 40d Multi Hach Lange). Water transparency was estimated using a standard Secchi disk of 20 cm in diameter. Water for Chlorophyll- a (Chl-a), and water chemistry were sampled at the surface and at 1, 2, 3, 5 m at littoral and Ankerkeha and the same measurements were undertaken at pelagic site (surface, 1, 5, 10, 15, 20 m depth). Samples were transferred and stored under ice until analyses were made at Addis Ababa University, Ethiopia. Total alkalinity was determined from the unfiltered water sample through titration with 0.1 N HCl with bromocresol green/methyl red used as an endpoint indicator (Wetzel and Likens, 2000). Water samples were filtered through Whatman GF/C filters and the filtrate was used for the determination of dissolved inorganic nutrients. Soluble reactive phosphorus (SRP) was determined spectrophotometrically using the ascorbic acid method, ammonium ($NH4^+$-N) was analyzed with the indophenol's blue method and nitrate (NO3-N) was analyzed using the sodium-salicylate method (APHA, 1995). Nitrite (NO2-N) determination was carried out using the reaction between sulfanilamide and N-naphthyl-(1)-ethylendiamin-dihydrochloride. The reactive silica (SiO_2) was measured using molybdosilicate method (APHA, 1995). To determine total phosphorus (TP), unfiltered water samples were digested using potassium-peroxide sulfate, autoclaved at 120 ◦C for 50 min and measured following the standard SRP procedure (APHA, 1995). Ammonium ion was analyzed in Addis Ababa University, Department of Geology, Isotope Laboratory.

2. 2. 3. Phytoplankton biomass

Phytoplankton biomass was estimated as chlorophyll-a concentration spectrophotometrically from composite water samples filtered through glass filters (GF/C). Chlorophyll-a was extracted from the phytoplankton concentrate with aqueous acetone (90%). The filters were manually ground with a glass rod to enhance the extraction of pigments. The concentration of chlorophyll-a was calculated using absorbance measurements made at 665 and 750 nm (Talling and Driver, 1963).

$$\text{Chl-a } (\mu g\ L^{-1}) = \frac{26.73[(665b-750b)-(665a-750a)]\times Ve}{Vf\times Z}$$

Where 665b and 750b are absorbance at 665nm and 750nm before Acidification, respectively. 665a and 750a are absorbance at 665 and 750 nm after acidification, respectively.

- **Ve** = Volume of extract in ml
- Vf = Volume of sample filtered in liter
- Z= Path length of the cuvette (1cm)
-

2. 2. 4. Trophic State Determination

The Trophic state of Lake Hayq was determined using Carlson's (1977) trophic status index (TSI) determination method for an inland water body, which was calculated based on Secchi disk depth (SD), chlorophyll-a content (Chl-*a*), and concentration of total phosphorus (TP).

Carlson (1977) trophic state equation:

TSI SD = 60-14.41 (lnSD)..Equation 1

TSI TP = 14.41 ln (TP) +4.15...Equation 2

TSI Chl-a = (9.8) (ln chl-*a*) +30. 6...Equation 3

TSI_C (Average) = (TSI-SD+TSI-TP+TSI-CHL-A)/3.................... Equation 4

Where: TSI stands for trophic state index, CTSI for Carlson's trophic state index, ln for natural logarithm, SD for Secchi depth (meter), TP for total Phosphorous (μgL^{-1}), and Chl-*a* for chlorophyll-*a* (μgL^{-1}). From this equation, Carlson's estimated the trophic state values ranging for Oligotrophic lakes (TSI, <40), Mesotrophic ($40 \leq TSI < 50$), Eutrophic ($50 \leq TSI \leq 70$), and Hypereutrophic (TSI, >70) state.

2. 2. 5. Phytoplankton composition and abundance

Net samples from the euphotic zone were collected for phytoplankton taxa identification using 15µm mesh size in dry (October- March; low rainfall availability) and wet (April – September; higher rainfall availability). For the identification of phytoplankton and estimation of their abundance, the composite samples were preserved with Lugol’s % solution in 125 ml sampling bottles in triplicate. Phytoplankton taxa were identified to the genus or, when possible, to the species level using appropriate keys (Gasse, 1986; John *et al*., 2002). The preserved composite samples were concentrated in 1 L measuring cylinders for 48 hours in the dark to produce 10 times concentrated samples (concentration factor-10). Using aliquot samples, the cells of the major phytoplankton found in 40 randomly selected squares (grids) of the Sedgwick-Rafter chamber were counted in triplicates under an inverted microscope at a magnification of 200× and 400×. The abundance of the major taxa was calculated using the equation in Hötzel and Croome (1999):

$$\text{Abundance (algal units ml}^{-1}\text{)} = \frac{N\,x\,1000\,mm^3}{A\,x\,D\,x\,F}$$

Where N = number of cells counted, A= area of field (mm^2), D = depth of a field (mm) and F= number of fields counted.

2. 2. 6. Zooplankton composition and abundance

Three replicates samples were taken at each station on each sampling date, twice both in dry and wet seasons using 30µm and 100µm. To determine numerical abundance, samples were vertically hauled from 5 to 10 m to the surface based on the depth of the sampling sites. The volume of water filtered (V) was calculated from $V = \pi r^2 h$, where r = radius of net ring (0.13 m) and h the distance towed (5-10 m). The samples were immediately preserved with formalin to a final concentration of approximately 4%. The concentrated original sample of 250 ml was mixed homogeneously and a 25 mL subsample was taken with a wide mouth pipette (Wetzel and Likens 2001), then poured into a gridded glass chamber where three pre-selected grids/strips were counted and hand-tallied. The species were examined under a compound and inverted microscope at 100x and 400x magnification power following Edmondson and Winberg (1971) in Addis Ababa University and Wollo University. Zooplankton species were identified using different materials (Fernando, 2002; François *et al*., 2012). The number of individuals per Litter (N) was calculated as follows.

$$N = \frac{n \times SSF \times GF}{V}$$

where n is actual count, SSF is sub-sample factor, GF is grid factor and V is the volume of water filtered through the net which was determined using the formula ($V= \Pi r^2 h$) where r is the radius of the net mouth and h is the depth from which the sample was taken.

2. 2. 7. Data Analysis

The collected data (water quality, phytoplankton, and zooplankton) were summarized using descriptive statistics (Percentages, pie chart and bar graphs) and multivariate Statistical analysis, two-way ANOVA was used to determine the difference in water quality parameters variations with seasons and sites using SPSS (Version 16) Statistical software and Redundancy Analysis (RDA) was used to examine the relation between water quality parameters and phytoplankton with higher relative importance among the sampling sites through using CANOCO 4.5 software.

2. 3. Results

2.3.1. Physicochemical water quality parameters

In Lake Hayq, DO, percentage oxygen Saturation and water temperature varied significantly with seasons and sampling sites. However, conductivity and total alkalinity were not different statistically with seasons and sampling sites (Table 2.2). The highest DO (7.91±0.22 mg L^{-1}) was recorded at littoral site during wet season. The lowest DO (6.82±0.21 mg L^{-1}) was recorded at pelagic site during dry season. The highest percentage saturation (118.8±3.54) was recorded at littoral site during wet season. The lowest percentage saturation (99.05±4.05) was recorded at pelagic during dry season. The highest water temperature (24.256±0.48 °C) was recorded at littoral during wet season. The lowest water temperature (22.44±0.79 °C) was recorded at pelagic during dry season. The highest conductivity (914.73±65.05 µScm^{-1}) was recorded at pelagic during wet season. The lowest conductivity (853.89±56.29 µScm^{-1}) was recorded at Ankerkeha during wet season. The highest total alkalinity (9.5 $meqL^{-1}$) and the lowest total alkalinity (8.6 $meqL^{-1}$) were recorded at pelagic site during wet and dry seasons, respectively (Table 2.1).

The water transparency (Secchi disk depth) of Lake Hayq varied among sampling months and sampling sites. The highest Secchi disk depth was observed at pelagic site in May (Figure 2.1). The monthly surface water temperature variation in Lake Hayq was lower among sampling sites. The highest value was recorded at Ankerkeha River in December and lowest was recorded in January at pelagic site (Figure 2.2). The value of pH was variable among sampling months and sites. The highest values were observed in December at littoral and pelagic sites and the lowest was observed in July at Ankerkeha and pelagic sites (Figure 2.3). The values of monthly conductivity in Lake Hayq was not different among sampling sites (Figure 2.4).

Table 2.1: Seasonal variation of some physicochemical water quality parameters at Ankerkeha, littoral and pelagic sampling sites in Lake Hayq (January-December, 2018)

Parameters	Season	site	Mean± SD	DF	F	Sig
DO (mgL^{-1})	Dry	Ankerkeha	6.83±0.13	55	100.687	.000*
		littoral	6.95±0.16			
		pelagic	6.82±0.21			
	Wet	Ankerkeha	7.58±0.13			
		littoral	7.91±0.22			
		pelagic	7.36±0.37			
Saturation (%)	Dry	Ankerkeha	99.1±0.85	55	99.88	0.000*
		littoral	101.53±0.95			
		pelagic	99.05±4.05			
	Wet	Ankerkeha	112.37±2.58			
		littoral	118.8±3.54			
		pelagic	107.982±5.9			
Temperature (°C)	Dry	Ankerkeha	22.463±0.86	55	28.372	0.000*
		littoral	22.725±0.67			
		pelagic	22.44±0.79			
	Wet	Ankerkeha	23.48±0.53			
		littoral	24.256±0.48			
		pelagic	23.036±0.41			
Conductivity (µScm^{-1})	Dry	Ankerkeha	876.38±31.05	55	0.796	0.376
		littoral	869±25.82			
		pelagic	880.5±29.11			
	Wet	Ankerkeha	853.89±56.29			
		littoral	891.67±79.18			
		pelagic	914.73±65.05			
Total alkalinity (meqL^{-1})	Dry	Ankerkeha	9.02±0.21			
		littoral	9.25±0.07			
		pelagic	8.6±0			
	Wet	Ankerkeha	8.8±0.56	2	0.318	0.587
		littoral	8.9			
		Pelagic	9.5±0.14			

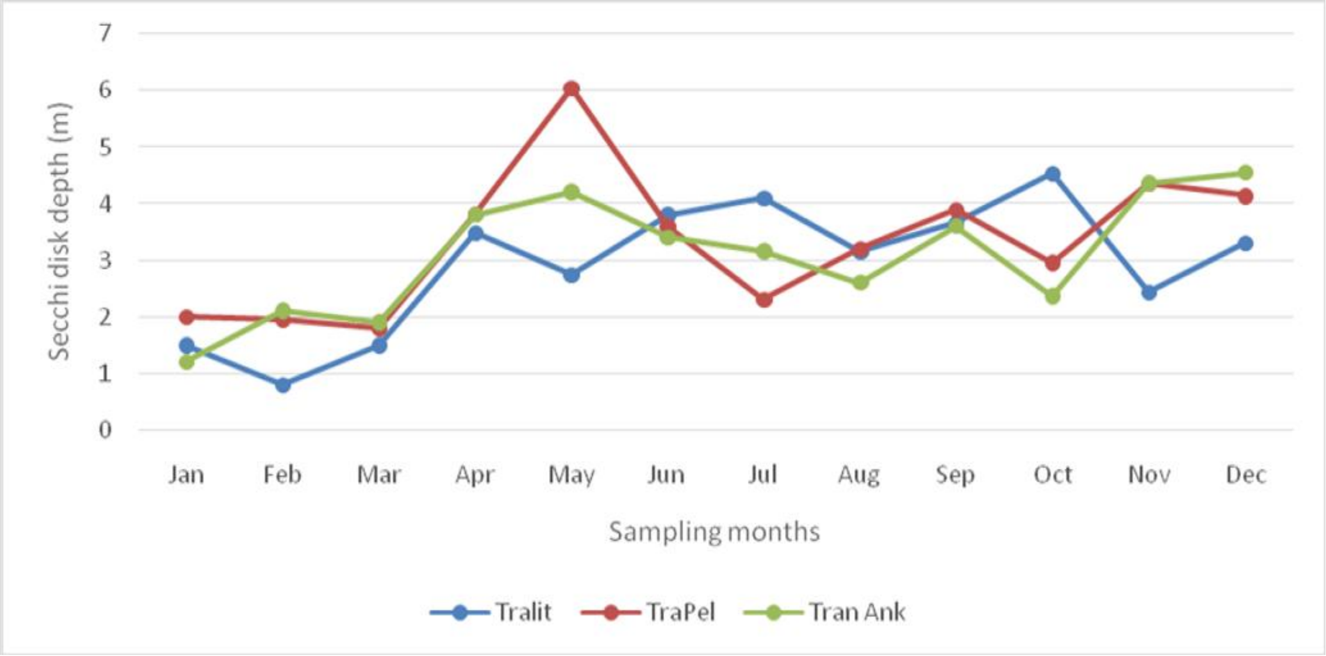

Figure 2.1 Monthly variation of water transparency (m) among the sampling months (January-December,2018)

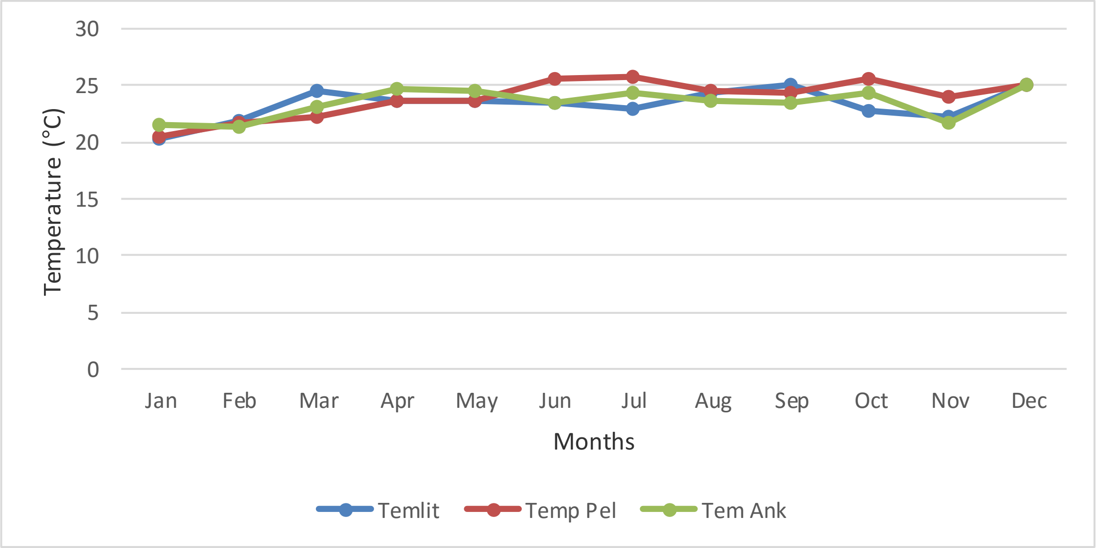

Figure 2.2 : Monthy variation of surface water temperature among sampling sites (Lit-Littoral, Pel=Pelagic and Ank-Ankerkeha) (January -December, 2018)

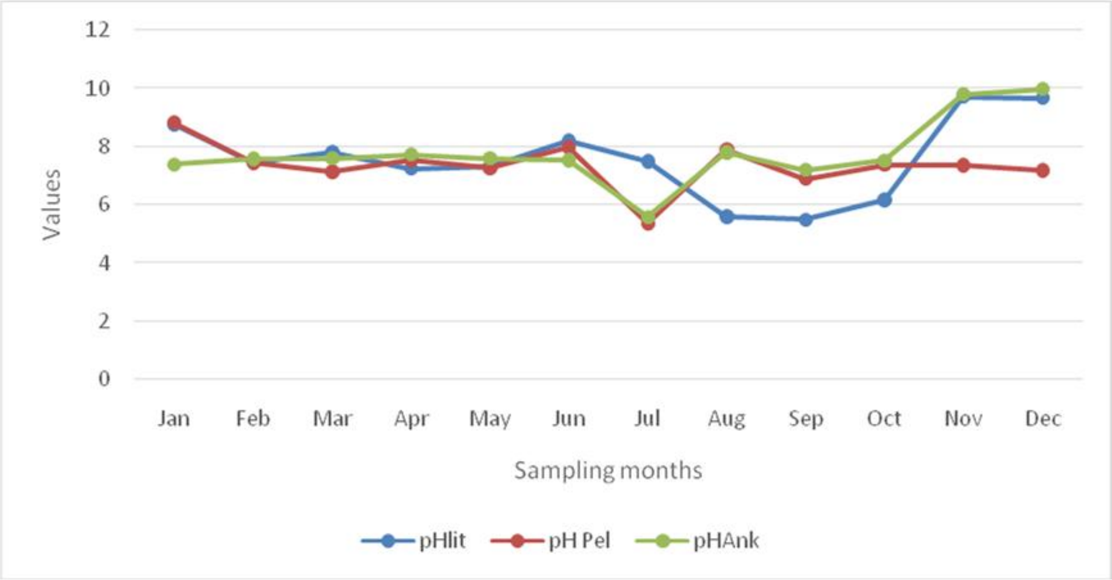

Figure 2.3: Monthly variation of pH among sampling sites (lit-Littoral, Pel- Pelagic and Ank- Ankerkeha) (January-December,2018)

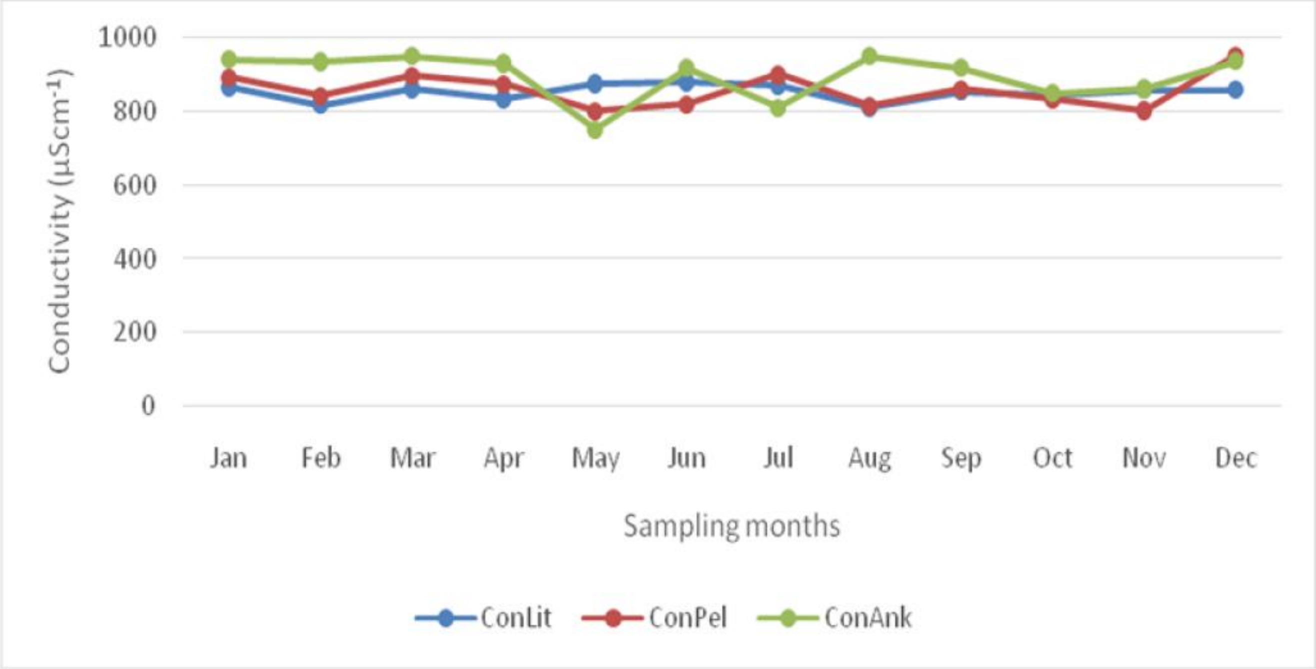

Figure 2.4: Monthly variation of conductivity among sampling sites (Lit-Lottoral, Pel-Pelagic and Ank- Ankerkeha) (January-December,2018)

Depth profiles of temperature and dissolved oxygen in Lake Hayq

Water temperature and DO slightly varied with depth and season in Lake Hayq. The highest water temperature at the deepest depth (20m) was 22.6 ^{o}C in wet season and the lowest water temperature was 21.65 ^{o}C in dry season. In Lake Hayq, the temperature difference along the depth profile was very low (< 1 ^{o}C) in dry and wet seasons. During the study period, the concentration of dissolved oxygen at the maximum depth (20 m) showed temporal variations from 6.29 mg L^{-1} in wet season to a maximum of 6.73 mg L^{-1} in dry season at the open water site. The oxygen saturation in at deepest depth varied slightly from 91.5 in wet season to 96.1 in dry season (Table 2.2).

Depth profile of conductivity and pH

Similar to DO and water temperature, conductivity and pH varied slightly along the depth profile from the surface to the deepest portion of the lake. The highest (889 µS cm^{-1}) and the lowest (879 µS cm^{-1}) conductivity were recorded during wet and dry seasons, respectively in 20 m depth. The highest (8.84-8.94) and the lowest (8.5) pH was recorded during dry and wet seasons, respectively at 20 m depth (Table 2.2).

Table 2.2: Depth profiles of some physicochemical parameters recorded at Ankerkeha, Littoral and Pelagic sites in Lake Hayq during dry and wet seasons (January-December, 2018).

			Site		
Physicochemical Parameters	Season	Depth(m)	Ankerkeha	Littoral	Pelagic
DO (mgL^{-1})	Dry	0	6.84±019	6.865±0.21	6.96±0.04
		1	6.775±0.12	6.885±0.18	6.98±0.01
		3	6.81±0.098	6.955±0.11	6.96±0.01
		5	6.885±0.20	7.105±0.035	6.86±0.01
		10			6.42±0.09
		20			6.73±0.08
	Wet	0	7.69±0.14	8.04±004	7.49± 0.22
		1	7.625±14	7.82 ±0.28	7.36
		3	7.54	7.835±0.16	7.48±0.16
		5	7.605±0.15	8.075±0.30	7.485±0.15
		10			7.48±0.03
		20			6.29
Saturation (%)	Dry	0	100.25±0.92	100.9±1.4	101.95±1.49
		1	98.6±0.14	101±0.99	102.15± 1.77
		3	98.65±0.50	101.7±0.29	101.85±2.05
		5	98.9±0.57	102.5±0	99.55±3.04
		10			92.7±2.97
		20			96.1±1.69
	Wet	0	113.9±3.11	121.65±1.77	110.85±4.13
		1	113.25±3.46	117.9±5.23	108
		3	111.1	114.4	110.3±3.39
		5	112.8±3.67	117.15±2.89	109.95±2.76
		10			109.2±1.69
		20			91.5

Table 2.2 Continued: Depth profiles of some physicochemical parameters recorded at Ankerkeha, Littoral and Pelagic sites in Lake Hayq during dry and wet seasons (January-December, 2018).

			Site		
Physicochemical parameters	Season	Depth (m)	Ankerkeha	Littoral	Pelagic
Temperature (°C)	Dry	0	22.95±0.92	23.05±0.92	22.95±1.06
		1	22.6±0.98	22.950 ±0.78	22.85±0.92
		3	22.35±0.92	22.8±0.70	22.65±0.92
		5	21.95±1.20	22.1±0.28	22.45±92
		10			22.1±0.85
		20			21.65±0.36
	Wet	0	22.95±0.36	24.65±0.64	23.4±0.56
		1	23.75±0.64	24.45±0.49	22.9
		3	23.70 ±0.85	24.05±0.35	23.25±0.50
		5	23.8	24.05±0.64	23.1±0.28
		10			23±0.28
		20			22.6
Conductivity (µS cm^{-1})	Dry	0	878±42.43	855±25.46	885.5±38.89
		1	876.5±27.58	856.5±27.58	888±33.94
		3	867.5±50.51	870±7.07	879±33.94
		5	883.5±37.48	894.5±34.65	894.5±37.47
		10			857±22.63
		20			879±43.84
	Wet	0	914±50.91	919±113.14	912±63.64
		1	830.5±98.23	930±66.47	965
		3	856±8.49	907.5±129.40	938±86.27
		5	820	821±28.28	920.5±77.08
		10			923.5±106.77
		20			889
pH	Dry	0	8.7-8.97	8.76-8.89	8.75-8.97
		1	8.72-8.88	8.76-8.9	8.77-8.95
		3	8.76-8.91	8.81-8.95	8.78-8.99
		5	8.77-8.86	8.85-9	8.74-8.97
		10			8.76-8.99
		20			8.84-8.94
	Wet	0	7.67-9.01	7.78-9	7.75-8.92
		1	7.78-9.01	7.78-8.91	7.77
		3	7.72-9.01	7.89-8.9	7.77-8.95
		5	8.49-8.95	7.76-9.01	7.76-8.8
		10			7.75-8.77
		20			8.85

2. 3. 2. Inorganic nutrients and chlorophyll-*a*

The major inorganic nutrients analyzed in the present study were nitrogen (nitrite-NO_2, nitrate-NO_3, NH_3, and NH_4), phosphorus (soluble reactive phosphorus-SRP, and total phosphorus-TP), and dissolved silicate (SiO_2). The concentrations of each of the measured nutrients are found in Table 2.3. There was a significant variation in Nitrite and Ammonium ($P < 0.05$) among sampling between seasons (dry and wet). However, significant difference was not observed in other nutients and Chl-*a* ($P > 0.05$) (Table 2.3)

The least NO_2 (7.17 ± 2.14 µgL^{-1}) was recorded at Ankerkeha site during dry season and the highest NO_2 (112.27 ± 26.23 µgL^{-1}) was recorded at Ankerkeha during the wet season. The least NO_3 (31.17 ± 9.30 µgL^{-1}) was recorded at Ankerkeha site during dry season and the highest NO_3 (162.25 ± 2.97 µgL^{-1}) was recorded at pelagic site during the wet season. The least NH_3 (24.24± 1.97 µgL^{-1}) was recorded at littoral site during the dry season and the highest NH_3 (52.297 ± 24.64 µgL^{-1}) was recorded at pelagic during wet season. The least NH_4 (0.85 µgL^{-1}) was recorded at Ankerkeha site during dry season. The highest NH_4 (210 µgL^{-1}) was recorded at pelagic during wet season. The least SiO_2 (128.17 ± 51.74 µgL^{-1}) was recorded at Ankerkeha during dry season. The highest SiO_2 (192.24 ± 9.20 µgL^{-1}) was recorded at pelagic during wet season. The least SRP (1.37± 0.98 µgL^{-1}) was recorded at littoral during the wet season and the highest SRP (17.67±11.20 µgL^{-1}) was recorded at Ankerkeha during the dry season. The least TP (16.42 ± 17.03 µgL^{-1}) was recorded at pelagic during wet season and the highest TP (54.33 ± 17.21µgL^{-1}) was recorded at littoral during dry season. The least Chl-*a* (3.85±0.49 µgL^{-1}) at Ankerkeha during wet season. The highest Chl-*a* (5.3±0.14 µgL^{-1}) was recorded at pelagic during dry season (Table 2.3).

Table 2.3: Spatial and Temporal variation of Algal nutrients of Lake Hayq

		Sites					
Nutrients	Season	Ankerkeha	Littoral	Pelagic	DF	F	Sig.
NO_2 (µgL^{-1})	Dry	7.17±2.14	20.063 ±15.09	20.59±14.50	2	3.799	0.03*
	Wet	112.27±26.23	58.91±34.44	72.25±59.45			
NO_3 (µgL^{-1})	Dry	31.17± 9.30	87.23± 65.62	89.56±63.06	2	2.243	0.13
	Wet	158.13± 7.48	156.17± 5.25	162.25± 2.97			
NH_3 (µgL^{-1})	Dry	42.57± 6.05	24.24± 1.97	29.64± 5.66	2	0.771	0.47
	Wet	49.30± 32.91	31.02±14.28	52.297± 24.64			
NH_4 (µgL^{-1})	Dry	0.85	0.86	0.87	2	66.02	0.01*
	Wet	160	140	210			
SiO_2 (µgL^{-1})	Dry	128.17± 51.74	134.03± 66.36	153.93± 93.78	2	0.197	0.82
	Wet	192.01± 9.79	191.38± 7.46	192.24± 9.20			
SRP (µgL^{-1})	Dry	17.67±11.20	12±4.42	13.83±7.88	2	0.397	0.68
	Wet	2.79±2.31	1.37± 0.98	1.98±1.72			
TP (µgL^{-1})	Dry	44.17±21.74	54.33±17.21	43.33±3.98	2	0.938	0.40
	Wet	41.39±42.47	28.03±27.50	16.42±17.03			
Chl-a (µgL^{1})	Dry	4.21±1.15	5.3±0.14	5.04±0.37	2	3.017	0.113
	Wet	3.85±0.49	4.4±0.28	4.5±0.14			

Note: *- significant at 0.05 Probability

2. 3. 4. Trophic status

The trophic status index of Lake Hayq based on total phosphorus (TP), Secchi-disk depth (SD), and Chlorophyll a (Chlorophyll a) are presented in table 2.4. The trophic status index value based on Secchi's disk-depth was lower (41.95) than the trophic status index value based on total phosphorus (56.56) and chlorophyll-a (45.34). The Carlson's trophic state index value was 47.95, therefore, Lake Hayq was in the mesotrophic state (40-50).

Table 2 .4: Trophic Status Index of lake Hayq

TP	TSI (TP)	Secchi-disk depth	TSI (Sec)	Chl-*a*	TSI Chl-*a*	TSIc
38	56.56	3.5	41.95	4.5	45.34	47.95

2. 3. 5. Phytoplankton composition

A total of 44 phytoplankton taxa classified under Chlorophyta (17), Bacillariophyta (16), Cyanophyta (5), Dinophyta (2), Euglenophyta (2) and Cryptophyta (1) were recorded in Lake Hayq (Table 2. 5). Chlorophyta (39%), Bacillariophyta (37%), and Cyanophyta (12%) were algal groups comprising the maximum taxa composition in Lake Hayq (Figure 2.5).

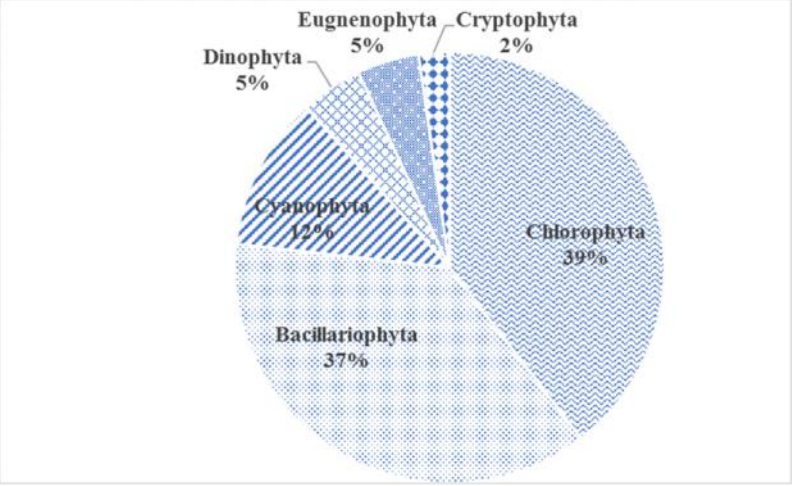

Figure 2.5: Phytoplankton taxa composition of Lake Hayq

Table 2. 5: Phytoplankton composition of Lake Hayq

C**yanophyta**	**Chlorophyta**	**Bacillariophyceae**	**‘Others group’**
Anabaena Sp.*	*Anthrodesmus Sp.*	*Epithemia sorex*	*Peridinium Sp**
Merismopedia Sp.	*Chlorella Sp.*	*Amphora strigosa*	**Dinophyta**
Microcystis aerugenosa	*Clostrium Sp.*	*Aulacoseira*	*Cryptomonas Sp.*
Microcystis flos-aquae	*Coelastrum Sp.*	*Coscinodiscus Sp.**	**Cryprophyta**
Oscillatoria Sp.	*Cosmarium Sp.*	*Cyclotella Sp.*	*Gymnodinium Sp.*
	*Oocysts Sp.**	*Cymbella aspera*	**Euglenophyta**
	Pandorina Sp.	*Epithemia adnata*	*Euglena Sp**
	Pediastrum boryanum	*Fragilaria Sp.*	*Phacus Sp.*
	Pediastrum duplex	*Gomphonema Sp.*	
	Pediastrum simplex	*Gyrosigma Sp.*	
	Scenedesmus Sp.	*Navicula*	
	Straurasstrum quadricauda	*Nitzschia Sp.*	
	Straurasstrum uplandicum	*Rhopalodia Sp.*	
	Straurasstrumcingulum	*Surirella angusta*	
	Straustrum obesum	*Surirella robusta*	
	Tetraedron Sp.	*Synedra Sp.*	
	Volvox Sp.		

Note: species marked with * are the most dominant from each division

2. 3. 6. Phytoplankton abundance

Among the phytoplankton groups identified from Lake Hayq, Dinophyta, and Cryptophyta were the most and the least dominant taxa numerically (Table 2.6). Dinophyta, Chlorophyta, and Bacillariophyta were the dominant groups in abundance. Dinophyta were dominant in both dry and wet seasons at all sites. However, there was no distinct variation of Bacillariophyta and Chlorophyta among sampling sites and seasons (Table 2.6).

Table 2.6: Spatial variation of major phytoplankton taxa in Lake Hayq

phytoplankton taxa (cells/ ml)	Season	Sites		
		Littoral	Pelagic	Ankerkeha
Bacillariophyta	Dry	143.3	266.86	200
	wet	89.85	282.21	364.33
Dinophyta	Dry	5500.5	24200	2312
	wet	8000	21330.5	3675
Chlorophyta	Dry	447.85	951.37	431.2
	wet	736	1552.59	515.1

2. 3.7. Phytoplankton biomass

Biomass of phytoplankton measured (µgL^{-1}) varied with season and among the sampling sites in Lake Hayq. There was no significant difference (ANOVA, $P > 0.05$) in phytoplankton biomass among sites in in dry and wet seasons in. The highest mean phytoplankton biomass (5.3±0.14 µgL^{-1}) was recorded at the littoral site in dry and the lowest (3.85±0.49 µgL^{-1}) was recorded at Ankerkeha river mouth in wet season as indicated in Table 2.3.

2. 3. 8. Redundancy Analysis (RDA)

The correlation of the environmental factors (Oxygen saturation, DO, NO_2, NO_3, NH_3, NH_4, SRP, TP, Chlorophyll-a, Secchi disk depth, pH, Conductivity, and Temperature) with a mean abundance of the major phytoplankton taxa (*Cymbella, Coscionodiscus, Nitzcchia, Cosmarium, S.updiculum, Cyclotella, Gymnodinium, Anabaena, Straustrum, phacus, Filagilaria, S.cingulum, Surirela, M.aeruginosa, Anthrodesmus, Oocyst, Tetradron, M. flosaquae, Peridinium, E. adnata, Aulacoseria, Rhopalodia*, and *Synedra*) in sampling sites (littoral, pelagic, and Ankerkeha) of Lake Hayq was analyzed using a constrained Redundancy Analyses (RDA, CANOCO 4.5 Software). The environmental parameters and phytoplankton species were positively correlated in the littoral and Ankerkaha sites unlike the Pelagic site (Figure 2.7). For example, Dissolved Oxygen, Oxygen saturation, Temperature, conductivity, chlorophyll-a, and Secchi disk depth were positively correlated with *Rhopalodia, Aulacoseria, Epithemia,* and

Peridinium species. The first and second axes together explained 100% of the cumulative percentage variance of species-environment relations (Table 2.7). The first axis explains 96.2% and the second axis explainsonly 3.8% of species-environment relations (Table 2.7). The environmental parameters (pH, NO_2^- NO_3^- NH_3 NH_4+ SiO_2, SRP, and TP) had a strong positive correlation with Axis 1 but some of the parameters (DO, oxygen saturation, temperature, Conductivity, Secchi disk depth, NO_2, TP, and chlorophyll - a) had a strong positive correlation with Axis 2.

Table 2.7: Summary of the statistics of the RDA (Redundancy Analysis)

Axes	1	2	3	4
Eigen values	0.962	0.038	0	0
Species-environment correlations	1	1	0	0
Cumulative percentage variance				
of species data:	96.2	100	0	0
of species-environment relation:	96.2	100	0	0
Sum of all eigenvalues	1			
Sum of all canonical eigenvalues	1			

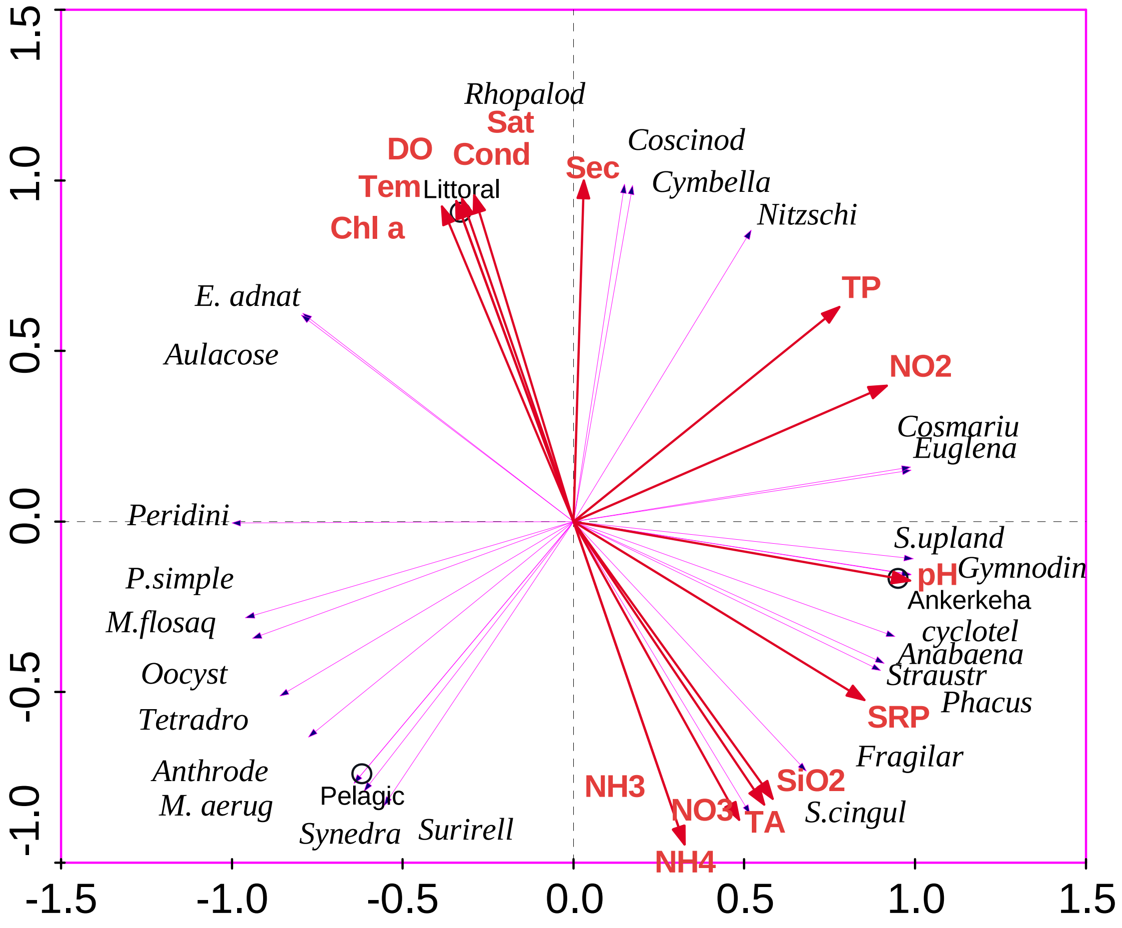

Figure 2.6: Tri-plot of the Redundancy Analyses (RDA) for major phytoplankton species (Purple arrow and environmental variables (red arrows) and Balck circle (Sampling sites, Pelagic, Ankerkeha, and Littoral): Coscinod-*Coscinodiscus*, *Cymbella*, Nitzschi-*Nitzschia*, Cosmariu-*Cosmarium*, *Euglena*, S.upland- *S. uplandicum*, Gymnodin-*Gymnodinium*, Cyclotel-*Cyclotella*, *Anabaena*, Straustr-*Straustrum*, *Phacus*, Fragilar-*Fragilaria*, S.cingil-*S.cingulum*, Surirell-*Surirella*, *Synedra*, M. aerug- *M.aeruginosa*, Anthrode- *Anthrodesmus*, *Oocyst*, M. flosaq-*M.flosaquae*, P.simple- *P.simplex*, Peridini- *Peridinium*, Aulacose- *Aulacoseria*, E.adnat-*E. adnata*, Rhopalod-*Rhoplalodia*, TP- total phosporus, NO_2, pH, SRP-Soluble reactive phosporus, SiO_2, TA-total alkalinity, NO_3, NH_3, NH_4^+, Chl-a-chlorophyll-a, Tem-Temperature, DO -Dissolved oxygen, Cond- Conductivity and Sat- Oxygen saturation

2. 3. 9. Zooplankton taxa composition

Totally 28 zooplankton taxa were identified from Lake Hayq (Table 2.8). Among these, 16 were taxa of Rotifers 7 Cladocerans, 4 to Copepoda, and 1 Ostracoda. At the littoral site, a total of 18 species were identified. Of these, 11 belonged to Rotifera, 4 to Cladocera, and 3 to Copepoda. At Ankerkeha site, a total of 17 zooplankton species were identified. Of these, 7 belonged to Rotifera, 5 to Cladocera, and 4 to Copepoda. The highest taxa (16) were identified in wet season at littoral and pelagic sites and the lowest taxa (2) were identified at Ankerkeha River during the dry season

Table 2. 8: Zooplankton species identified from Lake Hayq during January-December, 2018

Cladocera	Copepoda	Rotifera	Ostracoda
Bosmina longirostris	*Cyclops napulii**	*Anuraeopsis fissa*	*Ostracod Sp.*
Cerodaphinia cornuta	*Meso cyclops equatorialis*	*Anuraeopsis navicula*	
Diaphanosoma excisum	*Thermocyclops ethiopiansis*	*Asplanchia intermedia*	
*Diaphanosoma sarsi**	*Tropocyclop Sp.*	*Bdelloids Sp.*	
Leptodora sp.		*Brachionus angulari*	
Moina micrura		*Brachionus calcyflorus*	
Sida Sp.		*Brachionus dimidiatus*	
		Brachionus quadridentatus	
		Filinia Sp.	
		Hexathran Sp.	
		*Keratella tropica**	
		Lecane bulla	
		Lepadella Sp.	
		Polyarthra vulgaris	
		Testudinella Sp.	
		Trichocera Sp.	

Note: species with * are the most dominant taxa from each group of taxa

2. 3. 10. Percentage composition of zooplankton taxa

The Rotifers contributed 57% followed by Cladocera with 25%, Copepoda with 14%, and Ostracoda with 4% (Figure 2. 7). At the Littoral site, Rotifera contributed 61% followed by Cladocera (22%) and Copepoda (17). At Pelagic site, Rotifera contributed 60%, Copepoda (20%), and Cladocera (20%). At Ankerkeha Site, Rotifera contributed 41% followed by Cladocera (29%) and Copepoda (24%) (Figure 2.8).

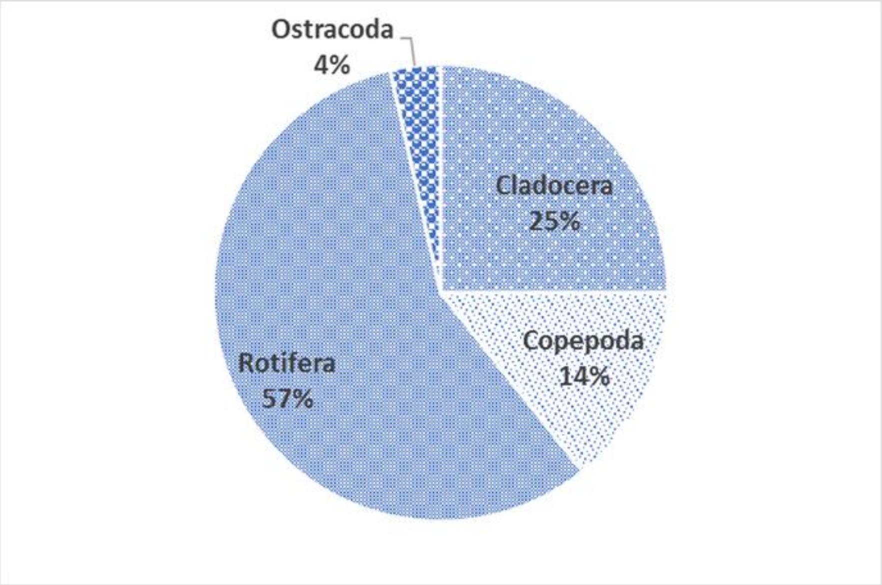

Figure 2.7: Zooplankton composition of Lake Hayq (January-December, 2018)

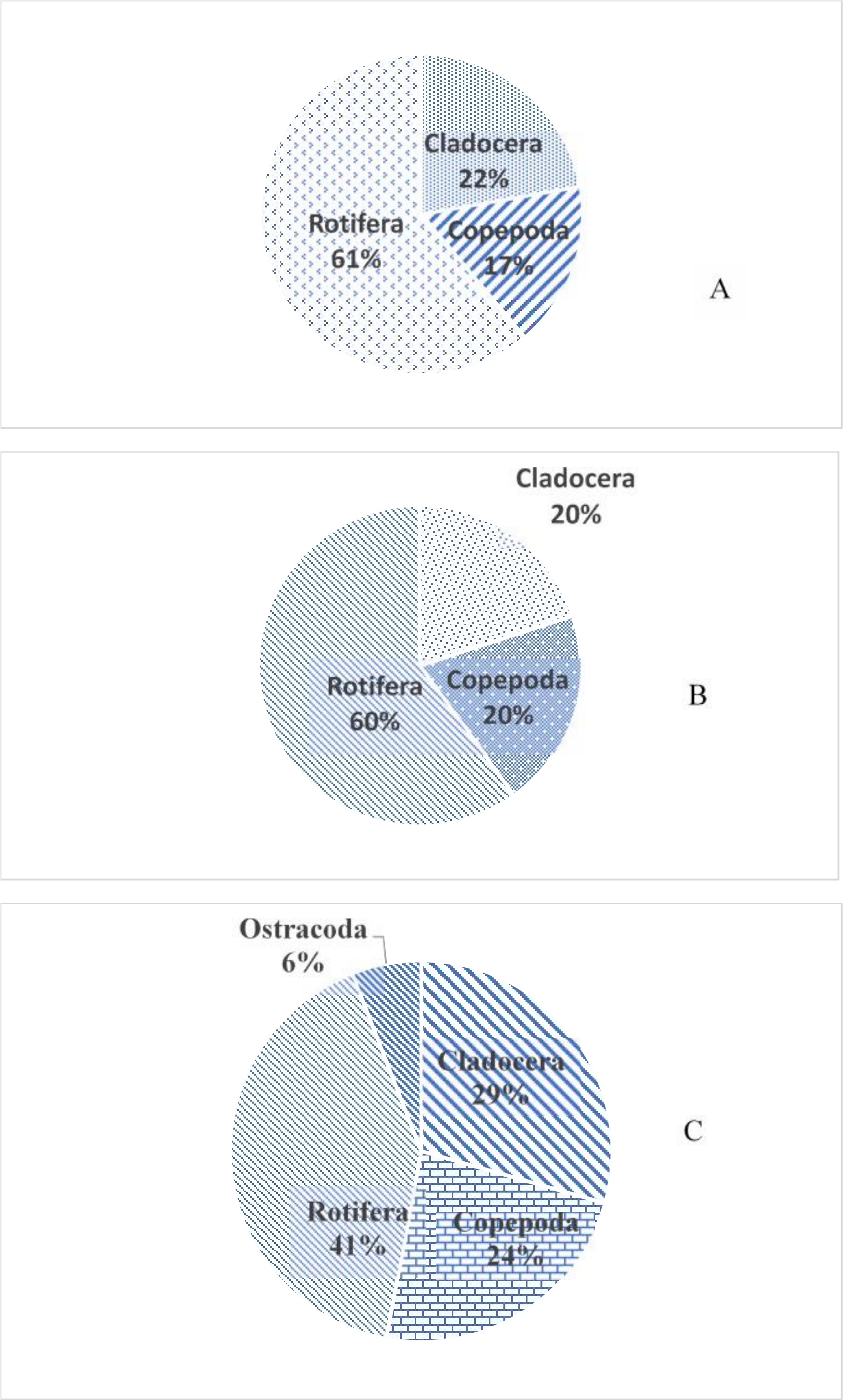

Figure 2. 8: Proportion of zooplankton taxa composition in three sampling sites, Littoral (A), Pelagic (B) and, Ankerkeha (C) of Lake Hayq

2. 3. 11. Zooplankton population density

The density of rotifers was the highest compared to copopods and cladoceran taxa as shown in figure 2.9. The highest mean density (212.62±241.12individual/L) of Rotifera was recorded at littoral and the lowest mean density (53.3 ±65.51 individual/ L) at the Ankerkeha site. The highest mean density (80.5±103.04 individual/L) of Cladocera was recorded at pelagic and the lowest mean density (66.02 ±71.23 individual/L) was recorded at the Ankerkeha site. The highest mean density (204.79 ±86.71 individual/L) of Copepoda was recorded at littoral and the lowest mean density (49.54±66.20 individual/L) of Copepoda was recorded at Pelagic site (Table 2.9). The highest density of Copepoda (98.51± 101.45 individual/L) was recorded during dry season. The highest density of Rotifera (210.85±278.34 individual/L) and Cladocera (84.05 ±110.03 individual/L) were recorded during wet season respectively (Table 2.10). Among the zooplankton taxa identified from Lake Hayq, density (individual/L) of Rotifers was the highest compared to Cladocera and Copepoda. The major Rotifera were *Keratella tropica* (382 individual/L), *Anuraeopsis navicula* (297 individual/L), and *Anuraeopsis fissa* (275 individual/L). The dominant Cladocera were *Ceriodaphnia cornuta* (108 individual/L), *Diaphanosoma excisum* (99 individual/L). The dominant Copepoda were Napuli (110 individuals/L), *Mesocyclops equatorialis* (95 individual/L) and *Thermocyclops ethiopiansis* (70 individual/L).

Table 2. 9: Abundance (density) of zooplankton groups (mean ± SD) of Lake Hayq at three sampling sites (Ankerkeha, littoral, and pelagic)

Sites	The density of zooplankton taxa (individual/L, mean and SE			
	Copepoda	Cladocera	Rotifera	Mean total
Ankerkeha	58.16 ±74.08	66.02 ±71.23	53.3 ±65.51	59.16
Littoral	204.79 ±86.71	74.47± 124.39	205.79±318.98	161.68
Pelagic	49.54±66.20	80.5±103.04	212.62±241.12	114.22
Mean total	104.16	73.66	157.24	111.68

Table 2. 10: Abundance (density) (mean ± sd) of zooplankton group in Lake Hayq sampled in dry and wet season

Season	Density of zooplankton taxa			
	Copepoda (mean ±SD)	Cladocera (mean ± SD)	Rotifera (mean ± SD)	Mean total
Dry	98.51± 101.45	53.28 ± 81.219	127.3 ± 242.09	93.03
Wet	36.2 ± 33.35	84.05 ±110.03	210.85 ±278.34	110.37
Mean total	67.34	68.67	169.08	101.69

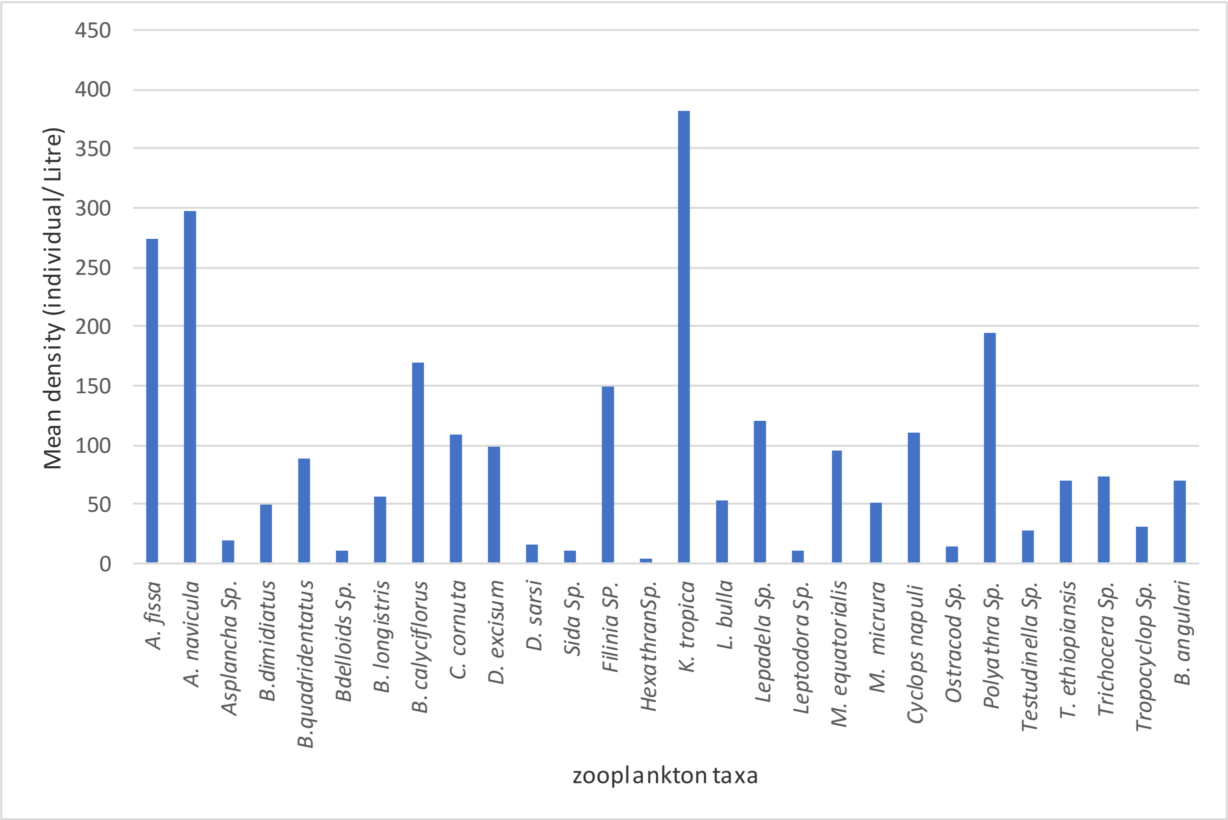

Figure 2. 9: Abundance (individual/L) of zooplankton species of Lake Hayq (January December, 2018)

2. 3. 12. Redundancy Analysis (RDA)

The correlation of the environmental factors (DO, NO_3, NH_4, SRP, TP, Chlorophyll-a, Secchi-disk depth, pH, Total alkalinity and Temperature) with a mean abundance of major zooplankton species (*A. navicula, C. cornuta, D. excisum, Filinia, K.tropica, M. equatorialis, A. fissa B.quadridentatus, B.calyciflorus, Lepadella*, and *Polyathra*) in sampling sites (Littoral, Pelagic, and Ankerkeha) of Lake Hayq was analyzed using a constrained Redundancy Analyses (RDA, CANOCO 4.5 software). Most of the zooplankton taxa were correlated positively with chlorophyll-a, temperature, dissolved oxygen, Secchi disk depth at Littoral site. However, only *D.excism* in pelagic site was positively correlated with NH_4, NO_3, total alkalinity (Figure 2.11). The first and second axes together explained 100% of the cumulative percentage variance of species-environment relations (Table 2.11). The first axis explains 85% and the second axis explains 15 % of species-environment relations (Table 2.11). DO, temperature, Secchi disk depth, TP, Chl-a had a strong positive correlation with Axis 1, and NH_4 and Chl-a had less correlation with Axis 2 (Figure 2.10).

Table 2. 11: Summary of the statistics of the RDA (Redundancy Analysis)

Axes	1	2	3	4	Total variance
Eigenvalues:	0.85	0.15	0	0	1
Species-environment correlations:	1	1	0	0	
Cumulative percentage variance					
of species data:	85	100	0	0	
of species-environment relation:	85	100	0	0	
Sum of all eigenvalues					1
Sum of all canonical eigenvalues					1

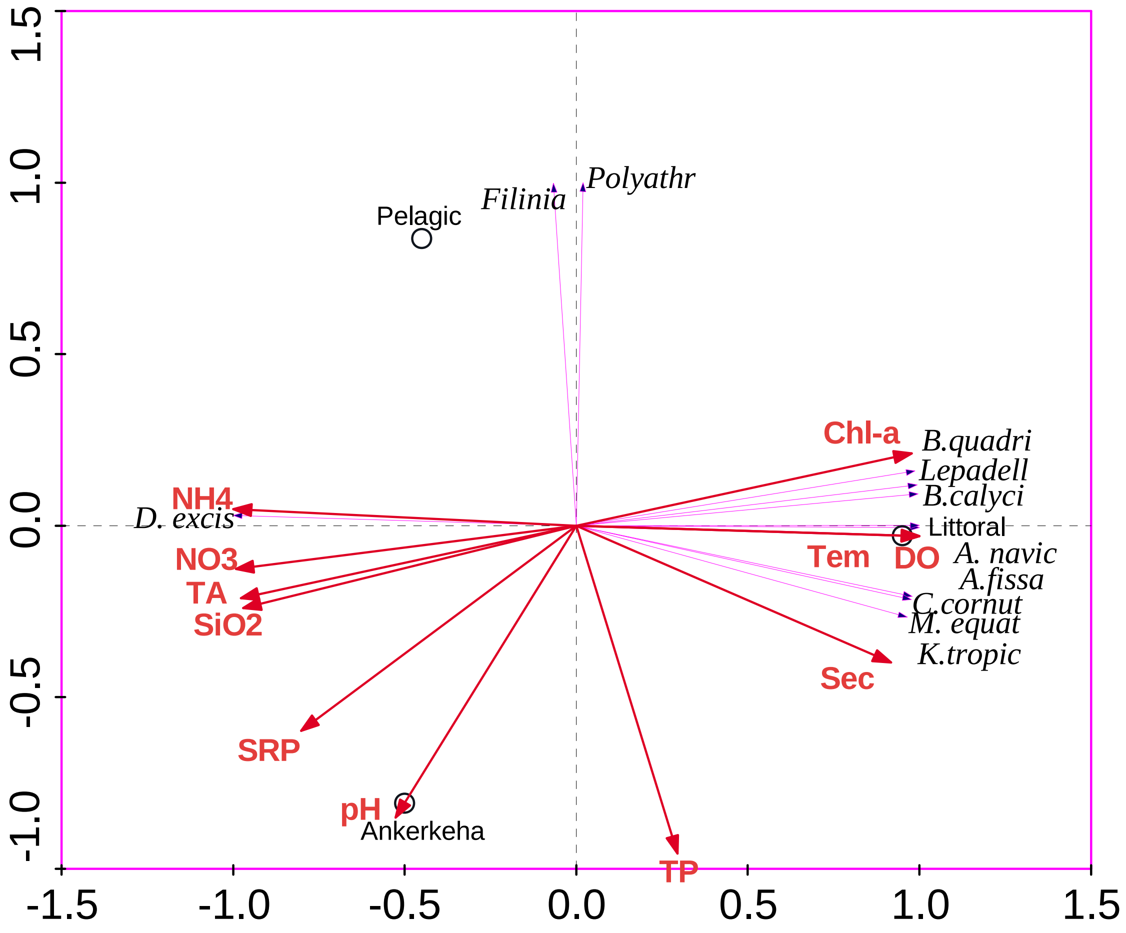

Figure 2. 10: Tri-plot of the Redundancy Analyses (RDA) for dominant zooplankton species (purple arrow and environmental variables (red arrows) and Balck circle (Sampling sites, Pelagic, Ankerkeha, and Littoral): B.quadri- *B. quadridentatus,* Lepadell- *Lepadella*, B.calyci- *B. calcyflorus* A. navic - *A. naviculla*, *A. fissa*, C.cornut- *C. cornuta*, M.equat- *M. equatorialis* K. tropic- *K.tropica*, D.excis-*D.excism*, *Fininia*, and Polyathr-*Polyathra*

2. 4. Discussion

2. 4. 1. Physicochemical water quality parameters

Lake Hayq is a highland lake with a mean depth of 31 m and maximum depth of 81 m. Though, the lake is located in the highland (about1900 m), the average surface water and deeper layer water temperature varied between 23 ^oC and 22 ^oC, respectively, which was higher than most highland lakes in Ethiopia. Despite its location in higher altitude, Lake Hayq has higher average surface water temperature of 23 °C which was higher than Lake Hashengie (19 °C: Vijverberg *et al*., 2012) and Lakes Dendi, Wonchi and Ziqualla (16.7 °C; Fasil Degefu *et al*., 2014) and comparable with Lake Tana (23.9 °C; Dessie Tibebe *et al*., 2019) and Lake Tinshu Abaya (23 °C : Yirga Enawgaw, 2019). However, it was less than other rift valley lakes, Chammo (26-30.4 °C: Addisu Fekadu and Solomon Chanie, 2017) and Lake Kuriftu (28-30 °C; Zelalem Dessalegn and Demeke Kifle, 2016). The unusual higher temperature in Lake Hayq might have been the result of deep volcanic activity (Vijverberg *et al.,* 2012). In the present study, there was no significant water temperature difference between seasons and sampling sites ($P > 0.05$) which could be due to the higher depth of the lake and the lower variability of the atmospheric temperature during the last 10 years (2009-2018). In lake Hayq, there was no oxygen problem, the average concentration of DO was 7.24 mg L^{-1} at the surface and minimum mean DO at 20 m depth was 6.29 mg L^{-1} and 91.5 % saturation. In our sampling periods, the water temperature difference along the depth profile was less than 1 °C indicated that the lake was at mixing condition. However, the maximum depth that we have considered was 20 m at pelagic site which could be our limitation in missing the lake stratification strata below this depth if any. The level of DO in Lake Hayq was higher than Lakes Dendi, Wonchi and Ziqualla (Fasil Degefu *et al.,* 2014) and comparable with other lakes, Lake Tinshu Abaya (Yirga Enawgaw, 2019), Lake Tana (Dessie Tibebe *et al*., 2019).

The pH of Lake Hayq was 8.84-8.94 where CO_3^- is dominant and these values were greater than Lakes Dendi, Wonchi, and Ziqualla (7.91- 8.27) and Lake Tana (7.9; Dessie Tibebe *et al.*, 2016) where HCO_3^- is dominant. However, the pH of Lake Hayq was comparable with Lake Tinshu Abaya (about 8.7: Yirga Enawgaw, 2019), Lake Adale (8.7-9.2: Zelalem Desalegn,

2013) and lower than Lake Chamo (9.3: Addisu Fekadu and Selemon Channie, 2017) and lakes Chitu and Shall (nearly 10; Tadesse Ogato, 2017). In lake Hayq, there was no significant difference in pH between seasons and sampling sites ($P > 0.05$) which could be associated with the higher buffering potential of the lake related to higher value of total alkalinity (8.6 - 9.5 meq L^{-1}).

The total alkalinity of Lake Hayq (8.6 - 9.5 meq L^{-1}) which was almost similar to earlier reports for the same lake (Tadesse Fetahi *et al.,* 2014). This value was higher than Lake Kuriftu (3.1 meq L^{-1}; Zelalem Desalegn and Demeke Kifle, 2014) and Lake Tinishu Abaya (7.91- 8.27; Yirga Enawgaw, 2019). But, the total alkalinity value of Lake Hayq was lower than Lake Shala (223 meq L^{-1}; Tadesse Ogato and Demeke Kifle, 2017) and Lake Chitu (737±41meq L^{-1}; Tadesse Ogato, 2017). Total alkalinity concentrations for natural waters may range from 0 meq L^{-1} (very low) to more than 10 meqL^{-1} (very high) (Boyd, 2000).

The mean conductivity of Lake Hayq was 876.38±31.05 - 914.73±65.05 µScm^{-1} which was higher than Lake Tana (148.5 µScm^{-1}; Dessie Tibebe *et al.*, 2019), Lake Tinishu Abaya (420.5 µScm^{-1}, Yirga Enawgaw, 2019). However, it was lower than Lake Chamo (1253-2127 µScm^{-1}; Addisu Fekadu and Solomon Chanie, 2017), Lake Abaya (1146 µScm^{-1}; Fasil Eshetu *et al.*, 2017) and and Lake Chitu (61.9±2.7 mS cm^{-1}; Tadesse Ogato, 2017).

In the present study, the mean Secchi-disk depth of Lake Hayq was nearly 3.5 meters giving an euphotic depth of about 10 m and a mean chlorophyll-a of 4.5 µgL^{-1}. The Secchi-disk depth measured by different scholars in Lake Hayq were different at different times and they related the values with the introduction of Nile tilapia in 1978. Before the introduction of the fish, the lake was very clear with an average Secchi-disk depth of 9 m and <1 µgL^{-1} chlorophyll-*a* concentration (Baxter and Golobitsch, 1970). However, Elizabeth Kebede (1992) reported a very low Secchi-disk depth value of 1.2 m and relatively high chlorophyll-*a* of 17µgL^{-1}, which is associated with the change of trophic status from oligotrophic to eutrophic state. The trophic status change was also recently confirmed by Tadesse Fetahi *et al*. (2014) that have reported mean Secchi disk depth (0.8-6.3 m) and Chlorophyll-*a* (12.9 µgL^{-1}). The higher algal biomass and seasonal change and persistent occurrence of heavy taxa diatoms in Lake Hayq were influenced by atelomixis, partial mixing (Padisák *et al.*, 2009; Tadesse Fetahi *et al.*, 2014). On the other hand, very low Chlorophyll-*a* (<5 µgL^{-1}) and a higher Secchi-disk depth value of 5 meters were reported by Vijverberg *et al*. (2012) in their snapshot sampling. As indicated in Vijverberg *et al*. (2012), the higher water temperature in a deeper layer might be due to geothermal activities in the bottom layer that may contribute to vertical mixing seasonally and increase nutrients for excessive phytoplankton growth (eutrophication) temporarily. However, in the present study, the mean Secchi-disk depth (3.5 m), mean chlorophyll-a (4.5 µgL^{-1}), and TSIc value (47.95) showed that the lake is mesotrophic. The change in trophic status of Lake Hayq might be due to common carp invasion which has a grazing effect on phytoplankton as observed from the gut content analysis of common carp (Assefa Tessema, Unpublished, 2018) and sedimentation of the lake, especially through Ankerkeha River (Hassen Mohammed *et al*., 2015).

The overall mean Secchi disk value was 3.5 m in Lake Hayq which was comparable with Lake Wonch (5 m; Fasil Degefu *et al*., 2014) and lower than Lake Dendie (12 m: Fasil Degefu *et al*., 2014). This value was higher than most shallow highland lakes, Lake Tana (0.87 m: Dessie *et al*., 2019), Lake Ziqualla (1 m; Fasil Degefu *et al*., 2014) and Lake Kuriftu (0.6 m: Zelalem Desalegn and Demeke Kifle, 2014) and most rift valley lakes, Lake Chamo (0.12- 0.6 m; Addisu Fekadu and Solomon, 2017), Lake Abaya (0.09- 0.19 m: Fasil Eshetu *et al.,* 2017) and Lake Tinishu Abaya (0.18 cm: Yirga Enawgachew, 2019). The higher water transparency in lake Hayq is a characteristic of most deep highland lakes. The higher Secchi disk depth in Lake Hayq could be associated with the newly expanded invasive macrophytes that traps sedimentation from runoff and lower algal biomass (mean 4.5 µgL^{-1}).

Water temperature, DO, and pH are the most important physicochemical parameters that control the toxicity of other parameters such as ammonia (FAO, 1993). According to the Canadian Council of Ministers of the Environment (CCME) (2017), temperature (20-30 °C), dissolved oxygen (> 5 mgL^{-1}), and pH (6.5-9) are safe water quality standard for protection of aquatic life. In the present study, the overall mean water temperature (23 °C), Dissolved Oxygen (7.24 mg L^{-1}), and pH (8.84-8.94) were in the range of safe water quality standards for aquatic life (CCME, 2017).

2. 4 .2. Algal nutrients, phytoplankton biomass, and trophic state

The concentration of algal nutrients was lower in the present study. Significant variation was observed in Nitrite and Ammonium (*P*<0.05). However, slight difference in other algal nutrients (Nitrate, Ammonia, SRP, SiO_2 and TP) were observed in sampling sites between dry and wet season. Most of the dissolved inorganic nutrients (DIN) and Chl-*a* were higher in pelagic site which could be associated with thermal mixing caused by higher water temperature at deeper portion of the lake. The concentration of TP was the highest in littoral site during dry season which might be associated with waste released from lodges and cattle manure dumped during cattle watering from the lake.

In the present study, the mean phytoplankton biomass measured in terms of Chlorophyll-a was 4.5 μgL^{-1}. Earlier, low algal biomass as low as < 1 μgL^{-1} was reported in the 1940s (Baxter and Golobits, 1997). However, higher mean algal biomass (13 μgL^{-1}) was reported by Elizabeth Kebede *et al*. (1992). According to these authors, the higher algal biomass was explained by the introduction of Nile tilapia to the lake in the 1970s which had a grazing effect on zooplankton, particularly on filter-feeder Cladoceran group. The higher algal biomass of the lake was confirmed by Zinabu Gibremariam and Taylor (13 μgL^{-1}, 1997) and Tadesse Fetahi *et al*. (12 μgL^{-1}, 2014).

The results of the current study were higher than other highland lakes of Ethiopia, Dendi, Wonchi, and Ziqualla (Chlorophyll-a <3 μgL^{-1}) (Fasil Degefu *et al*., 2014) but lower than Lake Tana (Chlorophyll-a: 44 μgL^{-1}) (Dessie Tibebe *et al*., 2019). The mean algal biomass of Lake Hayq was also lower than rift valley lakes of Ethiopia, Lakes, Hawassa (18.7± 5.2 μgL^{-1}; Girma Tilahun and Gunnel, 2010), Lake Chamo (12 μgL^{-1}; Fassil Eshetu *et al*., 2017), Lake Chitu (72-234 μgL^{-1}; Tadesse Ogato *et al*., 2016) and Lake Shala (16.6 μgL^{-1}; Tadesse Ogato and Demeke Kifle, 2017).

The change trophic state of Lake Hayq from Eutrophic to mesotrophic could be associated with reduced total phosphorus and chlorophyll-a and the increment in Secchi disk depth. In the present study the values of algal nutrients were intermediate, TP (38 μgL^{-1}), SRP (5.86 μgL^{-1})

and DIN (286 µgL^{-1}) in Lake Hayq These values were higher than Lakes Dendi, Wonchi and Ziqualla (DIN = 65.4-109 µgL^{-1}; SRP = 2.9-15.7 µgL^{-1} and TP = 6.7- 21.6 µgL^{-1}; Fasil Degefu *et al.*, 2014). But much lower than rift valley lakes, Lake Tinishu Abaya (DIN = 729.8 µgL^{-1}, SRP = 39.2 µgL^{-1} and TP = 178.27 µgL^{-1}; Yirga Enawgaw,2019), Lake Chamo (TN = 2735 µgL^{-1}, TP = 1725 µgL^{-1}) and Lake Abaya (TN = 1840 µgL^{-1}, TP=2900 µgL^{-1}) (Fasil Eshetu *et al.*, 2017) and Lake Tana (NO_3^- = 763 µgL^{-1}, SRP = 326 µgL^{-1},and TP = 862 µgL^{-1}; Dessie Tibebe *et al.*, 2019).

The lower algal biomass in the present study could be related to the low algal nutrient concentration in the lake particularly the concentration of phosphorus. Dissolved inorganic nitrogen ($NO_3^- + NO_2^- + NH_4^+$) and SRP are the main forms of N and P that are readily bio-available for algal growth in waters, which has a Redfield atomic ratio of N:P = 16:1 (i.e. algae absorbs N and P in the average ratio of 16 atoms of N to 1 atom of P). In the present study, the mean dissolved inorganic nitrogen (DIN) and SRP concentrations are 286 µgL^{-1} and 5.86 µgL-1 (Table 2.3), respectively resulting in a Redfield ratio of 49. The ratio is very high indicating phosphorus is the major limiting factor for algal growth in Lake Hayq. High water transparency suggest that light is not limited. Furthermore, the lower algal biomass in the present study might be due to the diet overlap, common carp and Nile tilapia feed on algae at smaller size (see chapter 5).

In the present study, the Carlson trophic state value of Lake Hayq was 47.95 lower than the previous report (56) for the same lake (Tadesse Fetahi *et al*., 2014). But, higher than other highland lakes, Dendi (23.37), Wonch (37.84) and Ziquall (45.56) (Fasil Degefu *et al*., 2014). But it was lower than Lake Tana (69.77: Dessie Tibebe *et al*., 2019) and Lake Tinishu Ababya (74.03; Yirga Enawgaw, 2019).

The lower trophic state value in Lake Hayq could be the lower TP and chlorophyll-a values associated with lower density of algal biomass and grazing pressure from common carp.

2. 4 .3. Phytoplankton composition and abundance

In the present study, a total of 44 phytoplankton taxa were identified, which were grouped under six divisions: Chlorophyta, Bacillariophyta, Cyanophyta, Eugleonophyta, Dinophyta, and Cryptophyta. In the 1940s, Lake Hayq was dominated mainly by *M. flosa-aquae*, *M. aeruginosa*, *Phormidium* and *Peridinium* and some heavy diatoms such as *Gomphonema* and *Epithemia* taxa, but since the 1990s, other phytoplankton groups and taxa have become relevant (Zanon 1941; Cannicci and Almagia, 1947; Baxter and Golobitish, 1970; Tadesse Fetahi *et al*., 2014). The number of taxa was slightly higher than that of Tadesse Fetahi *et al*. (2014) who reported 40 phytoplankton species from the same lake. However, the number of phytoplankton taxa in this study were lower than Lake Tana (61) (Akoma, 2010) and higher than Lakes, Dendi (16), Wonchi (26) and Ziqualla (18) (Fasil Degefu *et al*., 2014), which are all highland lakes. In the present study green alage and diatoms were dominant in most of the sampling seasons in terms of species composition. The result of this study was similar to the study conducted by Tadesse Fetahi *et al*. (2014). However, *Peridinium*, a member of the Dinophyta, was numerically abunadant than other taxa of phytoplankton in Lake Hayq.

The higher abundance of *Peridinium* in Lake Hayq could be associated with atelomixis, partial mixing of the lake that seems to favor the taxa due to their special adaptation mechanisms (presence of flagella and mixotrophic feeding habits) (Barbosa, 2002; Souza *et al*. 2008). The lower value of Carlson's trophic state index in the current study might be due to the lower total phosphorus and Chlorophyll-*a*. Typical concentrations of TP in lakes range from 10 µg/L to 80 µg/L (Wetzel, 2001), while in polluted waters it may reach 200 µg/L (Dodson, 2005). The TP value of Lake Hayq is in the range of less polluted water bodies.

Based on trophic state, Lake Hayq is mesotrophic (intermediate productivity) which is suitable for fish production (FAO, 1993). The primary production in lakes is limited by nutrients, principally phosphorus (U.S. EPA, 2000). The optimum TP, Chlorophyll-*a*, Secchi disk depth associated with the optimum amount of dissolved oxygen in Lake Hayq is suitable for healthy fish production. However, the change in trophic state from eutrophic to mesotrophic in Lake

Hayq could brought reduction in food availability and might caused reduction in fishery production in general and stunted growth of Nile tilapia in particular.

2. 4. 4. Zooplankton taxa composition and abundance

Cladocerans, copepods, and rotifers are the major groups of zooplankton in Lake Hayq that remain the same taxonomic composition compared to the previous studies. However, the number of taxa and dominance has changed over the last decade. During the present study, a total of 28 zooplankton taxa were identified for the lake which is higher than zooplankton species reported earlier for the same lake and similar other highland lakes. For instance, Tadesse Fetahi *et al*. (2011a) recorded 11 zooplankton taxa (6 Rotifers, 3 Cladocera, and 2 Copepods) in Lake Hayq while Fasil Degefu *et al*., (2015) have reported 14 taxa (7 Rotifers, 6 Cladocera, and 1 Copepoda) for Lake Wonchi, similar highland lakes in central Ethiopia. Similarly, Tsegazeabe Hadush *et al.* (2012) found 15 species for Lake Hashenge, another highland lake in the northern part of the country (7 Rotifera, 5 Cladoceran, and 3 Copepods). The present numerical abundance in Lake Hayq was higher compared to Lake Tinshu Abaya (18 species in total; 11 Rotifers, 5 cladoceran, and 2 copepods), a Rift valley Lake (Yirga Enawgaw and Brook Lemma, 2018) but lower than Lake Ziway (57 species; 49 rotifers, 5 cladocerans, and 3 copepods) (Adamneh Dagne *et al*., 2008).

Zooplankton taxa of Lake Hayq were almost similar to the finding of Lake Bhimtal, India that had 29 total zooplankton taxa (16 species of Rotifers, 8 species of Cladocera and 5 species of Copepods (Malik and Shikha, 2016). But this number was lower than Lake Tana, the largest lake in Ethiopia, with 44 taxa identified (16 Rotifers, 16 Cladoceran, and 12 Copepods) (Imoobe and Akoma, 2010).

The high number of taxa in the present study might be associated with a greater number of sampling sites (3 sites). Further, of the three sites, two were littoral zone – a place of refugia for zooplankton that may increase the composition and abundance of the organisms.

Bigger sized zooplankton such as *Daphnia* and *Diaphanosoma* were reported in Lake Hayq since the 1930s. However, these species were not reported in the 1990s and the possible justification for this disappearance was the introduction of Nile tilapia (*Oreochromis niloticus*) in the 1970s (Elizabeth Kebede *et al*., 1992) and this was fully supported by later study (Tadesse Fetahi *et al*., 2011a). The latter authors observed total mixing in Lake Hayq resulting in low dissolved oxygen (< 2 mg L^{-1}) along the entire water column and consequently massive Nile tilapia death and the disappearance of Cladocera in the system. Due to the low abundance of Nile tilapia, large-sized zooplankton, *Diaphanosoma species* were encountered in this study for the first time indicating, the loosening of grazing pressure of Nile tilapia on Cladocera taxa.

The highest zooplankton species composition and abundance were identified in the littoral site of Lake Hayq similar to the other studies conducted in Lake Tana (Imoobe and Akoma, 2010), Lake Hashenge (Tsegazeabe Hadush *et al*., 2012), and Lake Ziway (Mesfin Gebrehiwot *et al*., 2017). In the present study, the density of rotifers was the highest followed by copepods and cladoceran, unlike the previous studies that reported the dominance of copepods over their study periods for the same lake (Elzabeth *et al*., 1992; Tadesse Fetahi *et al*., 2011a). In the present study, the dominant species in terms of density was *Keratella tropica* whereas *Thermocyclops ethiopinesis* was the most dominant species in the previous report (Tadesse Fetahi *et al*., 2011) for the same lake. Such high rotifer abundance was also reported for Lake Hawassa, which was justified with a low abundance of copepods. Copepod may consume rotifer as a major diet (Zinabu Gebre-Mariam and Taylor, 1989), which corroborates the low rotifer abundances in former times. In the present study, however, the numerical abundance of copepod is low resulting in low grazing pressure on rotifers. Thus, the highest rotifer density was recorded.The dominance of Rotifers in the present study might be associated with atelomixis, partial or incomplete mixing which is mixing of the top layer, epilimnion (Francisco and Judit, 2002; Tadesse Fetahi *et al*., 2011), and higher transparency of the lake (Roberto *et al*., 1998; Revania *et al*., 2014).

The lower abundance, density of zooplankton in the present study might be also associated with the destruction of the littoral zone and change in land-use patterns in the catchment and predation pressure from fishes, especially from newly invading common carp species. The lower zooplankton composition and density depend on the quality of the littoral zone (a refuge for zooplankton) and land-use patterns of the catchment that has a direct and indirect impact on lake ecology (Edwine *et al*., 2017; Shaikhom and Prem, 2019).

In the present study, most of the Rotifers and some Cladocera, *C. cornuta,* and Copepods, *M. equatorialis* have a strong positive correlation with Chl-a, Temperature, Secchi disk depth and dissolved oxygen and negatively correlated with NH_4^+, pH, SRP, SiO_2 and total alkalinity. Environmental variables including temperature, conductivity, dissolved oxygen, ammonium, pH, organic substance, and chloride have considerable influence on the zooplankton community structure and abundance (Cuicui *et al*., 2019).

Chapter 3: Diversity, distribution, and relative abundance of fish species in Lake Hayq

3. 1. Introduction

Ethiopia is called the water tower of East Africa due to its huge freshwater potential. The country has many lakes and reservoirs, small water bodies, and large floodplain areas distributed all over the country from lowland to highlands covering a total surface area of about 13,637 km^2 (Gashaw and Wolff, 2014).Though fish diversity studies in Ethiopia are still under investigation in different water bodies (lakes and rivers) by researchers, the fish diversity of the country is estimated to be over 200 species (Gashaw Tesfaye and Wolff, 2014; Abebe Getahun, 2017).

The distribution of fish communities and seasonal movements depend on environmental conditions. Species typically favor areas that optimize their physiological processes to minimize energy expended for survival (Matthews, 1990). Studies of the distribution patterns of fish communities in space and time provide insight into the resource partitioning among the species and the nature of interspecific interactions (Wootton, 1990).

Inland lakes have significant importance for food supply and employment at local, regional, and in some cases national level (FAO, 2011). Hence, information on seasonal changes on fish composition and abundance and the effects of environmental variables on the fishery is crucial both for fishery managers and fishermen for sustainable fishery utilization (Mensah *et al*., 2019).

Knowledge of the distribution pattern of a species can provide essential information for the development of models for fisheries management since fishing activities will have different impacts on the varying habitats within a water body (Pet & Piet, 1993 cited in Tesfaye Wudneh, 1998). Studies on species diversity and abundance are important to obtain information on the quality and quantity of the available habitats. Since the 20th century, many fish species have suffered continuing declines in abundance and distribution, some at an alarming rate. In many parts of the world human population growth, agricultural development, and industrialization contribute to the loss of species diversity of inland water fishes (Abebe Getahun and Stiassny, 1998).

The freshwater systems of Ethiopia are conventionally placed into six freshwater ecoregions: The Ethiopian highlands, Lake Tana, Northern Rift, Lake Turkana, Shebele-Juba, and the Red Sea Coastal based on the similarity of fish fauna (Thieme *et al*., 2005 in Abebe Getahun, 2017). Lake Hayq is grouped under the Ethiopian highlands' ecoregion (Abebe Getahun, 2017)

Though the number of fish species is increasing from the newly identified species and subspecies in Ethiopia, recently the total number of indigenous fish diversity in Ethiopia is estimated to be 191 species and subspecies. Of these, 53 species and 1 subspecies are endemic (Abebe Getahun, 2017).

Lake Hayq is one of the highland lakes of Ethiopia that have significant ecosystem services: provisioning (e.g. food, freshwater, fuel, genetic resources), cultural (e.g. spiritual, aesthetic), Regulating (e.g. climate, water, natural hazard mitigation) and supporting (e.g. primary production, nutrient cycling) (MEA, 2005).

Lake Hayq has two native fish species (*Garra dembecha* and *Clarias gariepinus*) and two introduced fish species (*O. niloticus* and *C. carpio*) (Tadesse Fetahi *et al*., 2011a). *Cyprinus carpio* was introduced to Lake Hayq accidentally in 1994 through Ankerkeha River from the nearby Lake Ardibo where it was introduced intentionally for food security purposes (Fiseha woldemariam, Personal communication). Fisheries of Lake Hayq plays crucial role in providing ecosystem services that provide benefits directly for many fishermen and indirectly for people living around the lake (Tadesse Fetahi *et al*., 2011; Workiye Worie and Abebe Getahun, 2015: Zuriash Seid, 2016).

However, Lake Hayq is facing several problems caused by anthropogenic and natural factors such as water pollution, siltation, buffer zone destruction, overfishing, land use and land cover change, and illegal settlement (Tadesse Fetahi *et al*., 2011a: Assefa Tessema and Kelemework Geleta, 2013: Workiye Worie and Abebe Getahun, 2014: Dereje Tewabe *et al*., 2015; Ruchi *et al*., 2016).

Nile tilapia production was the most important fishery of Lake Hayq since the 1970s. However, the stunted growth of Nile tilapia was observed since 2010 and the contribution of common carp fishery is becoming more significant than Nile tilapia in Lake Hayq. Many factors were reported for this problem by different researchers (Workiye Worie and Abebe Getahun, 2014; Dereje Tewabe *et al*, 2015; Zuriash Seid, 2016; Eldalh Mekonene *et al*, 2019a). However, there was limited information on spatial and temporal data about fish species diversity, distribution, and relative abundance and the associated environmental factors in Lake Hayq. Therefore, current information on seasonal diversity, distribution, and relative abundance of commercially important fish species of Lake Hayq were reported in this chapter.

3. 2. Materials and methods

3.2.1. Sampling sites and sampling protocol

The three sampling sites described in chapter one, Table 1.2 were used. Fish specimens were collected each month for one year using gill nets of 4, 6, 8, 10, and 13 cm stretched mesh size through setting the nets overnight in the lake and beach seines of 6 cm mesh size during day time. Immediately after capture, fishes were identified. Data such as total length (TL) in cm, total weight (TW) in g were measured. Maturity stages of the fishes were identified using five scale maturity stage following Babiker and Ibrahim (1979).

3.2.2. Species diversity and relative abundance

All fishes caught with gill nets and beach seines were sorted by species and mesh size for determination of relative importance of fishes of Lake Hayq. The one-year sampling time was grouped into two seasons Dry (October - March) and wet (April- September) based on amount of rainfall availability around the lake. Thus, the temporal distribution pattern (among sampling seasons) and the spatial distribution among sampling sites (littoral, pelagic, and Ankerkeha) were computed using the Index of Relative Importance (IRI). Estimation of relative abundance of fish was made by the contribution of the catch in each sampling effort. An Index of Relative Importance (IRI) and Shannon Diversity Index (H') were used to evaluate relative abundance and diversity of fish, respectively. An IRI is a measure of relative abundance or commonness of the species based on the number and weight of individuals in catches as well as their frequency of occurrence (Kolding, 1989). IRI gives a better replacement of the ecologically important species rather than the weight, number, or frequency alone (Sanyanga, 1996).

$$\%\mathbf{IRI} = \frac{(\%\mathbf{W_i} + \%\mathbf{N_i}) \times \%\mathbf{F_i}}{\sum_{j-1}^{s-1}(\%\mathbf{W_j} + \%\mathbf{N_j}) \times \%\mathbf{F_j}} \times \mathbf{100}$$

Where, %Wi and %Ni are percentage weight and the number of each species of the total catch, respectively. %Fi is a percentage frequency percentage of each species in a total number of settings. %Wj and Nj are percentage weight and the number of total species in total catch. Fj is the percentage frequency of occurrence of total species in a total number of settings.

The Shannon index of diversity (H'): H' is a measure of species weighted by the relative abundance (Begon *et al.*, 1990). H' is calculated as follows:

$$H' = \sum pi \ln pi$$

Where, pi - the proportion of individuals in the i^{th} species. Shannon index is used to indicate the diversity of fishes at different sampling sites of lakes.

3. 2. 3. Data analysis

The collected data, physicochemical parameters (chapter II, section 2.2.2), fish species diversity, relative abundance among seasons, and sites were tested were summarized using Shannon index and index of relative abundance. The correlation between fish abundance and environmental parameters (physicochemical parameters) was analyzed using RDA (since gradient length < 3) through the application of CANOCO 4.5 software.

3. 3. Results

3. 3. 1. Fish species diversity

A total of 1980 fish specimens belonging to three species, *C. carpio* (1055*)*, *O. niloticus* (892), and *C. gariepinus* (33) categorized under three families (Cyprinidae, Clariidae, and Cichlidae) were collected from Lake Hayq between the 12 months sampling periods which were merged in two seasons (dry and wet). The dominant fish species in abundance were *C. carpio* (53.28 %), followed by *O. niloticus* (45.05 %). Whereas, *C. gariepinus* which is the native fish species was the least abundant (1.67 %) in Lake Hayq. The composition of males was higher except in *C. gariepinus* (Table 3.1).

Table 3.1: Catch composition and abundance of commercially important fishes of Lake Hayq

Fish species	Sex	Dry	wet	Total
C. carpio	F	36	33	69
		264	84	348
		27	15	42
	M	56	31	87
		311	158	469
		27	13	40
C. gariepinus	F	1	2	3
		7	4	11
		2	1	3
	M	0	1	1
		6	6	12
		2	1	3
O. niloticus	F	74	4	78
		235	22	257
		4	0	4
	M	111	25	136
		302	111	413
		4	0	4
Total		1469	511	1980

3. 3 .2. Fish diversity index

Lake Hayq harbors few fish species and as a result, the Shannon diversity index values among sampling months were less than 1 except in February. The highest Shannon diversity index (1.04) and the lowest Shannon index (0.01) were recorded in February and December, respectively (Figure 3.1)

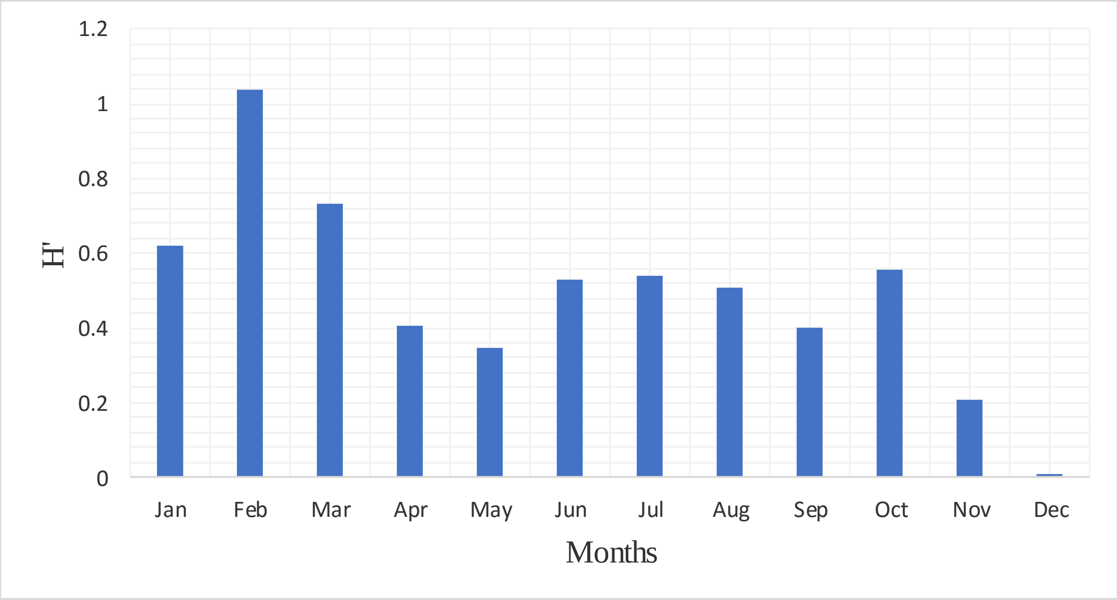

Figure 3. 1: Monthly variation of Shannon diversity index (H') of fishes in Lake Hayq (January-December, 2018).

3. 3. 3. Relative abundance of fishes of Lake Hayq

The index of relative importance (IRI) of *C. carpio* and *O. niloticus* varied with season and sexes. The highest and the lowest index of relative importance of *O. niloticus* were 63.33% and 0.11 respectively. The highest and the lowest index of relative importance of *C. carpio* were 98.64 and 4.09, respectively. The index of relative importance values was higher for males than females and the highest index of relative importance value was recorded at Littoral site compared Ankerkeha and Pelagic sites.

Table 3.2: Seasonal variation of Index of relative abundance (IRI) of *O. niloticus* and *C. carpio* in three sampling sites (Ankerkeha, littoral and pelagic) of Lake Hayq (January- December, 2018)

Fish species			site		
O. niloticus	Season	Sex	Ankerkeha	Littoral	Pelagic
	Dry	F	10.80	32.16	1.92
		M	19.80	29.48	5.80
	Wet	F	5.08	23.79	0.09
		M	7.59	63.33	0.11
C. carpio	Dry	F	6.90	37.25	2.09
		M	3.92	45.75	4.09
	Wet	F	15.63	59.63	98.64
		M	15.12	31.75	7.58

3. 3 . 3. 4. Redundancy Analysis (RDA)

The correlation between fish species (*C. carpio*, *O. niloticus*, and *C. gariepinus*) with environmental variables (DO-Dissolved Oxygen, Tem-Temperature, pH, Sec- Secchi disk, NO_3^- Nitrate, SRP-Soluble reactive phosphorus, Chl-a -Chlorophyll a) at three sampling sites (Littoral, Pelagic, and Ankerkeha) in Lake Hayq was analyzed using a constrained Redundancy Analyses (RDA, CANOCO 4.5 Software). All fish species, *C. carpio, O. niloticus,* and *C. gariepinus* were positively and strongly correlated with some environmental variables (Secchi-disk, water temperature, dissolved oxygen, and chlorophyll-*a* at littoral site (Figure 3. 2).

The first and second axes together explained 100% of the cumulative percentage variance of species-environment relations (Table 3.3). The first axis explains 98.9% and the second axis explains 1.1 % of species-environment relations (Table 3. 3). DO, temperature, Secchi disk depth, TP, and Chl-*a* had a strong positive correlation with Axis 1 and pH, Secchi disk, NO_3, SRP and TP had a positive correlation with Axis 2.

Table 3.3: Summary of the statistics of the RDA (Redundancy Analysis)

Axes	1	2	3	4	Total variance
Eigen values:	0.989	0.011	0	0	1
Species-environment correlations:	1	1	0	0	
Cumulative percentage variance					
of species data:	98.9	100	0	0	
of species-environment relation:	98.9	100	0	0	
Sum of all eigenvalues					1
Sum of all canonical eigenvalues					1

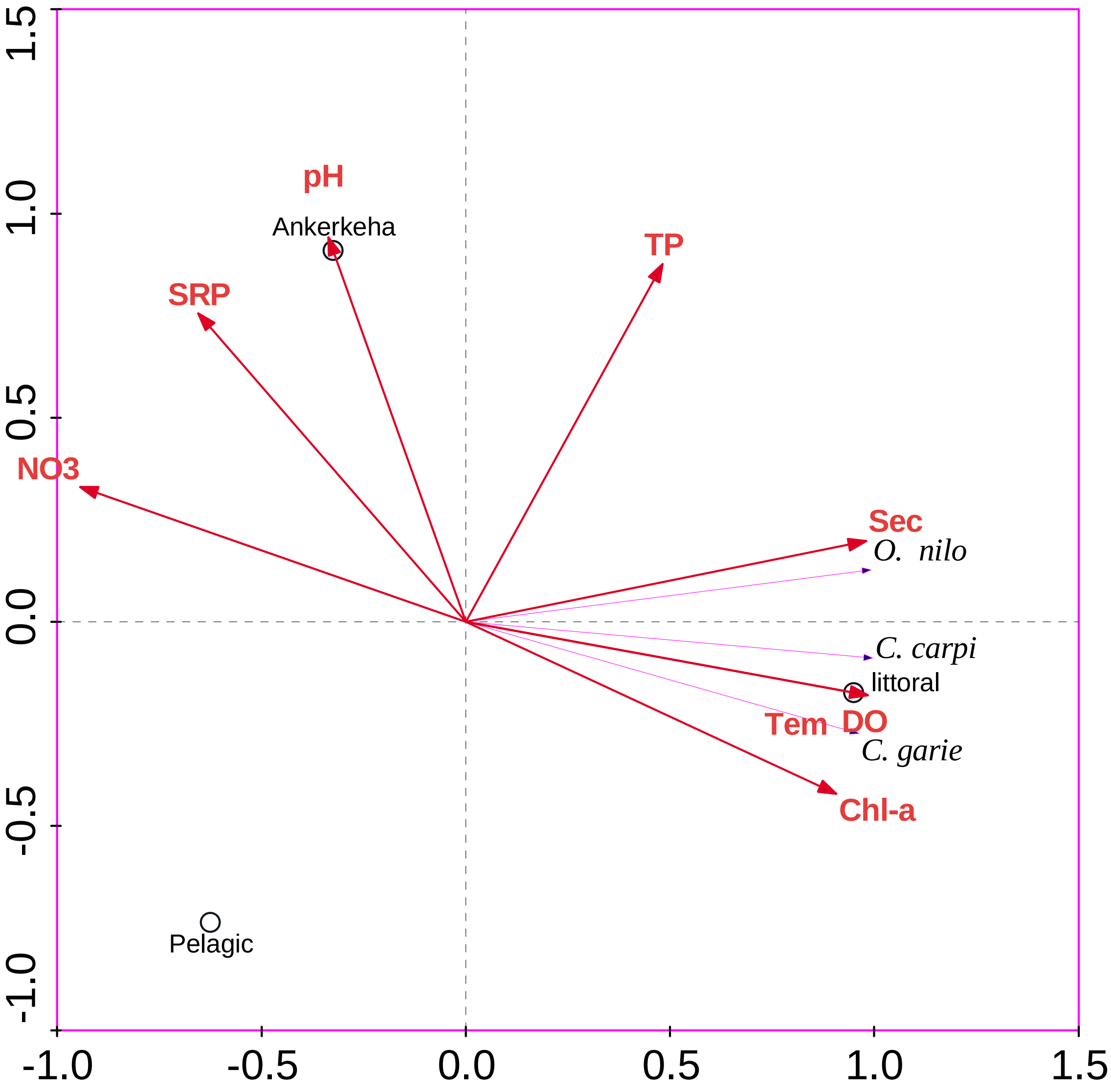

Figure 3. 2: Tri-plot of the Redundancy Analyses (RDA) for fish species (Purple arrow and environmental variables (red arrows) and Balck circle (Sampling sites, Pelagic, Ankerkeha, and Littoral**)**: O. nilo- *O. niloticus,* C. carpi- *C. carpio*, C. garie- *C. gariepinus*, TP- total phosphorus, SRP- Soluble reactive phosphorus, NO_3, Chl-a-chlorophyll-a, Tem-Temperature, DO -Dissolved oxygen, Sec- Secchi-disk and pH

3. 4. Discussion

3. 4. 1. Fish species diversity

In the present study, only three commercially important fish species were recorded during the sampling period. *Garra dembecha*, ecologically important fish species was reported in Lake Hayq (Zuriash Seid, 2016). However, this species was not collected in this study which might be related to the mesh size used. The diversity of fish species of Lake Hayq (4) was very low similar to other highland lakes of Ethiopia, Lakes Dendi and Wonchi (2 fish species in each lake) (Fasil Degefu *et al*., 2014), Lakes Ardibo, Maybar and Golbo (2 fish species each) (Assefa Tessema and Kelemework Geleta, 2013). However, fish species of Lake Hayq are much lower than Lake Tana (28 fish species) (Abebe Getahun and Eshete Dejen, 2012) and Rift valley lakes such as Chamo and Abaya (Golubtsov and Mina, 2003). The lower fish species diversity in Lake Hayq might be due to higher depth. But, the higher fish species diversity of Lake Tana could be due to the lower depth and intralacustrine speciation. Whereas more resource abundance and higher water temperature could be potential reasons for higher fish species in Rift valley lakes, Chamo, and Abaya (Golubtsov and Mina, 2003).

3. 4. 2. Distribution and relative abundance of fishes

In the present study, the contribution of *C. carpio* was the highest (53.28%) followed by *O. niloticus* (45.05%), and *C. gariepinus* (1.67%). In the present study, the relative abundance of commercially important fishes (*O. niloticus, C. carpio*, and *C. gariepinus*) varied with sampling sites and the highest abundance was recorded at littoral area. The higher fish abundance at the littoral site might be associated with the availability of more food and shelter at this site compared to pelagic and Ankerkeha sites. Highest fish abundance was reported in dry season which could be related to more food or nutrient after rainfall coming from the watershed and availability of sunlight for photosynthesis.

The dominance of *C. carpio* was also reported by Eldalh Mekonene *et al*. (2019a) in their monitoring data collection program (2013-2017). According to these authors, the catch composition of *C. carpio, O. niloticus* and *C. gariepinus* were 10%, 58%, and 32 %, respectively during the first phase (2008-2012) data collection program. However, in the second phase (2013-2017) monitoring program, the catch composition has been changed to 83. 9 %, 4.5 %, and 11.5 % for *C. carpio*, *O. niloticus*, and *C. gariepinus,* respectively. This change in fish species composition could be associated with selective fishing pressure on Nile tilapia and due to the invasive behavior of common carp.

3. 4. 3. Correlation between fish abundance and environmental variables

In the present study, Secchi disk depth, Chlorophyll-a, Water temperature, and dissolved oxygen were positively and strongly correlated with the abundance and distribution of *O. niloticus*, *C. carpio*, and *C. gariepinus* at littoral site with Axis 1. A similar result was reported by Yağci *et al*. (2016) for Lake Eğirdir in Turkey where water temperature, dissolved oxygen, and saturation of dissolved oxygen were the most important physicochemical parameters affecting fish distribution.

Generally, the distribution of fish species can be affected both by biotic (predation, competition) and abiotic factors (water temperature, dissolved oxygen) which have direct and indirect effects on the fish population (Jackson *et al*., 2001). Physicochemical parameters such as water temperature and oxygen can affect and restrict the survival, growth, and distribution of fishes (Akbulut, 2009).

Though determination of physiological optima for any species of fish for one particular physicochemical or climatic variable is complicated, factors such as life-history stage, seasonality, reproductive stage, migration, and food availability could make these connections ambiguous (Wootton 1984, Paramo *et al*., 2003, Watanabe *et al.*, 2008). To minimize energy expended for survival, species typically favor areas that optimize their physiological processes, because, environmental variables can influence the fish distribution and seasonal movement (Matthews, 1990).

The canonical correspondence analysis conducted for some environmental variables such as pH, TDS, conductivity, Secchi disk depth, nitrite with fish species showed that environmental variables could influence the distribution and abundance of fishes (Lake Buyo in Cote d'Ivoire) (Binta *et al*., 2019), (Lake Volta in Ghana) (Mensah *et al*., 2019).

The natural diversity of most aquatic systems has witnessed various changes in stock diversity and abundance resulting from structural changes in habitat, food composition, and uncontrolled exploitation. These have altered the ecology of the fish resources with the disappearance of some species and the dominance of others (Ipinmoroti, 2013). Commercially important fish species declined for the last 25 years in Lake Tana most probably with recruitment overfishing and increased recession farming around the lake (Eshete Dejen *et al*., 2017).

Common carp (*Cyprinus carpio*) is one of the most widely introduced and distributed fish species worldwide. Originally introduced into many areas for aquaculture production, common carp have become highly abundant in many ecosystems (Britton *et al.*, 2007). Common carp populations exert negative effects on shallow aquatic ecosystems, inducing regime shift from the clear-to turbid-water state (Weber and Brown, 2009), potentially reducing native species abundance and diversity (Haas *et al*., 2007) and altering basic ecosystem processes and services (Weber and Brown, 2013).

In the aquatic system, change in the fish community has a direct or indirect effect on the other components of the system including, physical, chemical, and biological characteristics. Loss of habitat and degradation have a negative effect on fish fauna (Basavaraja *et al.,* 2014). Currently, the commercial fishery activities of Lake Hayq are highly affected due to the overexploitation of Nile tilapia. The production of catfish was very low as compared to Nile tilapia and common carp. According to the fishermen of Lake Hayq, the catfish catch has dramatically reduced since the introduction of Nile tilapia in Lake Hayq, mainly because Nile tilapia feeds on the eggs of catfish during the reproduction season (Fiseha Woldemariam, Personal Communication). Currently, Nile tilapia is overfished and stunt growth of Nile tilapia, maturing at about 12 cm and 40 g body weight is an indication for overfishing of Nile tilapia in Lake Hayq. Recently, the same problem of reduction of Nile tilapia due to common carp competition for food was reported in Lake Ziway (Abebe Tesfaye, 2018).

Chapter 4: Some aspects of reproductive biology, length-weight relationship and condition factor of common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) in Lake Hayq

4. 1. Introduction

Fish is used as a source of cheap protein source in most of the African countries. Small-scale fisheries operating mostly in the developing countries account for half of the total fish production globally. The contribution of inland catches in Africa covers about 25% of global inland catches (FAO, 2018). However, the production of fish has drastically decreased, and catches per unit of effort (CPUE) have become low in natural water bodies (Adite and Winemiller, 1997; Houehanou *et al*., 2016). The major factors for reduction in the production of fishes in Africa are postharvest loss, illegal fishing, and overfishing (FAO, 2016). Nile tilapia fish species, one of the most important fish species in tropical and subtropical freshwater bodies in Africa are also faced with many challenges of illegal fishing (overfishing, fishing during breeding season and ground, fishing with narrow sized mesh size and destruction of habitat) (Mohammed and Uraguchi, 2013).

The fish production potential in Ethiopia is estimated to be 94,500 tons per year (Gashaw Tesfaye and Wolff, 2014). However, only 30-38% of this potential is currently used (Assefa Mitike, 2014). Though the contribution of the fishery for GDP is insignificant, the sector is being used as a means of livelihood for many people involved in the processes of production to marketing. The artisanal freshwater fishery is one of the most important economic activities in Ethiopia (FAO, 2012). Improvements in the fishery sector would contribute to poverty alleviation and environmental sustainability in Ethiopia (Global Fish Alliance, 2010).

Common carp (*Cyprinus carpio*) is one of the widely cultured commercially important freshwater fish species in the world (FAO, 2013). *Cyprinus carpio* is native to Eastern Europe and Central Asia. It is can tolerate a wide range of water quality parameters. In natural water bodies, this species can survive in very low water temperature and it can tolerate low concentrations and supersaturation of dissolved oxygen (Banarescu and Coad, 1991).

Common carp are omnivorous fish species that consume animals (aquatic insects, macroinvertebrates, and zooplankton) and plant origin (phytoplankton, macrophytes) (Weber and Brown, 2009). C*yprinus carpio* grows rapidly, achieves sexual maturation in the second year of life, is highly fertile (about 2 million eggs per female) (Balon, 1975). The combination of these features allows the species to develop invasive potential (Troca and Vieira, 2012).

Common carp have been introduced into many water bodies throughout the world, including Europe, Australia, North America, and Africa. The wide distribution and successful introductions of common carp are mostly due to their tolerance of variable environmental conditions (Forester and Lawrence, 1978), as well as to their capability for early sexual maturity and rapid growth (Koehn, 2004).

Cyprinus carpio was first introduced to Aba Samuel Dam (Awash River Basin) in Ethiopia in 1940 from Italy (Abebe Getahun, 2017). Later, *C. carpio* has been introduced into Lake Ziway in the late 1980s (FAO, 1997; Lemma Abera *et al*., 2015) to highland lakes such as Hashenge, Ardibo and Maybar (Golubtsov and Darkov, 2008) for fish production and the introduction was successful. Common carp were introduced to Lake Hayq accidentally from Lake Ardibo in 1994 (Fiseha Wolde Mariam, Personal Communication) through Ankerkeha River which connects the two lakes during the rainy season. The common carp have established recently in Lake Hayq and dominated the other two commercially important fish species, Nile tilapia, and catfish. Fishermen of Lake Hayq believe that the current stunted growth of Nile tilapia (*O. niloticus*) is due to the recent invasion of common carp in the lake.

Nile tilapia (*O. niloticus*) contributes to more than 50% of the total landings in Ethiopia (Gashaw Tesfaye and Wolff, 2014). *Oreochromis niloticus* is widely distributed in Rift valley lakes such as Abaya, Chamo, etc., highland lakes such as Tana, Hayq, Ardibo, etc. and rivers such as Baro, Abay, etc. and it is the most preferred fish species in the country (Golubtsov and Mina, 2003).

The exploitation and consumption of fish in Ethiopia depends on socio-economic factors, resource accessibility, and religious causes (Mathewos Temesgen, 2017). Post-harvest loss, illegal fishing activities (fishing with narrow sized mesh size, fishing during the breeding season and at the breeding ground, application of poisonous plants), knowledge gap in fishery management, limited institutional, technical and financial capacity and low research and development capacities are the major challenges of fisheries in Ethiopia (Assefa Mitike, 2014).

In fisheries, continuous data on the length-weight relationship, size at first sexual maturity, and condition factor are important for the sustainable utilization of fish resources (Shalloof *et al.*, 2009). Information on length-weight relationship, fish condition, and length at first maturity of fishes is very important to estimate minimum harvestable fish size, the suitability of water bodies for fish, and their trophic status (Kumar *et al.*, 2017). Length-weight relationship, size at first maturity and condition factor of *O. niloticus* have been reported from different water bodies of Ethiopia (Demeke Admasu, 1994; Zenebe Tadesse, 1997; Fasil Degefu *et al*, 2012; Lemma Abera, 2012; Wokiye Worie, 2014; Mathewos Temesgen *et al.*, 2018; Tsegaye Teame *et al.*, 2018).

Though there are some research studies conducted on Lake Hayq’s morphometry, water balance, water quality, plankton structure, current information on growth condition, and reproductive biology of common carp and Nile tilapia is scarce. Therefore, this study aimed at determining the Length-weight relationship, condition factor, and some reproductive biology (sex ratio, fecundity, and size at first sexual maturity and breeding season) of common carp and Nile tilapia and recommend sustainable common carp and Nile tilapia fishery production and utilization in Lake Hayq.

4. 2. Materials and methods

4. 2 .1. Sampling techniques

Three sampling sites (Table 1.2) were selected based on the impact of human and livestock activities. The sampling sites were fixed with GPS and map was generated (Figure 1.7). Fish specimens were collected each month for one year using gill nets of 4, 6, 8, 10 and 13 cm stretched mesh size through setting the nets overnight in the lake and beach seine of 6 cm mesh size. Data such as length, weight, sex, and maturity stages were collected in the field immediately after the fishes were caught.

4.2.2. Some biological aspects of common carp and Nile tilapia

4. 2. 2. 1. Length-weight relationship

The relationship between total length (TL) and total weight (TW) of *C. carpio* and *O. niloticus* was calculated using power function as in Bagenal and Tesch (1978).

$$TW = aTL^b$$

Where TW – total weight (g)

TL- total length (cm)

a- the intercept of the regression line
b- the slope of the regression line

4.2. 2. 2. Condition factor (Fulton factor)

The wellbeing of common carp and Nile tilapia was determined by using the Fulton condition factor as indicated in Bagenal and Tesch (1978).

Fulton condition factor was calculated as:

$$\mathrm{FCF} = \frac{\mathrm{TW}}{\mathrm{TL}^3} * 100$$

Where, TW- total weight in gram and TL- total length in cm

4. 2. 2. 3 Sex ratio

Sex ratio was determined using the formula***:***

$$\text{Sex ratio} = \frac{\text{Number of females}}{\text{Number of males}}.$$

4.2.2.4. Fecundity

The absolute fecundity (AF) of individual females was determined gravimetrically (Bagenal and Braum, 1987), with the number of ripe oocytes counted from triplicates of 1 g sub-sample of the ovary. The relationship between absolute fecundity with Total length, Total weight, and Gonad weight were determined using least squares regression.

4.2. 2.5. Breeding season

The breeding season was determined from the percentages of fish with ripe gonads taken each month. The spawning periods of *C. carpio* and *O. niloticus* was determined based on monthly variations of the ripe gonads following (Fasil Degefu *et al.*, 2012).

4.2.4.6. Size at first maturity (L_{50})

Total length (cm) and total weight (g) of each specimen of common carp were measured at the sampling sites using the measuring board and sensitive balance, respectively. After dissection, the gonad maturity of each specimen was identified using a five-point maturity scale (Babiker and Ibrahim, 1979). Length at which 50% of both sexes reached maturity (L_{50}) were determined from the percentages of mature fish selected from peak breeding seasons (March -April) and fitted to the logistic equation described by Echeverria (1987).

4. 3. Data analysis

Descriptive statistics (frequency, percentages, and graphs), Inferential statistics (Chi-Square, independent t test, Linear and Logistic regression) were used to summarize the collected data by applying SPSS Software Package Version 16 and R 3.3.1 software.

4. 3. Results

4.3.1. Length-weight relationship

The total length of females and males of *C carpio* ranged from 11-50 cm and 10.5-52 cm, respectively and the total weight of females and males ranged from 19-1697 g and 18-1378 g, respectively. The length-weight relationship of both female and male *C. carpio* in Lake Hayq was curvilinear, and as a result, the line fitted to the data was described by the regression equation (Table 4.1). In this study the "b" values of both female and male *C. carpio* were approximately 3, showing nearly isometric growth (Figures 4.1- 4.2).

Table 4. 1: Length –weight relationship of *C. carpio in* Lake Hayq

Sex	Regression equation	R^2	n	Sig.
Female	$TW=0.017TL^{2.93}$	0.97	454	0.001
Male	$TW=0.018TL^{2.87}$	0.97	589	0.05

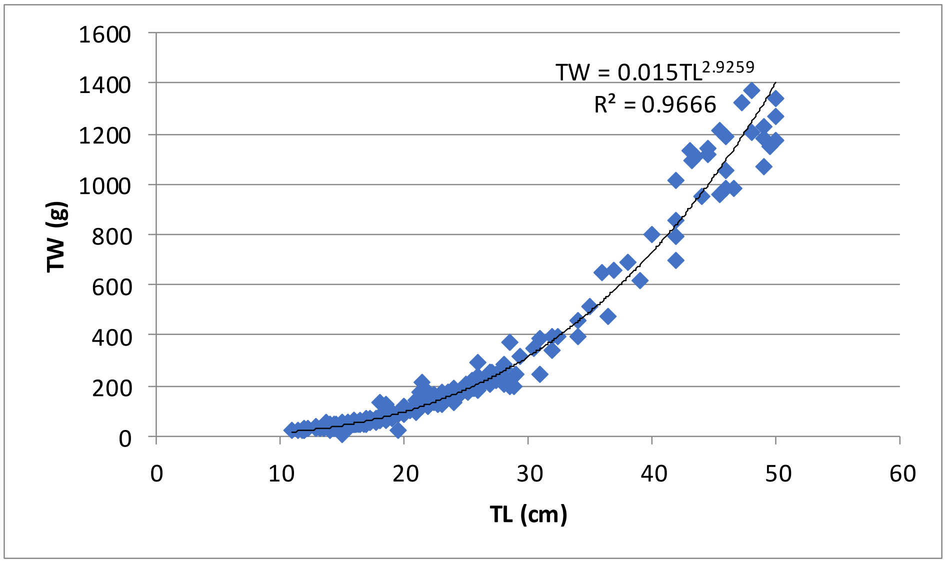

Figure 4.1: Length-weight relationship of female *C.carpio* in Lake Hayq (N=454)

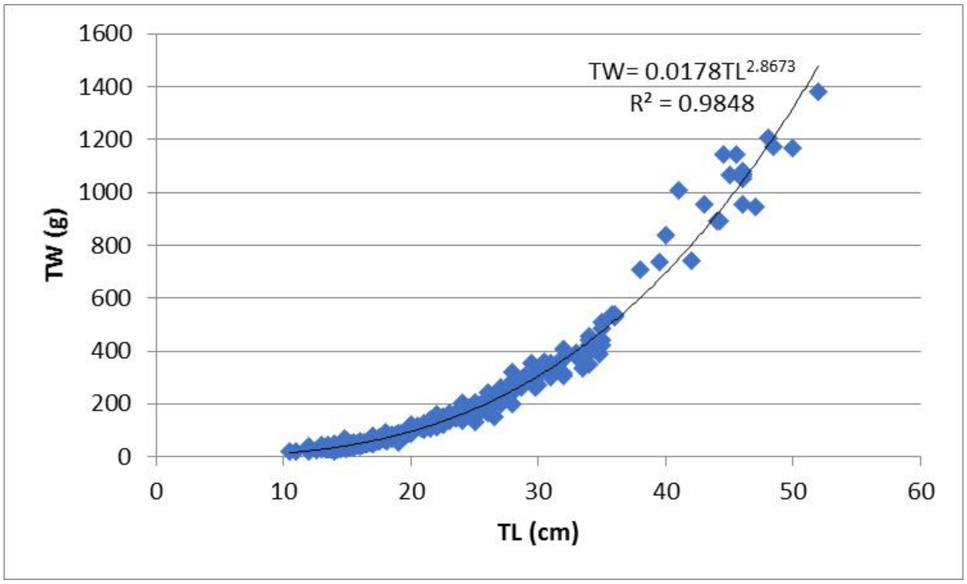

Figure 4.2: Length-Weight relationship of male *C. carpio* in Lake Hayq (N=596)

The relationship between total length and total weight of *O. niloticus was* curvilinear, and as a result, the line fitted to the data was described by the regression equation (Table 4. 2). The "b" values of both female and male *O. niloticus* were significantly different from 3, showing allometric growth (Figures 4.3 - 4.4). The length-weight relationship of both male and female Nile tilapia was strongly correlated since the R^2 value of female (0.89) and male (0.85) close to 1 (Table 4.2).

Table 4.2: Length –Weight relationship of male and female Nile tilapia in Lake Hayq

Sex	Regression equation	R^2	n	Sig.
Female	$TW=0.065TL^{2.50}$	0.888	339	0.001
Male	$TW= 0.099TL^{2.33}$	0.854	553	0.001

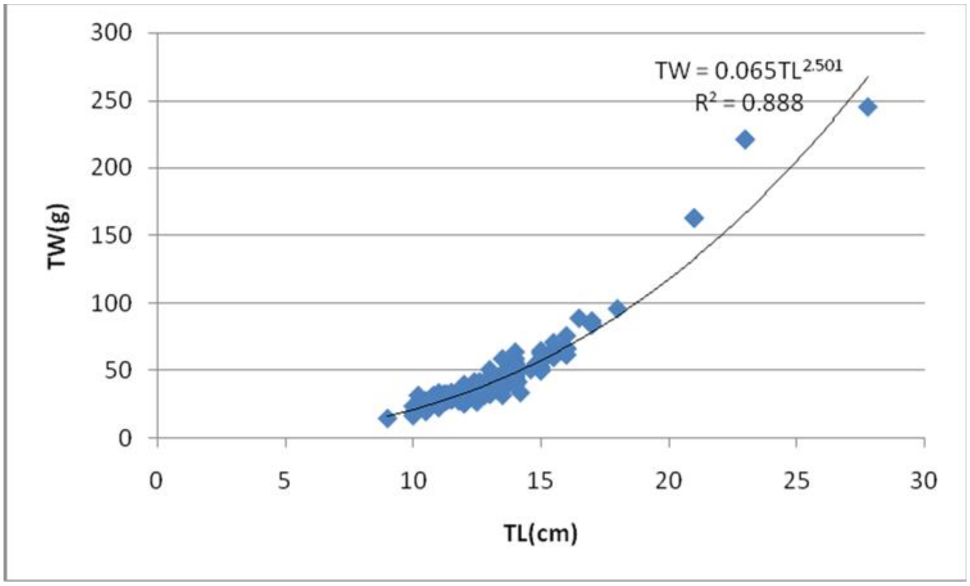

Figure 4.3: Length-weight relationship of female *O.niloticus* in Lake Hayq (N=339)

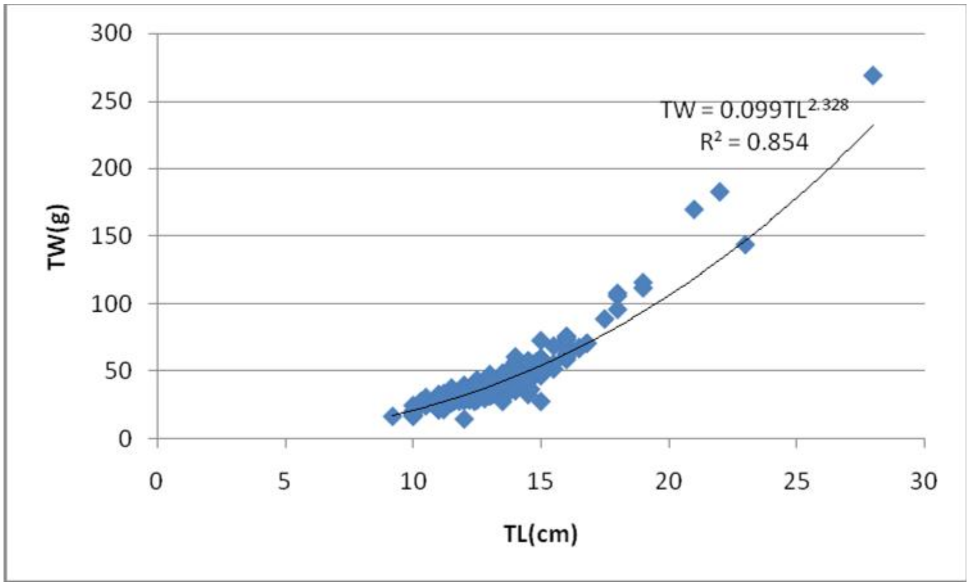

Figure 4.4: Length-Weight relationship of male *O. niloticus* in Lake Hayq (N=553)

4. 3. 2. Fulton's condition factor

The Fulton condition factor of female and male *C. carpio* ranged from 1-1.98 and 1-1.83, respectively. The mean and SE values of FCF of females and males were 1.23±0.013 and 1.21±0.011, respectively. The independent t-test analysis showed that there was no significant difference ($P>0.05$) in mean FCF between male and female *C. carpio* in Lake Hayq. There was no significant difference in FCF between sexes in *O.niloticus* of Lake Hayq (ANOVA, $P >0.05$). However, Fulton's condition factor of females was slightly higher than males' as shown in Table 4.3

Table 4.3: FCF (Fulton's condition Factor) of Nile tilapia

Sex	Mean FCF
Female	1.85
Male	1.80

4. 3. 3. Sex ratio

From 1055 specimens of *C. carpio* collected from Lake Hayq, 459 (43.5%) were females and 596 (56.5%) were males. The Chi-square test showed that there was a significant deviation between males and females from 1:1 ratio ($\chi^2 =22$, df=11, $P < 0.05$) between sampling months. From a total number of 892 collected *O. niloticus* from Lake Hayq during the study period, 339 (38%) were females and 553(62%) were males. Males were numerous than females. The Chi-square test showed that there was a significant deviation between males and females' numbers from 1:1 ratio in *O. niloticus* ($\chi^2 =79.5$, df=11, $p<0.05$) within sampling months.

4. 3. 4. Reproductive aspects of common carp

4.3.4.1. Size at first maturity

From the logistic regression model analyzed, male *C. carpio* matured at a smaller size (17.5cm) than female (21.5cm) in Lake Hayq as shown in Figure 4.5.

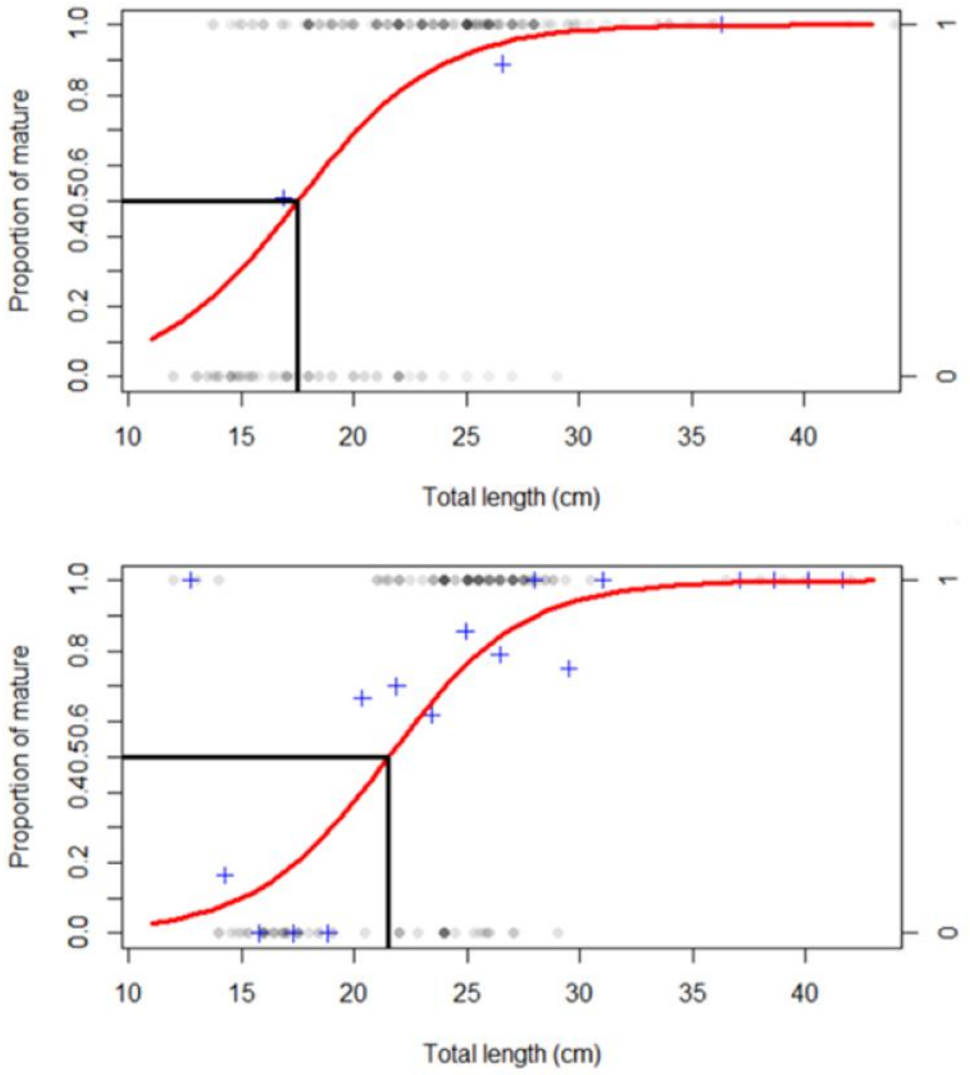

Figure 4.5: Length at first sexual maturity male (top) and female (bottom) of *C. carpio* in Lake Hayq

Oreochromis niloticus matured almost at the same size, females at 12.8 cm and males at 12.9 cm in Lake Hayq as shown in Figure 4.6.

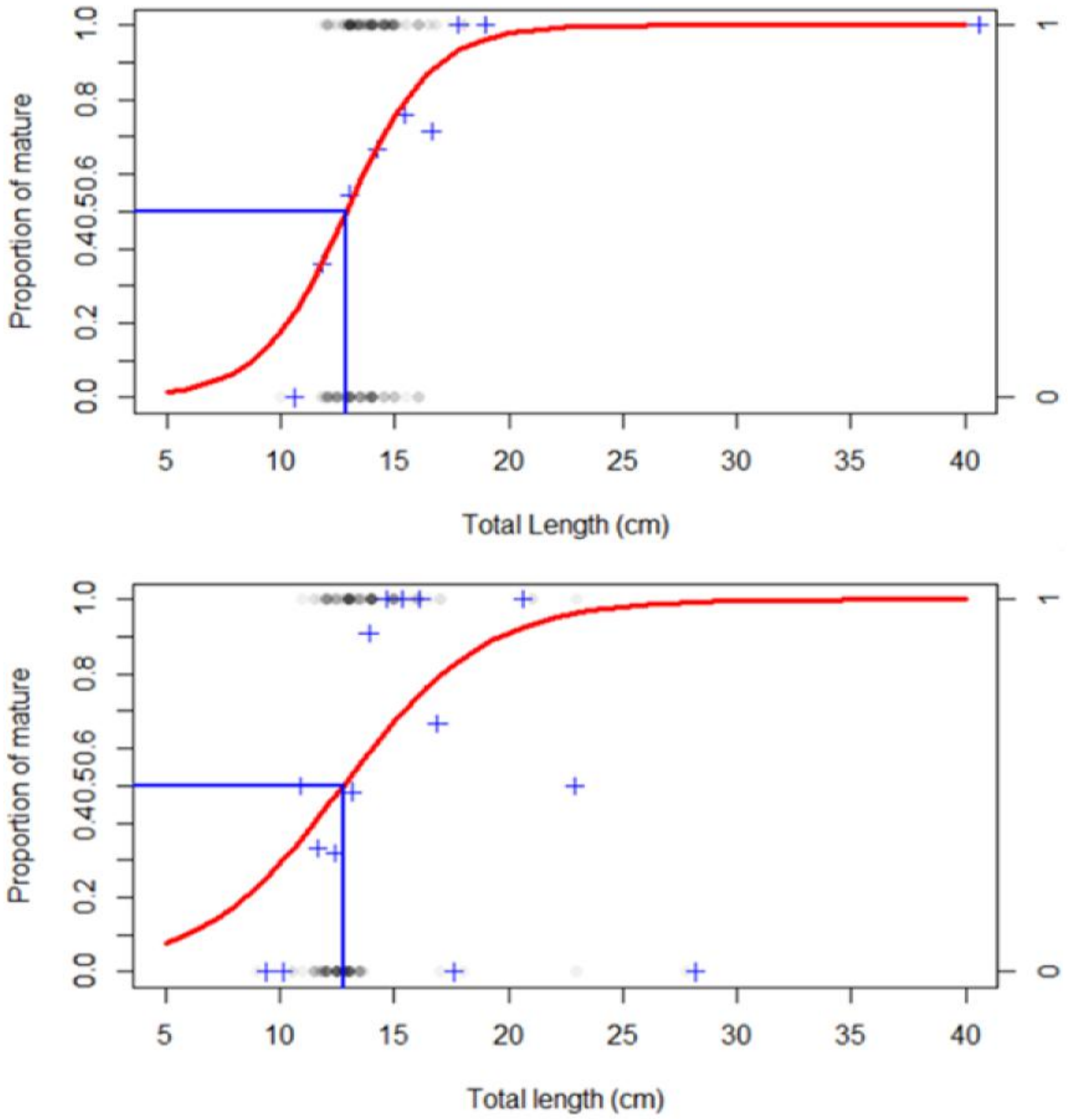

Figure 4.6: Length at first sexual maturity (L_{50}) of male (top) and female (bottom) *O. niloticus* in Lake Hayq

4.3.4.2. Fecundity

Sixty-seven fully mature *C. carpio* with TL (21-49 cm) and TW (104 - 1230g) were selected for fecundity study. The average absolute fecundity (AF) was 28100±17462. The relation between AF with TL, TW, and GW was linear (Figures 4.7-4.9). There was a significant relation in absolute fecundity with TL, TW, and GW ($P<0.05$).

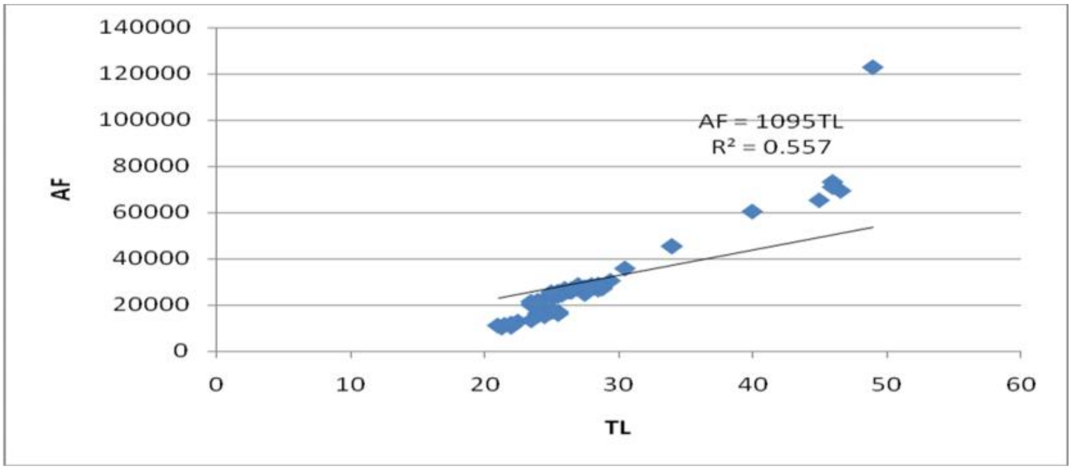

Figure 4.7: Relationship between absolute fecundity (AF) and total length (TL) in *C.carpio*

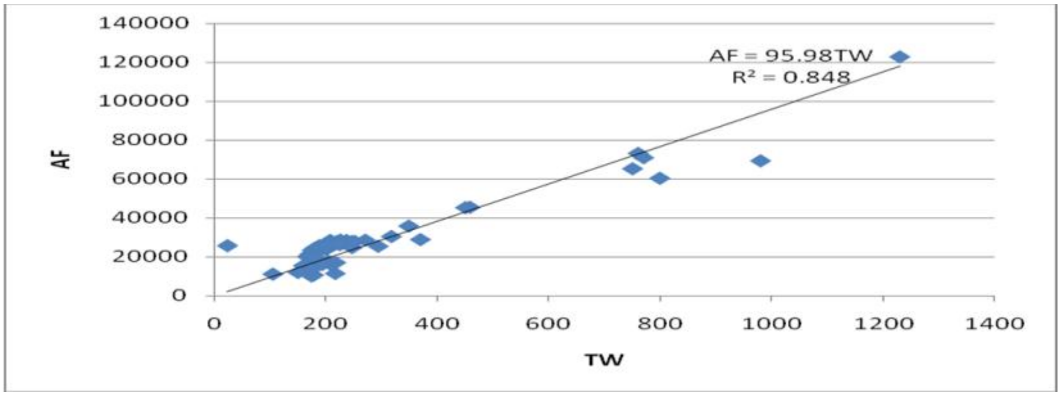

Figure 4.8: Relation between absolute fecundity(AF) and Total weight (TW) in *C.carpio*

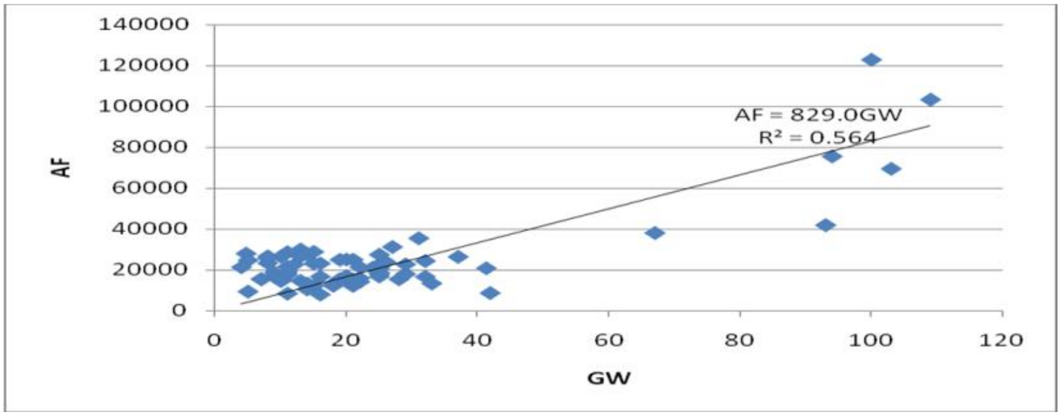

Figure 4.9: Relation between absolute fecundity (AF) and Gonad weight (GW) in *C. carpio*

Seventy fully mature *O. niloticus* with total length (10.5-27.8 cm) and total weight (22-245 g) were selected for fecundity study. From this analysis, the average absolute fecundity was 217 eggs per fish (Table 4). The absolute fecundity was positively correlated with total length, total weight, and Gonad weight (ANOVA, $P < 0.05$). It is common to see very small-sized Nile tilapia matured at total length (10.5 cm) and total body weight (40g) in Lake Hayq (Figure 4.13). The absolute fecundity of *O. niloticus* was weakly correlated with total length and total weight. However, it was strongly correlated with gonad weight (4.10- 4.12).

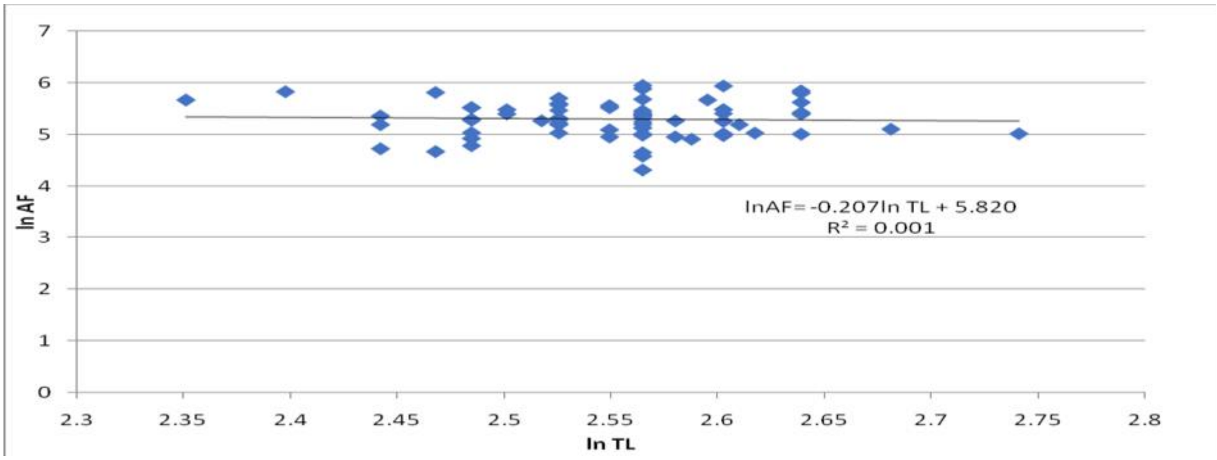

Figure 4.10: Relationship between absolute fecundity (AF) and total length (TL) in *O. niloticus*

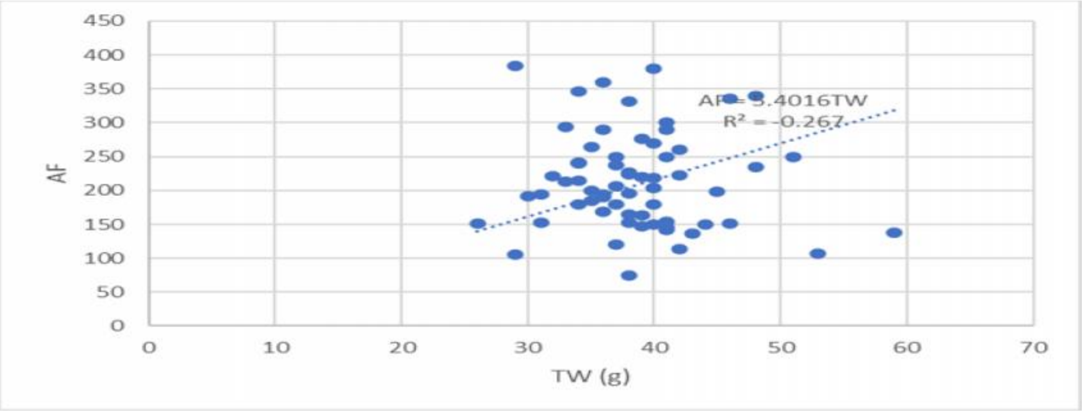

Figure 4.11: Relation between absolute fecundity(AF) and Total weight (TW) in *O. niloticus*

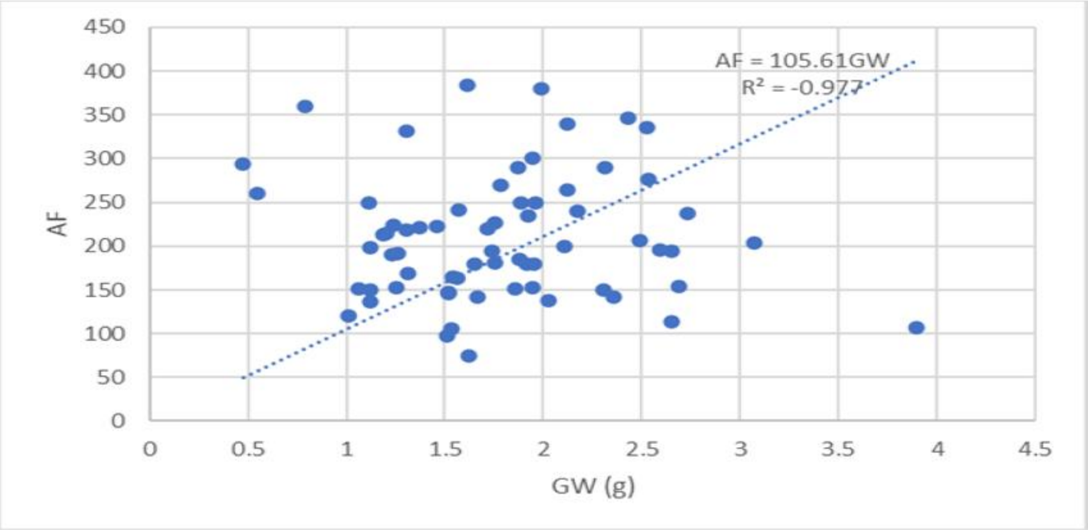

Figure 12: Relation between absolute fecundity (AF) and Gonad weight (GW) in *O. niloticus*

Table 4.4: Absolute fecundity (AF) of *O. niloticus*

Fish species	Range in TL (cm)	Range in TW (g)	Mean AF
O. niloticus	10.5-27.8	22-245	217

Figure 4.13: *Oreochromis niloticus* of Lake Hayq that matured at 40gram body weight and 10.5 cm total length

4.3.4.3. Breeding Season

In Lake Hayq ripe gonads of *C. carpio* were caught throughout the year. The peak breeding activities observed between January and April. However, the most intense breeding activities was observed in April (Figure 4.14). The ripe gonads of *O. niloticus* in Lake were caught between January and April, September, October and December. However, the most intense breeding activities was observed February to April (Figure 4.15).

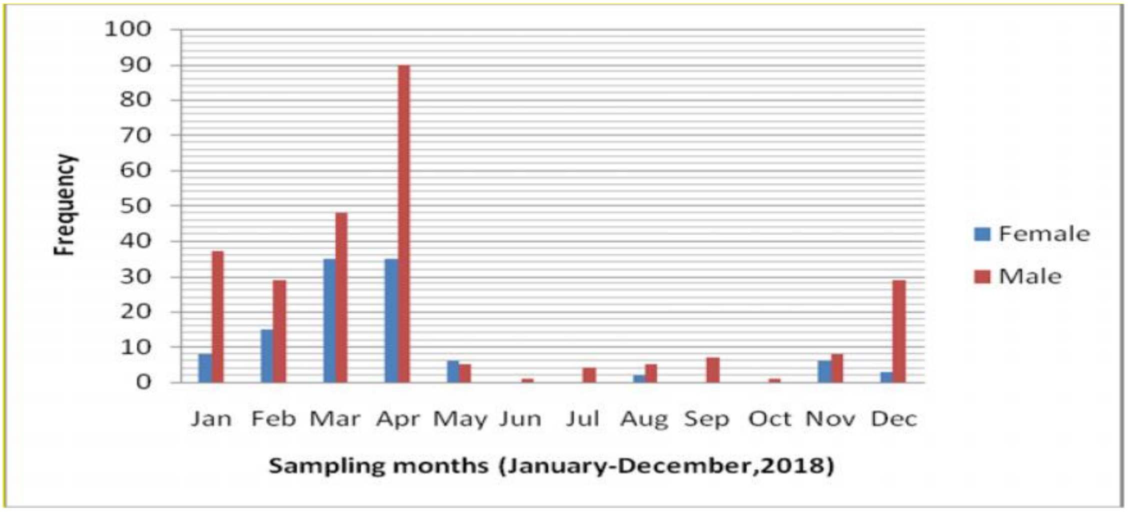

Figure 4.14: The breeding seasons of *Cyprinus carpio* in Lake Hayq indicated by the frequency of ripe gonads

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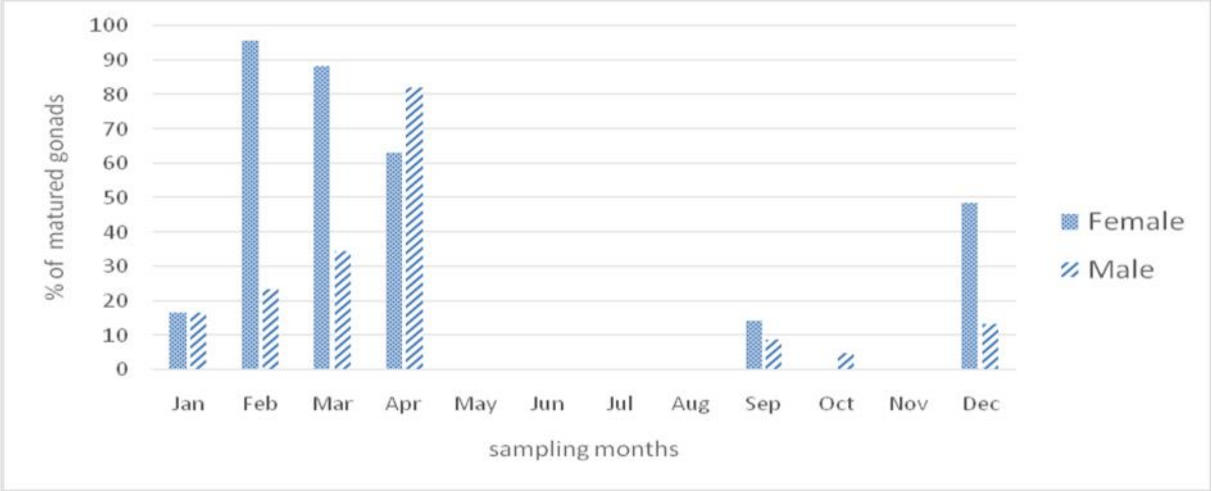

Figure 4.15: The breeding seasons of *Oreochromis niloticus* in Lake Hayq indicated by the frequency of ripe gonads

4. 4 Discussion

4. 4. 1. Length-weight relationship

In this study, the length-weight relationship of *C. carpio* in Lake Hayq showed nearly isometric allometric growth with a "b " value of 2.93 for females and 2.87 for males. These values were almost similar to 2.92 for both seses of *C.carpio* in Lake Amerti (Mathewos Hailu, 2013), 2.82 for *C.carpio* in Lake Ardibo for both sexes (Wubshet Asnake, 2010), 2.87 and 2.77 for female and male *C.carpio* in Foum El-Khanga Dam in Algeria (Sahtout *et al.*, 2017), but different (1.9 and 2.3 for female and male *C.carpio)* in Lake Naivasha in Kenya (Aera *et al*., 2014). The variation in growth type (isometric/ alometric) could be associated with several factors such as seasonal effect, habitat type, degree of stomach fullness, gonad maturity, sex, health, preservation techniques, food availability, differences in the observed length ranges, and fatness of the species as well as physical factors such as temperature and salinity (Wooten, 1998). In Lake Hayq both female and male *C. carpio* showed isometric growth, both length and weight growth pararelly which is a common phenomenon in normal condition in fishery. The variations in 'b' values between males and females may depend on various factors such as the number of specimens examined and the sampling season.

In the present study, the length-weight relationship of both male and female Nile tilapia was allometric growth (b= 2.50 for female and b=2.33 for male). The result of the present study was similar to of Lake Victoria in Kenya (Yongo *et al*., 2018), Lake Naivasha in Kenya (Njiru *et al*., 2014), Peele Reservoir in Burkina Faso (Parfait *et al*., 2018). However, it was different from previous studies in Lake Hayq (Workiye Worie and Abebe Getahun, 2014), Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013), Lake Hawassa (Demeke Admasu, 1990), Lake Ziway (Zenebe Tadesse, 1988), Baro River (Tesfaye Melak, 2009) and Lake Langano (Mathewos Temesgen *et al*., 2018) and Nile tilapia in Lake Tana (Zenebe Tadesse, 1997). The allomteric growth patern of *O. niloticus* in Lake Hayq could be associated with the current stunted growth.

4. 4. 2. Condition factor

In this study, the FCF of females and males of *C. carpio* were 1.23±0.13 and 1.21±0.011, respectively. These values were similar to 1.22±0.14 for *C.carpio* in Amerti Reservoir (Mathewos Hailu, 2013), but, lower from female (1.58) and male (1.57) *C.carpio* in Damsa Dam Lake in Turkey (Mert and Bulut, 2014), from both sexes of *C.carpio* (1.57) in Foum El-Khanga Dam in Algeria (Sahtout *et al.,* 2017) and 1.39 and 1.27 for female and male *C. carpio* respectively in Almus Dam Lake in Turkey (Karatus *et al.* ,2007). These variations in FCF of *C. carpio* in different water bodies could be based on differences in age, sex, season, stage of maturity, the fullness of gut, type of food consumed, amount of fat reserve and degree of muscular development (Pauker and Cottl, 2004)

In the present study, the mean FCF of female and male *O. niloticus* were 1.85 and 1.80, respectively. These values were higher than Lake Langeno (1.67, combined sexes) (Zenebe Tadesse, 1999), Lake Langeno (1.77, combined sexes) (Mathewos Temesgen *et al*., 2018). However, it was less than reported, Babogaya (1.97, females, 1.86, males) (Lemma Abera, 2012) and Lake Chamo (2.35, combined sexes) (Yirga Teferei and Demeke Admasu, 2002). The lower FCF of *C. carpio* and *O. niloticus* in the present study might be associated with less food availability in the lake (mesotrophic) (see chapter II).

The variation in FCF of Nile tilapia in different lakes might be associated with the quality of food, time, and duration of breeding (Weatherly, 1987; Demeke Admassu, 1990). Shortage of food during the dry season and starvation due to reproductive behavior (mouthbrooding) in Nile tilapia during the breeding season might reduce the condition factor (Medri *et al*., 1990).

4. 4. 3. Sex ratio

In the present study males were more numerous than females in both *C. carpio* and *O. nilotucs*, in Lake Hayq. The sex ratio (F: M) of *C. carpio* in this study was 0.77:1 female to male that showed deviation from hypothetical female to male ratio (1:1). The result of this study disagrees with Mathewos Hailu (2013) that has reported non-significant variation (1.15:1) between females and males in Amerti Reservoir. However, this result agrees with the report (1.53:1) female to male ratio in Damsa Dam Lake in Turkey, which is 1.53:1 (female to male ratio) (Mert and Bulut, 2014).

Similar to *C. carpio*, the number of males *O. niloticus* were more numerous than females (0.61:1 female to males) that showed significant deviation from expected 1:1 sex ratio (Chi-square, $P<0.05$). This result was similar to Lake Tana (Zenebe Tadese, 1997) and Lake Victoria in Kenya (Yongo *et al*., 2018). However, it was different from Lake Hayq (Workiye Worie and Abebe Getahun, 2014), Lake Babogaya (Lemma Abera, 2012), and Lake Langeno (Mathewos Temesgen *et al*., 2018).

These differences in the number of females to males in different water bodies might be associated with fishing efficiency, sampling season and fish stock status (Zenebe Tadesse, 1997; Lemma Abera, 2012). In the present study, the number of females were lower in both fish species which has its own negative effect in potential of the fishery to sustain itself. The problem is severe for *O. niloticus* than *C. carpio,* because its fecundity is very low compared to *C. carpio*.

There are different theories on the variation in number of female and male *O. niloticus* in water bodies. Fryer and Iles (1972) points out the dominancy of male in African waterbodies, because they generally present more growth than females. On the other hand, Gomez- Marquez, *et al*. (2003) reported that a greater number of females than males, because, male *O. niloticus* go to vulnerable area, the shallow part of the waterbodies after fertilization. However, females remain in submerged vegetation for incubation and protection of young to avoid predators. The variation in sex ratio could be associated with reproductive behavior of fishes, place of fish collection and the types of fishing gears used for sampling (Gomez- Marquez, *et al*., 2003).

4. 4. 4. Length at first maturity

In the present study, the size at first sexual maturity of *C. carpio* was 17.5 cm for males and 21.5 cm for females. These values were nearly similar to 15.8 and 22.5 for male and female *C. carpio* in Sidi Saad Reservoir in Tunisia (Hajlaoui *et al*., 2016). But, these values were different from 27cm and 28.3 cm for male and female *C.carpio* in Amerti Reservoir (Mathewos Hailu, 2013) and 27cm and 28.7 cm for male and female *C. carpio* in Lake Ziway (Lemma Abera *et al.*, 2015), 32.5 cm for combined sex in Lake Hashenge (Gashaw Tesfaye, 2019) and 34 and 42 cm for male and female *C. carpio* in Lake Naivasha in Kenya (Oyugi *et al*., 2011).The length at first maturity of *C. carpio* in the present was lower which could be associated with time of introduction.*Cyprinus carpio* introduced accidentally latter than other water bodies of Ethiopia.

The length at first sexual maturity of female and male Nile tilapia was 12.8 and 12.9 cm, respectively which mature at almost the same size. This size was smaller than previously determined for the same species (14.5 for females and 15.5 cm for males) in Lake Hayq (Workiye Worie and Abebe Getahun, 2014). The same is true for the other lakes as well; Tekeze Reservoir (15 cm for females and 14 cm for males) (Tsegaye Teame *et al.*, 2018); Lake Hashenge (23.9 cm, combined sex) (Gashaw Tesfaye, 2019); Lake Tana (21 cm, combined sex) (Degsira Amro *et al.*, 2019), Lake Hawassa (17.8 for males and 14.1 cm for females) (Bjorkil, 2004); Lake Chamo (42 cm, combined sex) (Teferi and Demeke Admasu, 2002); Fincha Reservoir (24.5 for males, 21.8 cm for females) (Fasil Degefu *et al*., 2012); Lake Langeno (16.4 for female and 15.8 for male) (Mathewos Temesgen *et al*., 2018) and Lake Hawassa (20.8 for females and 20.3 for males) (Tesfaye Muluye *et al*., 2016). The lowest L_{50} values reported in the present studyfrom Lake Hayq might be associated mainly with illegal fishing activities, fishing during the breeding season, use of narrow mesh sized gillnet (<8 cm, below the standards) and fishing beyond the lake fish production potential (overfishing) that have been practiced in the lake.

Heavy fishing can alter population structure, impair growth, and cause early maturation, which depended on the selectivity of the fishery (Jorgensen *et al*., 2007; Workiye Worie *et al.*, 2019). Illegal fishing activities, use of narrow sized mesh size gill nets can cause lower L_{50} values in lakes as reported for Lake Victoria in Kenya (Njiru *et al*. 2014; Yongo *et al*., 2018) and Lake Tana, Ethiopia (Degsira Amro et al., 2019). According to Bandara and Amarasinghe (2018), fishing pressure or fishing intensity is one of the major factors for early maturation and stunt growth in *O. niloticus*. Because they allocate much more resources for reproduction than somatic bodybuilding in water bodies where there is fishing pressure.

4. 4. 5. Fecundity

In the present study, the range and mean absolute fecundity of *C. carpio* were 10,316-122,600 and 28,100±17,462, respectively in Lake Hayq. These values were greater than the absolute fecundity range of 1610- 99,737 for *C. carpio* in Lake Ardibo (Wubshet Asnake, 2010). However, it is less than a range of 36,955-318,584 and mean of 170,937±1308 absolute fecundity recorded for *C. carpio* in Amerti Reservoir (Mathewos Hailu, 2013), a range of 75645-356745 and mean of 210538 for *C. carpio* in Lake Ziway (Lemma Abera *et al*., 2015). The fecundity of female *C. carpio* depends on body size and produce between 500,000 to 3 million eggs per spawning (Smith, 2004). Thus, the reproductive potential of *C. carpio* is exceptional as they mature early, are highly fecund, increase reproductive effort with age over their life span, and reproduces at least once each year when conditions are appropriate for survival of larvae. The lower absolute fecundity in Lake Hayq could be due to the smaller size of fish compared to the *C. carpio* in Amerti and Lake Ziway.

In the present study, the mean absolute fecundity of Nile tilapia in Lake Hayq was 217 eggs per fish. This value was higher than Golinga reservoir in Ghana (173 eggs per fish, mean) (Abarike and Ampofo-Yeboah, 2016). However, it was less than what was previously reported for the same species in Lake Hayq (290-1287eggs per fish) (Workiye Worie and Abebe Getahun, 2014), Lake Tana (730 eggs per fish, Mean) (Zenebe Tadesse, 1997), Lake Langeno (464 eggs per fish, mean) (Mathewos Temesgen *et al.,* 2018) and Tekeze Reservoir (399-2129 eggs per fish) (Tsegaye Teame *et al*., 2018).

The Lower fecundity rate in Lake Hayq might be associated with stunt growth caused by fishing pressure. Because, fecundity has a direct relationship with body weight and total length (Njiru *et al*., 2006)

The intensity of reproduction in fish depends on the mean number of eggs per fish and how often the eggs are laid by the fishes (Winberg, 1971). Female *O. niloticus* produces only a few hundreds of offspring in a single spawn but under favorable conditions, they spawn frequently every 4 to 6 weeks (Pullin, 1991). Fecundity is very low in *O. niloticus* as they are mouthbrooding (protect the young in the mouth cavity for several weeks till they are capable of leading an independent life) that have limited space available for rearing the young (Welcome, 1975; Peterson *et a*l., 2004). Though *O. niloticus* does not produce many progenies at each spawning, their offspring have very little risk of predation (Fryer and Illes, 1972).

Fecundity of the same fish species may vary from one water body to another water body due to differences in environmental variables such as temperature and food that affect the body size of the fish as the body size of fishes has a direct relation with fecundity (Njiru *et al*, 2006). Fecundity, the mean number of eggs per brood is usually higher in young fish than older fishes and it increases directly with body weight and length (Njiru *et al.*, 2006). Most species of tilapia breed continuously throughout the year during favorable environmental conditions, higher temperatures, and rainfall (Ross, 2000; Gomez-Marques *et. al.*, 2003). The peak breeding season of most tilapia species is usually associated with higher water temperature, rainfall, phytoplankton, and rising water level in lakes (Babiker, 1986). The difference in fecundity of Nile tilapia is associated with environmental factors such as temperature, altitude, and latitude and these factors vary from one location to the other (Abarike and Ampofo, 2016).

4. 4. 6. Breeding seasons

In this study, the percentage ripe gonads of *C. carpio* and *O. niloticus* were higher between February to April which could be associated with higher atmospheric and water temperature values of 26 and 23^{o}C, respectively. Rainfall availability might also contribute to more food availability (planktons, macrophytes, and detritus) together with temperature, and triggers the spawning both species in Lake Hayq. The mean monthly average water temperature of Lake Hayq was 23 ^{o}C and better rainfall was recorded during the spawning months. In agreement with the current study, peak breeding season was recorded in Amerti Reservoir (Mathewos Hailu, 2013) and Lake Ziway (Lemma Abera *et al*., 2015) when water temperature becomes higher and rainfall is available. *Cyprinus carpio* in Lake Hayq has more than one spawning season similar to that of Amerti Reservoir (Mathewos Hailu, 2013), Lake Ziway (Lemma Abera *et al*., 2015) and Lake Naivasha in Kenya (Oyugi, 2012). This may be related to the thermally stable warm environment and unlimited food resources (Muchiri *et al.*, 1995). The mean monthly surface water temperature that ranged from 21.1 to 25.1 ^{o}C during the study period appears to favor year-round spawning of common carp in Lake Hayq.

The present study result disagrees with the findings of Workiye Worie and Abebe Getahun (2014) that have reported August to September and January to February as breeding seasons. However, we couldn’t observe mature Nile tilapia during the aforementioned seasons. The difference in the breeding season might be associated with fishing pressure, destruction of habitat, and rainfall variability. The breeding seasons of Nile tilapia coincide with higher water temperature, rainfall availability, and seasonal flooding that brings nutrients for phytoplankton and higher phytoplankton biomass (Fryer and Iles, 1972; Demeke Admassu, 1994). In Lake Hayq both common carp and Nile tilapia had the same breeding season and ground. Hence, common carp might have competed Nile tilapia through sharing the resource.

Chapter 5: Food and feeding ecology of common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) in Lake Hayq

5. 1. Introduction

In ichthyology, fish ecology and fisheries, the information on diet and food habits are valuable in the decision-making process related to natural resources (Kido, 1996), quantifying the thread of an introduced or even invasive fish species to native fish populations (Fritts & Pearsons, 2004). Moreover, this information is also important in assessing ecosystem integrity and assemblage functional redundancy (Matthews *et al*., 1982), understanding of such subjects as resource partitioning, habitat preferences, prey selection, and developing conservation strategies. It is, therefore, a key element in the protection of species and ecosystems, understanding the natural history of a species and its role in the trophic ecology of aquatic ecosystems (Braga *et al.*, 2012). Consequently, the study of gut content is not only a way to know the diet but also a superior source of information on many aspects of fish biology and ecology.

Common carp is reported as invasive fish species in many countries. However, it is also commercially important fish species in Asia, for example, it is used as a means of livelihoods for more than 400,000 people in Pakistan (Muhammed *et al*., 2016).

Since the 1930s, tilapias have been intentionally dispersed worldwide for the biological control of aquatic weeds and insects, as baitfish for certain capture fisheries, for aquaria, and as a food fish. They have most recently been promoted as an important source of protein that could provide food security for developing countries without the environmental problems associated with terrestrial agriculture. Nile tilapia which are known as an aquatic chicken because of their potential as an affordable, high-yield source of protein that can be easily raised in a range of environments, from subsistence to intensive fish hatcheries (Gabrielle *et al*., 2005).

Animal populations need adequate quantities of usable resources to sustain and one of the most fundamental questions in ecology is what resources a particular species requires to exist (Litvaitis, 2000). Food is an essential resource which animals consume for survival (Johnson, 1980). Identification of the type of food required for existence and documentation of the information is important to preserve endangered species and manage exploited populations (Simpfendorfer *et al*., 2011).

The knowledge of diet composition and feeding habits is, therefore, an important introduction to the natural history of any species (Ahlbeck *et al.*, 2012). Food habits of different species have been investigated for a variety of specific reasons important in a broader sense. Knowledge of natural diet in an animal species is generally essential for studies of animal nutritional requirements and the recruitment dynamics within a species and across various habitats to understand trophic, material, and energy dynamics and to model outcomes for all ecosystems (Navia *et al*., 2010).

Data on feeding ecology can be used to construct food webs and predict possible changes in food chains and material and energy transfers between and within ecosystems (Baxter *et al.*, 2004: 2005). It helps us to explain interactions with other organisms - potential competitive interactions among sympatric and predator-prey interactions of species (Jaksić *et al*., 1993). Information on the diet also contributes to the understanding of ecosystem structure, community composition, and population dynamics (Ahlbeck *et al*., 2012). Feeding study in fish is important to determine the impact of non-indigenous and invasive species (Reshetnikov *et al.*, 2013; Števove & Kováč, 2016), interspecies interaction such as competition (Crow *et al*., 2010; Leduc *et al*., 2015), and niche overlap and niche partitioning (Guzzo *et al*., 2013; SA-Oliveira *et al*., 2014).

The common carp (*Cyprinus carpio*) is probably the first fish species whose distribution was widely extended by human introduction since it was introduced by the Romans from the River Danube throughout Europe (Balon, 1995). It is the third most frequently introduced species worldwide (Welcomme, 1992) and is almost cosmopolitan nowadays. The common carp also accounts for the world's second-highest farmed fish production, mainly from polyculture in Asia (Milstein, 1992), and the production of ornamental varieties is even more important in monetary value (Balon, 1995)

The common carp is a non-native, nuisance species in the United States (Nico *et al*., 2014) and throughout much of the world (Lever, 1996). The impacts of common carp on lakes are an example of deleterious synergistic effects (Weber and Brown, 2009). Common carp often become abundant (Crivelli, 1981), consume large amounts of prey (Parkos *et al*., 2003), destroy aquatic vegetation (Bajer *et al*., 2009), and suspend large amounts of sediment through their feeding activity (Chumchal *et al.*, 2005). Despite decades of effort to control common carp abundance using various strategies, sustained population reductions have proved difficult (Colvin *et al*., 2012). Because of their persistent and significant impacts, common carp are considered one of the most deleterious non-native aquatic nuisance species worldwide (Weber and Brown, 2009).

Though there were some studies conducted in Lake Hayq on water quality and plankton ecology, studies on the feeding ecology of Nile tilapia and common carp were limited. Therefore, this study was aimed at assessing the feeding ecology of both Nile tilapia and common carp and verify the existence of feeding competition between the two species and ontogenic dietary shifts in different stages of the two fish species.

5. 2. Materials and methods

5.2.1. Fish sample collection

Freshly caught fish specimens of common carp and Nile tilapia were collected from three sampling sites: littoral, pelagic, and Ankerkeha using gillnets of different mesh sizes (4,6,8,10,13cm) and beach seine monthly between January and December 2018. The total length was measured immediately after capture. Stomach from the Nile tilapia and 1/3 of the anterior part of the intestine of common carp were taken and preserved in 4% formalin. The two species were categorized into different size classes based on length class as small, medium, and large sizes. Ontogenic shifts in the diet of *C. carpio* and *O. niloticus* were done by dividing the fish into three size classes: small (<16 cm TL, N=62); medium (16-33cm TL, N=148); large (>33 cm TL, N=29) for the former and Small (<12 cm TL, N=53); medium (12-14.9 cm TL, N=188); large (>14.9 cm TL, N=13) for the latter.

5. 2. 2. Laboratory analysis

In the laboratory, the stomach contents were analyzed using a modified point method according to Hynes (1950) as reviewed by Hyslop (1980). The fullness of each stomach was estimated after contents were emptied into a petri dish. The different food items were identified and sorted into different food categories using a dissection zoom microscope or a standard compound light microscope following Vijverberg *et al*. (2014). The diets were identified to the lowest possible taxa using relevant identification keys (Idris, 1983). Diet was quantitatively analyzed using the frequency of occurrence (%F) and volumetric methods. The dominance of the prey items was determined using the Index of Preponderance (IP). The food selectivity was determined using forage ratio indices as mentioned below:

Frequency of occurrence was calculated as:

$$\%F_{fi} = \frac{N_{fi}}{N_f} \times 100$$

where $\%F_{fi}$ is the frequency of occurrence of given item i, N_{fi} is the number of stomachs in which given item i occurs and N_f is the total number of stomachs with some food items.

The volumetric method

$$\%V_i = \frac{V_i}{V_t} \times 100$$

Where $\%V_i$ is the percentage of the items, V_i is the volume of food item i and V_t is the total volume of food (gut content). Eye estimation was used to estimate the volume of each food items with respect to the total food items under field of vision in compound microscope.

The Index of Preponderance (IP)

The Index of Preponderance (IP) developed by Natarajan & Jhingran (1961) produces a single value for each attribute based on the frequency of occurrence and volume using the equation:

$$IP_i = 100 \times \frac{V_i \times F_i}{\sum_{i=1}^{p} V_i \times F_i}$$

where IP_i is the Index of Preponderance, $\%V_i$ is the percentage of the volume of item i, $\%F_i$ is the frequency of occurrence of given item i. A comparison of the values obtained enables a ranking of the prey in order of mathematical dominance as an expression of the importance within the diet and authors of this index are convinced that it has immense advantages especially when studying fish diet in open waters where animals have access to diverse organisms (Mohan & Sankaran, 1988), who also consider it to be an objective and suitable measure of prey dominance within the diet

Forage ratio (FR; Selection ratio; Preference index)

The forage ratio developed by Savage (1931) uses the relative quantity (percentage) of food item i in the gut as a proportion (percentage) of the total gut content and the relative quantity of the same food item in the environment as a proportion (percentage) of the total abundance of accessible food in the environment. The forage ratio is calculated using the formula:

$$FR_i = \frac{r_i}{p_i}$$

Where FR_i is the forage ratio, ri is the relative quantity (portion, percentage) of the food items i in the digestive tract content, and pi is the relative quantity of the food item i in the environment.

Dietary overlap

Schoener's overlap index was calculated for seasons and the length classes to determine the diet similarity as:

$$C_{xy} = 1 - 0.5 \left(\sum_{i=1}^{n} | p_{xi} - p_{yi} | \right),$$

where C_{xy} is the overlap between diet of individuals in the length classes or seasons x and y; p_{xi} is the proportion of prey i used by size classes or seasons x; p_{yi} is the proportion of prey i used by size classes or seasons y. This index ranges from 0 (no prey overlap) to 1 (all prey items in equal rate), values greater than 0.6 are usually considered biologically significant (Wallace, 1981).

5. 2. 3. Data analysis

Two-way ANOVA was used to analyze diet variation of common carp and Nile tilapia calculated as the frequency of occurrence (FO), percent volume (%V), and index of preponderance (IP) with months through the application of SPSS 16 Version software. The significance level was determined at alpha 0.05 probability level.

5. 3. Results

5. 3. 1. Diet composition

A total of 1000 fish specimens of *C. carpio* (500) and *O. niloticus* (500) were collected from Lake Hayq for gut content analysis. Of these, 240 (48%) and 254 (50.8%) had some food items in the gut of *C. carpio* and *O. niloticus,* respectively. The total length of the specimens with food items ranged from 11-50 cm and 9.2-18.5 cm for *C. carpio* and *O. niloticus,* respectively. A total of 58 food items: phytoplankton (34), zooplankton (11), insects (7), macrophytes, detritus, mud, fish scale, fish eggs, and unidentified food items were recorded in the gut of *C. carpio* (Table 5.1). A total of 70 food items, phytoplankton (43), zooplankton (11), insects (7), macrophyte, detritus, mud, fish scale, fish eggs, and unidentified food items were recorded in the gut of *O. niloticus* (Table 5.2). Except Chlorophyta and Bacillariophyta which were higher in the gut of *O. niloticus*, the number of other food items in both fish species was almost the same (Figure 5.1).

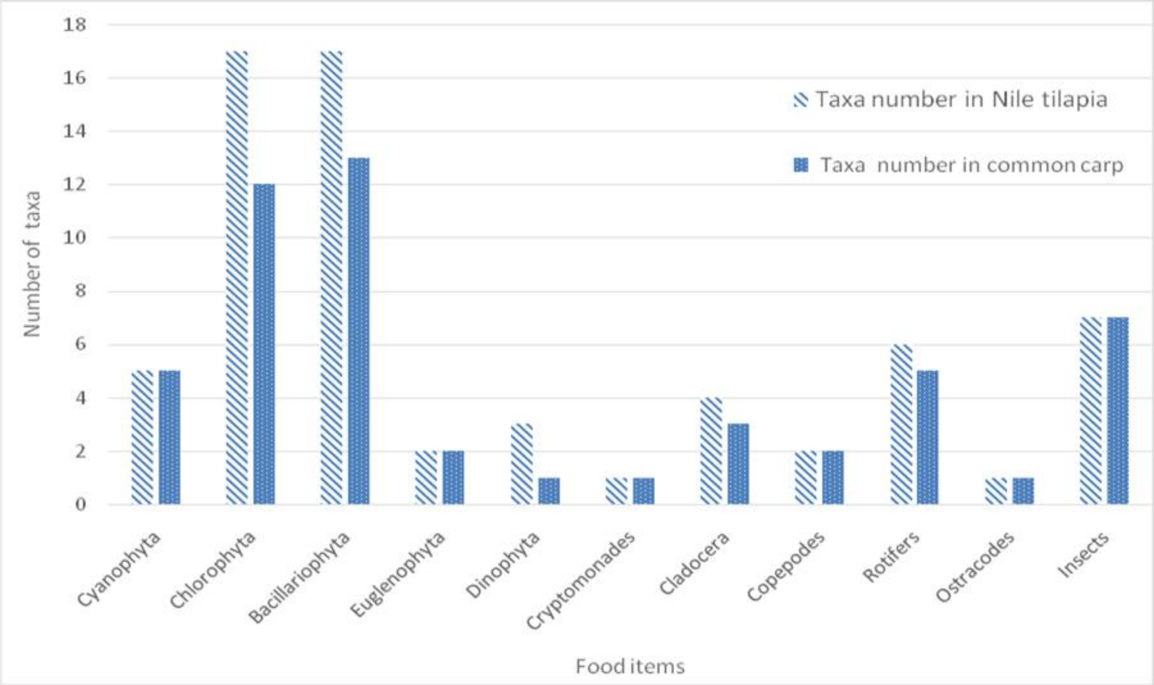

Figure 5. 1: Number of plankton and insects' taxa identified in the gut of *C. carpio* and *O. niloticus* in Lake Hayq.

Table 5.1: Food items identified from the gut of *C. carpio* in Lake Hayq

Phytoplankton					
Cayanophyta	**Chlorophyta**	**Bacillariophyta**	**Euglenophyta**	**Dinophyta**	**Cryptophyta**
Anabaena Sp. *Chroococcus Sp.* *M. eruginosa* *M. flosaquae*	*Chlamydomonas Sp.* *Chlorella Sp.* *Closterium Sp.* *Coelenastrum Sp.* *Monoraphidium Sp.* *Oocyst Sp.* *P. duplex* *P. simplex* *Scenedesmus Sp.* *Spirogyra Sp.* *Tetradron Sp.* *Volvox Sp.*	*Anphora Sp.* *Cosinodiscus Sp.* *Cyclotella Sp.* *Cymbella Sp.* *E. adnata* *E. sorex* *Gophonema Sp.* *Gyrosigma Sp.* *Melosira Sp.* *Merismopedia Sp.* *Navicula Sp.* *Nitzschia Sp.* *Rhopalodia Sp.* *Surirella Sp.*	*Eugenena Sp.* *Phacus Sp.*	*Peridinium Sp.*	*Cryptomonad Sp.*
Zooplankton					
Cladocera	**Copepodes**	**Rotifers**	**Ostrocodes**		
D. cornuta *D. excisim* *M. micrura*	*M. aequatorialis* *T. ethiopinesis*	*A. fissa* *Asplancha* *K. tropica* *L. bulla* *Testedunella Sp.*	*Ostracode Sp.*		
Insects					
Mollusks	Ephemeroptera	Coleoptera Trichoptera	Odonata	Diptera	Hemiptera
Others					
Macrophyte	Mud	Fish eggs	Fish scales	Detritus	Unidentified

Table 5. 2: Food items identified from the gut of *O. niloticus* in Lake Hayq

Phytoplankton					
Cayanophyta	**Chlorophyta**	**Bacillariophyta**	**Euglenophyta**	**Dinophyta**	**Cryptophyta**
Anabaena Sp.	*Anthrodesmus Sp.*	*Anphora Sp.*	*Eugenena Sp.*	*Ceratium Sp.*	*Cryptomonad Sp.*
Chroococcus Sp.	*Chlamydomonas Sp.*	*Aulacoseria Sp.*	*Phacus Sp.*	*Gledinum Sp.*	
M. eruginosa	*Chlorella Sp.*	*Cosinodiscus Sp.*		*Peridinium Sp.*	
M. flosaquae	*Clostrium Sp.*	*CyclotellaSp.*			
Oscillatoria Sp	*Coelenastrum Sp.*	*Cymbella Sp.*			
	Crococus Sp.	*E. adnata*			
	Geocapsa Sp.	*E. sorex*			
	Monoraphidium Sp.	*Gophonema Sp.*			
	Oocyst Sp.	*Gyrosigma Sp.*			
	P. duplex	*Lyngbya Sp.*			
	P. simplex	*Melosira Sp.*			
	S. cingulum	*Merismopedia Sp.*			
	S. updiculum	*Navicula Sp.*			
	Scenedesmus Sp.	*Nitzschia Sp.*			
	Spirogyra Sp.	*Rhopalodia Sp.*			
	Tetradron Sp.	*Scenedesmus Sp.*			
	Volvox Sp.	*Surirella Sp.*			
Zooplankton					
Cladocera	Copepodes	Rotifers	Ostrocodes		
D. cornuta	*M. equatorialis*	*A. fissa*	*Ostracode Sp.*		
D. excisim	*T. ethiopinesis*	*Asplancha Sp.*			
D. magna		*K. tropica*			
M. micrura		*L. bulla*			
		Testedunella Sp.			
Insects					
Molluscs	Ephemeroptera	Coeloptera	Odonata	Diptera	Hemiptera
Trichoptera					
Others					
Macrophyte	Mud	Fish eggs	Fish scales	Detritus	Unidentified

5. 3. 2. Frequency of occurrence, mean percentage volume and rrelative importance of food items

The major food items in *C. carpio* were Bacillariophyta, Cladocera, and Detritus. Bacillariophyta occurred in 67.08% of the gut and contributed 30.91% of the total volume of the food items. Cladocera occurred in 28.33% of the gut and contributed 19.55% of the total volume of the food items. Detritus occurred in 33.33% of the gut and contributed 11.44% of the food items. The major food items in *O. niloticus* were Chlorophyta, Bacillariophyta, and Cyanophyta in their order of importance. Chlorophyta occurred in 62.99% of the gut and contributed 17.71% of the total volume of food items. Bacillariophyta occurred in 56.3% of the gut and contributed 28.43% of the volume of food items. Cyanophyta occurred in 25.98% of the gut and contributed 22.03% of the total volume of food items. Based on Index of Preponderance, Bacillariphyta (57.21%), Cladocera (15.28 %), Detritus (10.52%), and Macrophytes (8.39%) had the highest contribution in the diet of *C. carpio.* Whereas, Bacillariophyta (40.44%), Chlorophyta (28.20%), Cyanophyta (14.47%), Macrophytes (13.51%), and Detritus (8.20) had the highest contribution in the diet of *O. niloticus.* Other food items, Copepods, Rotifera, mud, fish scales, fish eggs, insects, and unidentified food items had less contribution to the diet of the two fish species (Table 5.3).

Table 5.3: Frequency of Occurrence (%F), mean percentage volume (% V) and Index of Preponderance (IP) values of food items in *O. niloticus* and *C. carpio*

	O. niloticus			*C. carpio*		
Diets	%F	%V	IP	%F	%V	IP
Cyanophyta	25.98	22.03	14.47	6.67	2.34	0.43
Chlorophyta	62.99	17.71	28.20	18.75	2.37	1.23
Bacillariophyta	56.30	28.43	40.44	67.08	30.91	57.21
Euglenophyta	0.79	0.13	0.00	7.08	3.43	0.67
Dinophyta	5.51	2.22	0.31	1.25	0.16	0.01
Cryptomonads	0.00	0.00	0.00	2.50	0.32	0.02
Cladocera	4.33	2.08	0.23	28.33	19.55	15.28
Copepods	1.97	0.12	0.23	2.92	0.24	0.02
Rotifers	7.48	2.36	0.45	6.67	2.82	0.52
Insects	2.76	0.77	0.05	0.00	0.00	0.00
Detritus	20.47	8.20	4.24	33.33	11.44	10.52
Macrophytes	31.10	13.51	10.62	22.50	13.52	8.39
Mud	0.00	0.46	0.00	9.58	4.65	1.23
Fish scales	0.00	0.05	0.00	7.08	0.52	0.10
Fish eggs	0.00	0.02	0.00	5.42	0.19	0.03
Unidentified	20.47	1.91	0.99	12.08	1.18	0.39

5. 3. 3. Spatial and Temporal variation of diets

Except for macrophytes and mud food items, there was no significant difference in diet contribution of food items between months in *C. carpio* (ANOVA, *P* >0.05) (Table 5.4). The contribution of macrophytes at littoral and mud at Ankerkeha sites was the highest during wet season. During the rainy season, the macrophyte and mud food items were more abundant at the littoral site and Ankerkeha River which may have come through runoff and flood by Ankerkeha River, a tributary river of Lake Hayq that brings silt and mud from the catchment every year.

Table 5.4: Diet variation of *C. carpio* between months (January -December 2018)

Diets variation within the total length	F	Significance
Bluegreen algae	2.435	0.116
Green algae	0.763	0.65
Diatoms	2.527	0.006*
Euglena	6.853	0.005*
Cladocera	1.893	0.087
Copepoda	0.486	0.716
Rotifers	1.278	0.34
Insects	1.257	0.29
Detritus	1.114	0.365
Macrophytes	2.995	0.005*
Mud	3.52	0.019*
Fish scales	2.566	0.088
Unidentified	28.131	0.000*

Note: *Significant difference

There was a significant difference (ANOVA, *P* < 0.05) in the mean volume contribution of food items (Cyanophyta, Chlorophyta, Bacillariophyta, Cladocera, Detritus, and unknown) in the gut of *O. niloticus* between months (January-December, 2018). However, there was no significant difference in the mean volume of food items among the sampling sites (ANOVA, *P* > 0.05) (Table 5.5).

Table 5.5: Monthly variation of some common food items in *O. niloticus* of Lake Hayq (January-December, 2018)

Diets	F value	Significance (P-value)
Cyanophyta	7.192	0.000*
Chlorophyta	2.412	0.009*
Bacillariophyta	2.721	0.003*
Dinophyta	0.392	0.863
Cladocera	4.7	0.045*
Rotifers	2.253	0.114
Insects	1.361	0.296
Detritus	2.089	0.084*
Macrophytes	1.918	0.079
Mud	9.481	0.2
Unidentified	3.295	0.005*

Note: * significant difference

5. 3. 4. Variation in diet composition with fish size

There was a significant difference in mean percentage volume of diatoms, Euglena, macrophytes, and mud among the three size classes, small (<16 cm), medium (16-33 cm), and larger (>33 cm) *C. carpio* (ANOVA, P <0.05). Large-sized *C. carpio* (> 33 cm TL) had the highest mean percentage volume of macrophytes and mud.

Whereas, the mean percentage of phytoplankton (Cyanophyta, Bacillariophyta, Dinophyta) and zooplankton (Cladocera, Copepods, insects) were highest in small-sized (< 16 cm TL) *C. carpio* (Figure 5.2). A significant difference was observed in Cyanophyta, Chlorophyta, Bacillariophyta, Cladocera, Detritus, and unknown food items in *O. niloticus* length classes, Small (<12 cm), Medium (12-14.9 cm) and Large (>14.9 cm) (ANOVA, $P < 0.05$).

In *O. niloticus* there was no remarkable difference in diet composition among the different lengths, small (<12 cm TL), medium (12-14.9 cm TL), and large (> 14.9 cm). However, animal-based diets (zooplankton and insects) were higher in small and medium-sized *O. niloticus* compared to the large-sized ones (Figure 5.3).

In both fish species, animal-based food items, zooplankton, and insects were dominant in smaller sized groups, whereas in medium-sized groups, the contribution of these animal origin food items decreased. In larger sized *C. carpio*, macrophyte was the dominant food item, unlike larger sized *O. niloticus* that preferred largely phytoplankton.

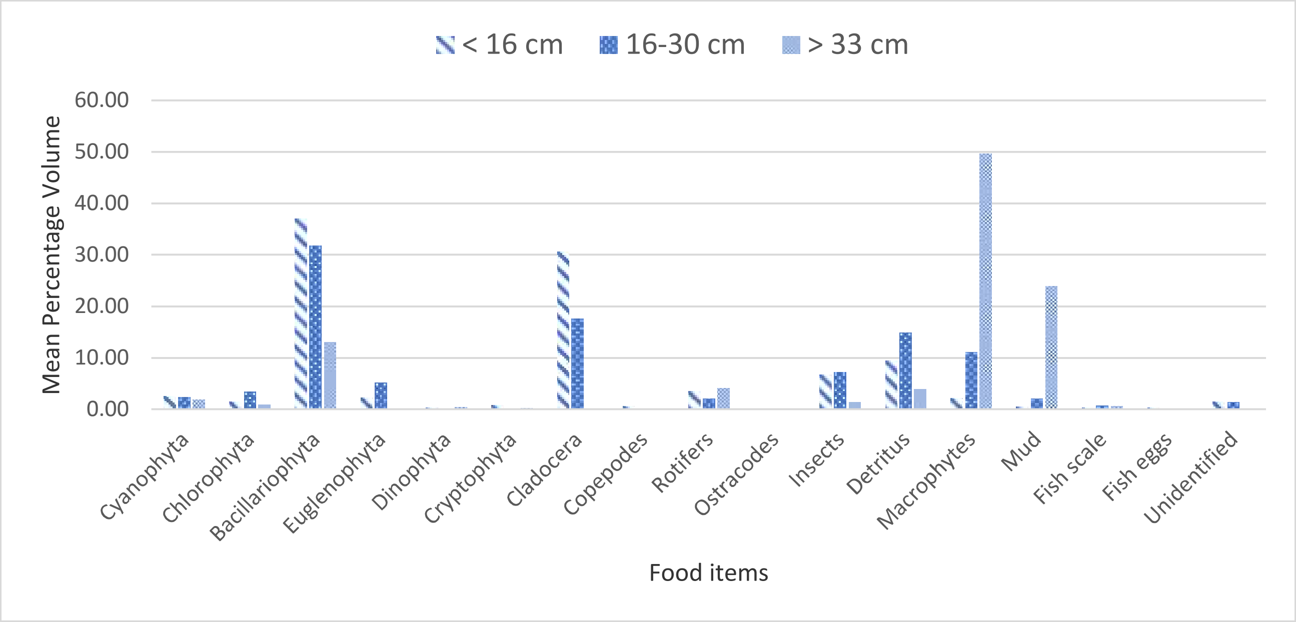

Figure 5.2: Mean percentage volume of food items in the gut of small (<16 cm), medium (16-33 cm) and large (>33 cm) length class *C. carpio* in Lake Hayq

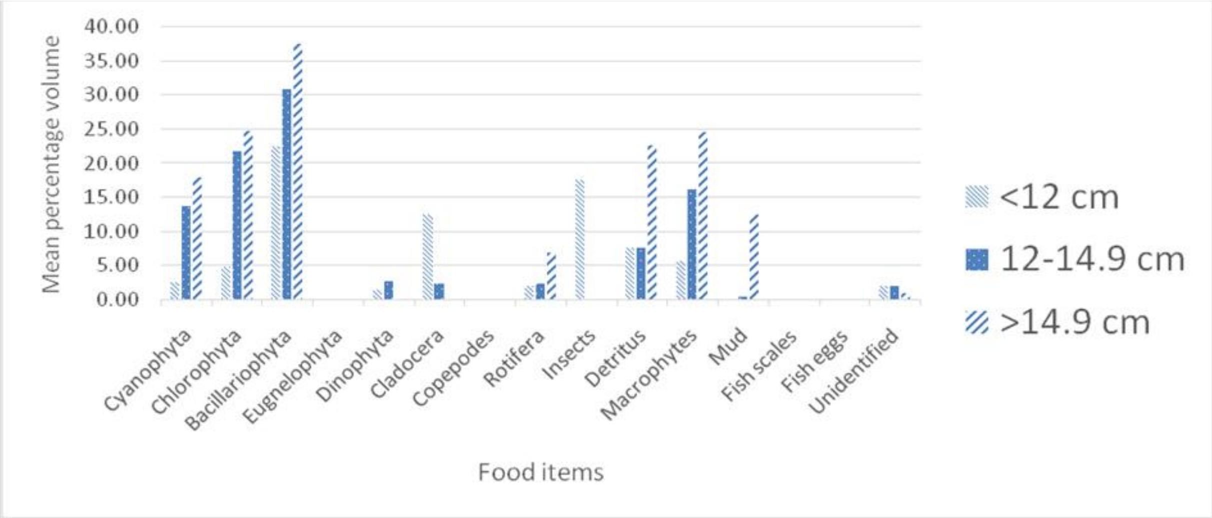

Figure 5.3: Mean percentage volume of food items in the gut of small (<12 cm), medium (12-14.9 cm) and large (>14.9 cm) length class of *O. niloticus* in Lake Hayq

5. 3. 5. Food selectivity

The food selectivity of the dominant food items, which are of phytoplankton and zooplankton origin was determined using food selectivity index, Forage ratio. *O. niloticus* had more preference for Bacillariophyta, Cyanophyta, and Chlorophyta whereas *C. carpio* had more preference to Bacillariophyta, Cladocera, and Euglenophyta in order of preference. As the value of the ratio approaches to 1 the fishes' preference is stronger (Table 5.6).

Table 5.6: Forage ratio of food items in both *O. niloticus* and *C. carpio* in Lake Hayq

Food items	Forage ratio	
	O. niloticus	*C. carpio*
Cyanophyta	0.57	0.62
Chlorophyta	0.45	0.06
Bacillariophyta	0.79	0.86
Euglenophyta	0.03	0.78
Cladocera	0.09	0.81
Copepoda	0.01	0.01
Rotifers	0.04	0.05

5. 3. 6. Diet overlap

The diet overlaps of both *C. carpio* and *O. niloticus* was determined using Schoener's overlap index. There was a nonsignificant diet overlap among length classes in both *C. carpio* and *O. niloticus* (Overlap value <0.6). However, there was a diet overlap between small-sized *C. carpio* and *O. niloticus* (Overlap = 0.79). Smaller C. *carpio* and *O. niloticus* in Lake Hayq preferred mainly zooplankton and phytoplankton species. However, mature (large-sized) *C. carpio* preferred mainly macrophytes and detritus whereas large-sized *O. niloticus* preferred phytoplankton and detritus in order of preference. There was no significant difference in diet overlap among sampling sites and sampling months in the lake (ANOVA, $P > 0.05$).

5. 4. Discussion

Cyprinus carpio and O. niloticus in Lake Hayq feed on a variety of food items ranging from microscopic (phytoplankton and zooplankton) to bigger sized food items such as insect parts, mud and macrophytes based on the size of the fishes. The number of food items recorded from the gut of *O. niloticus* (70) was more than *C. carpio* (58) indicated that *O. niloticus* are more efficient feeders than *C. carpio.* However, more than 50% of the food items recorded in the guts of the two fish species were similar that indicated both fish species preferred most of the food items available in Lake Hayq.

Based on Index of Preponderance, Bacillariphyta (57.21%), Cladocera (15.28 %), detritus (10.52%), and macrophytes (8.39%) had the highest contribution in the diet of *C. carpio.* Whereas, Bacillariophyta (40.44%), Chlorophyta (28.20%), Cyanophyta (14.47%), macrophytes (13.51%), and detritus (8.20) had the highest contribution in the diet of *O. niloticus*. Therefore, the contribution of Bacillariophyta in the gut of the two fish species were the highest compared to other food items. However, the numerical abundance of Dinophyta Spp. was the highest in Lake Hayq. The highest contribution of Bacillariophyta in the gut of the two fish species could be associated with food preference.

Cyprinus carpio is omnivorous that feed on plant origin food items (phytoplankton, macrophytes, detritus) and animal origin food items (zooplankton, insects, fish scales, fish eggs), which is in agreement with many research reports in Ethiopian water bodies (Kassahun Asmamaw, 2005; Elias Dadebo *et al.*, 2015; Abebe Tesfaye, 2018) and also from other countries (Morgan, 1988; Sibbing, 1988). In the present study, the mean volume percentage contribution of Bacillariophyta and Cladocera in small-sized and detritus and macrophytes in large-sized class size *C. carpio* had a significant contribution. The present study agreed with the report by Elias Dadebo *et al*. (2015) for Lake Koka and Abebe Tesfaye (2018) for Lake Ziway where insects, detritus, and macrophyte were the dominant food items in the gut of *C. carpio*.

Seasonal change of food items in *C. carpio* was observed in Lake Hayq, more food items (phytoplankton, zooplankton, and insects) were consumed in dry seasons due to higher water temperature in tropics and detritus and macrophyte contribution were more during rainy seasons due to runoff and flooding from the catchment which is in agreement with the findings of Elias Dadebo *et al*. (2015).

There was a slight ontogenetic dietary shift in *C. carpio* in Lake Hayq among the three length classes. But significant change was observed between small (<16 cm) and large length classes (>33 cm). Small groups mainly feed on zooplankton (Cladocera, copepods, rotifers), insects (Chironomids larvae), whereas large-sized groups feed on mainly macrophytes, mud, and detritus which is similar to the report by Kloskowski (2011), Elias Dadebo *et al.* (2015) and Abebe Tesfaye (2018). Different factors might contribute to the dietary shift in fishes; -Settlement into the forage areas (Sivadas and Bhaskaran, 2009), change in environment, and fish size (Morgan, 1988) are some of the factors for change in diet between smaller and bigger sized *C. carpio*. Smaller sized fishes usually prefer the shore of the lake and feed on benthic invertebrates and mud (Christophore, 2008). Fishes as they grow change in physiology and feeding behavior observed due to growth in the alimentary canal and gap size of the mouth. Prey size generally is correlated with fish size (Zerihun Desta *et al*., 2007).

Many fish shift to less important foods when preferred food sources become depleted (Balcombe *et al*., 2005), which can affect foraging, swimming, and other social behaviors. This concept is also true for *C. carpio* that was observed to increase its preference for zooplankton in the absence of benthic macroinvertebrates (Balcombe *et al*., 2005). In natural habitats, carp fries feed mainly on zooplankton and phytoplankton. The juveniles and adults are omnivorous and feed on worms, insect larvae, plant seeds, and algae (Oyugi *et al*., 2012). This feeding of fish on a specific type of food reduces the competition among fish of different sizes. Therefore, feeding on a particular diet ensures that each size class of fish has its trophic niche within the aquatic system.

Oreochromis niloticus has been reported as omnivorous fish species in studies conducted in Ethiopia (Zenebe Tadesse, 1998; Flipos Engdaw *et al*., 2013; Mulugeta Wakjira, 2013; Workiye Worie and Abebe Getahun, 2015; Mulugeta Wakijira, 2016; Mathewos Temesgen, 2017; Tadesse Fetahi, 2018; Abebe Tesfaye, 2018; Yirga Enawgaw and Brook Lemma, 2018) and also in other countries (Ronald *et al*., 2011; Outa *et al*., 2014). Similar to these reports, *O. niloticus*, in the present study, are omnivorous feeding on both plant origin (phytoplankton, macrophytes, detritus) and animal origin (zooplankton, insects). Smaller sized *O. niloticus* (<12 cm) prefer zooplankton especially cladocerans and insects (Chironomidae larvae), whereas large ones (>14.9 cm) prefer Bacillariophyta, Cyanophyta and Chlorophyta phytoplankton groups and macrophytes. The mean percentage volume contribution of Bacillariophyta was the highest in the present study which is in agreement with Abd-Ellatif *et al*. (2019) report for Lake Naser in Egypt where Bacillariophyta, Chlorophyta, and Cyanophyta have contributed the highest mean percentage volume in the lake. Rumisha and Nehemia (2013) have also reported that Bacillariophyta and Cyanaophyta had a higher mean percentage volume in *O. niloticus* in Lake Victoria. However, the present study disagreed with the findings of Workiye Worie and Abebe Getahun (2015) for the same lake, Lake Hayq where Microcystis contributed the highest mean percentage volume reported when the lake trophic state was classified as eutrophic. On the other hand, outa *et al*. (2014) also have reported the preference of Chlorophyta and avoidance of Bacillariophyta and Cyanophyta by *O. niloticus*. The difference in diet preference in fishes might be associated with the availability of the diet, size of the fish, light intensity, water clarity, water temperature, and fish population (Abdel-Tawwab, 2003; Zerihun Desta *et al*., 2007).

Seasonal food items' contribution varied in *O. niloticus* in Lake Hayq. The mean percentage volume of mud and detritus was higher during the rainy season and phytoplankton and zooplankton during the dry season. A similar result was reported in Lake Victoria by Ronald *et al*. (2011).

In Lake Hayq, there was a slight ontogenetic dietary shift in *O. niloticus*. Smaller sized *O. niloticus* feed on zooplankton and insects. Whereas large-sized groups feed on phytoplankton, detritus, and macrophytes. which is in agreement with Workiye Worie *et al*. (2015) for the same lake and Outa *et al*. (2014) in Lake Naivasha. The contribution of phytoplankton in the diet of adult *O. niloticus* was the highest similar to Workiye Worie and Abebe Getahun (2015). However, the contribution of macrophytes was the highest in Lake Ziway (Tadesse Fetahi *et al*., 2017; Abebe Tesfaye, 2018).

Smaller sized *O. niloticus* and *C. carpio* preferred zooplankton specially cladocerans and copepods than rotifers that might be due to the bigger sizes of cladocerans and copepods. However, bigger sized *C. carpio* prefer macrophytes and detritus, and bigger sized *O. niloticus* prefer phytoplankton and detritus in Lake Hayq similar to other studies (Workiye Worie and Abebe Getahun, 2015; Tadesse Fetahi, 2017; Abebe Tesfaye, 2018).

In Lake Hayq, there was diet overlap between smaller and bigger sized *C. carpio* and *O. niloticus* as reported by Abebe Tesfaye (2018) for Lake Ziway. One of the possible reasons for the current stunt growth and low production of O. *niloticus* in Lake Hayq might be associated with the diet overlap between the small sized O. *niloticus* and *C. carpio.* Hence, the newly arrived common carp could have caused food limitation for Nile tilapia and might have caused stunted growth of Nile tilapia in Lake Hayq.

A study on feeding ecology of fishes provides important information on behavior, habitat use energy flow, and competition. Analysis of food items of the stomach of fishes can be used to evaluate effects on ontogeny or the establishment of exotic species (Chipps & Garvey, 2007).

Chapter 6: Impact of fishing activities on Nile tilapia (*Oreochromis niloticus*) Stock in Lake Hayq

6. 1. Introduction

Fish is an important commodity contributing to nutrition, food security, and employment in the world. The fishery is an important sector used for food security and a source of cheap protein for the poor living in developing countries (FAO, 2018). The contribution of small-scale fisheries is significant for the livelihoods of millions worldwide. Fisheries have the most important contribution to developing countries where the means of livelihoods are very limited. In Ethiopia, about half a million people depend on capture fishery directly and indirectly as a means of livelihood (Gashaw Tesfaye and Wolff, 2014).

Ethiopia is known as the water tower of Eastern Africa due to its huge freshwater potential. The country endawed with many lakes, rivers and reservoirs, small water bodies, and large floodplain areas distributed all over the country from lowland to highlands covering a total surface area of about 13,637 km^2 (Gashaw Tesfaye and Wolff, 2014). Though fish diversity studies in Ethiopia are still under investigation in different water bodies (lakes and rivers), the fish diversity of the country is estimated to be over 200 species (Gashaw Tesfaye and Wolff, 2014; Abebe Getahun, 2017).

The fish production estimated from 106 waterbodies in Ethiopia was 94,500 tons per year (73,100 tons/year from lentic and 21,400 tons/year from lotic systems) (Gashaw Tesfaye and Wolff, 2014). However, the actual fish production in Ethiopia is much below the potential and the production status is uneven across water bodies. In some lakes such as Tana, Chamo, Abaya, Hawassa, Ziway, and Hayq, there has been sign of overfishing (Gashaw Tesfaye and Wolff, 2016). However, in some lakes located in remote areas such as Lake Maybar and Golbo still unexploited and further development is required (Assefa Tessema and Kelemework Geleta, 2013; Gashaw Tesfaye and Wolff, 2014; Aschalew Lakew *et al.*, 2016).

Many factors could be mentioned for the low fish production in Ethiopia, traditional fishing practices, food habits of the people, poor facilities along the fish value chains, poor fishery regulation implementation system, pollution, weak coordination among water sectors and generally very little emphasis to the fishery sector (Lemma Abera, 2017; Alemayehu Abebe and Tamiru Chalchisa, 2019).

Lake Hayq is one of the highland lakes of Ethiopia where significant fishery activities and sources of livelihoods directly and indirectly for the people living around the lake. Before a decade, the fish production of Lake Hayq was very good and supports many fishermen and fish traders (Tadesse Fetahi *et al*., 2011a; Assefa Tessema and Kelemework Geleta, 2013; Zuriash Seid, 2016). However, the fish production trend especially, Nile tilapia stock has been declined from time to time (Workiye Worie, 2009; Assefa Tessema and Kelemework Geleta, 2013; Workiye Worie and Abebe Getahun, 2014; Dereje Tewabe *et al.*, 2015: Endalh Mekonnen *et al*., 2019a).

Though many studies were conducted on physical limnology (Boxter, 1970; Elizabeth *et al*., 1992), phytoplankton and zooplankton community structures and energy flows and food web structures (Tadesse Fetahi *et al*., 2011a, 2011b; 2014), lake morphometric and land use and land cover (Hassen Mohammed *et al*., 2013;2015), water quality (Ruchi *et al*., 2016). Howver, there is limited information on socioeconomic importance of fisheries, the status of the current fishing activities and its impact on Nile tilapia in Lake Hayq. Therefore, this study aimed to assess the socioeconomic importance of the fisheries, the status of fishing activities, and its implication on Nile tilapia stock and recommend measures to be taken for sustainable fishery of Lake Hayq.

6. 2. Materials and Methods

6. 2. 1. Study area

This study was conducted in two woredas (districts), Tehulederie, and Worebabo which are found in South Wollo Zone administrative zone. The two districts are located in Awash basin some 30 and 40 km far from Dessie and 430 and 440 km from Addis Ababa, respectively. The specific areas selected for the survey study were seven Kebeles (2, 5, 012, 015,017, and 027) from Tehulederie woreda and one Kebele (02) from Worerbabo woreda that are bordering Lake Hayq.

6. 2. 2. Data collection

Before the actual data collection program, permit to collect data in the study area was obtained from Tehulederie Woreda Agriculture and Rural Development office which administers the lake. Qualitative and quantitative data were collected using a structured questionnaire, focus group discussion, and personal observation during the period of January 2018 - December 2018. Items of the questionnaire were tested and refined based on information obtained during a pilot survey. Major data addressed in the questionnaires included socio-demographic characteristics of the respondents, fishing activities, types of fishing gears used, commercial fish species, kind of fish harvested, amount of fish production per month, number of fishing days, income from fishing, income from other activities, the objective of fishing, market places, the average price of each fish per kg and awareness of fishermen about fishery regulatory acts of the Federal and Regional Governments, major challenges of fisheries of Lake Hayq and institutional support.

Sampling and sampling procedure

The sample size of fishermen was determined using a sample size determination formula (Bartlett *et al.*, 2001). Multi-stage (four stages) sampling techniques were used for the selection of fishermen in Lake Hayq. At first stage Districts bordering Lake Hayq were selected (Tehulederie and Worebabo). In the second stage, Kebeles bordering Lake Hayq (2, 5, 012, 015, 017, 027) from Tehulederie woreda, and 02 from Worebabo were selected purposively based on level of fishing activities. In the third stage, fishers were selected purposively from non-fishers in collaboration with fishery experts. At the fourth stage, a simple random selection of fishermen was done and interviewed using pre-tested structured questionnaires as indicated in Erkie Asmare *et al*. (2016).

Sample size determination

The sample size of respondents was determined using the single population proportion formula as follows, assuming a 50 % probability, 95% confidence level, and 5% desired level of precision.

$$n_o = \frac{\left(Z_{a/_2}\right)^2 .p(1-p)}{d^2}$$

Where,

- n_o is the fisherman to be studied.
- $Z_{a/_2}$are 1.96 at 95% level of confidence and 5% level of significance
- d is 5% level of precision
- p is 50% (0.5)

$$n_o = \frac{(1.96)^2.0.5(1-0.5)}{(0.05)^2}$$

$$n_o = \frac{(3.8416)(0.5)(0.5)}{(0.0025)}$$

$$n_o = \frac{(0.9604]}{(0.0025]}$$

$$n_o = 384.16$$

Since the total population of fishermen (N) according to Tehulederie District is 405 in Lake Hayq during the survey, and the value of no (385) is > 5 % of the total population, finite population correction formula was being employed to come up with the desired sample size (n).

$$n = \frac{n_o}{1 + {}^{n_o}/_N}$$

The final sample size became 198.

Sampling procedure

The final sample size calculated (198) was allocated for Lake Hayq fishermen selected randomly until the total sample size was obtained. In addition to face to face interviews with fishermen, Participatory Rapid Appraisal (PRA) was conducted with 30 fish traders and 8 Hotels (5 in Hayq town and 3 in Dessie town) that specialized only in fish dish preparation. Data such as the trend of fish supply and demand, price of fishes, most preferred fish species by consumers, other sources of fish other than Lake Hayq, and the balance between demand and supply of fish production, major challenges of the fisheries of Lake Hayq were collected.

6. 2. 3. Data analysis

Qualitative and quantitative data were summarized using both descriptive (pictures, frequencies, percentages, pie chart and bar graphs) and inferential statistics (Chi-square, ANOVA) through the application of Excel version 16 and SPSS Software version 16. Data that were not normal and categorical were analyzed using the Chi-square test of association, but those data which were continuous and normal were analyzed using one-way ANOVA.

6. 3. Results

6. 3. 1. Socio-demographic characteristics of fishermen

The age of the fishermen ranged from 14 to75 and the lowest mean age of the fishermen was 31.05±13.062 observed at 02 Kebele (Worebabo District) and the highest mean age (39.75±11.21) was observed at Kebele 027 (Tehulederie District). The overall mean age of fishermen was 35.19 ± 10.79 which was in working force age groups (<65). The family size of fishermen ranged from 1- 8 and the lowest mean family size (1) was recorded at kebele 012 and the highest mean family size (3.17±1.88) was observed at Kebele 027. The experience of fishermen of Lake Hayq ranged from 5 to 21 years (Table 6.1).

Table 6. 1: Some socio-demographic characteristics (Age, Family size and Fishing experience) of fishermen in Lake Hayq

Kebele	Range, Mean ± SD	Age	Family size	Fishing experience (years)
02	Range	14-60	1-6	10
	Mean ± SD	31.05	3	10
012	Range	25-45	1	8
	Mean ± SD	33	1	8
015	Range	25-42	1-4	6-16
	Mean ± SD	32.35	2	9.41-10
017	Range	18-60	1-4	10
	Mean ± SD	31.67	2	10
2	Range	24-75	1-5	5-21
	Mean ± SD	39.75	3	13.61
027	Range	16-50	1-8	9-12
	Mean ± SD	34.38	4	10.23
5	Range	18-48	1-6	8-12
	Mean ± SD	31.28	3	9.19

Marital status and educational levels of fishermen

Most of the fishermen of Lake Hayq (102, 51.5%) were unmarried, followed by married (94, 47.5%) and divorced (2, 1%). The chi-square test analysis showed that there was a significant difference in marital status among fishermen of Lake Hayq ($\chi^2 = 207.4$, df=21, $P < 0.05$). The educational status of fishermen of Lake Hayq was illiterate (29, 14.6%), Primary (102, 51.5%), Secondary (59, 29.8%), and Diploma (8, 4%). The chi-square test analysis showed that there was a significant difference in the educational background among the fishermen of Lake Hayq ($\chi^2 = 257.5$, df = 28, $P < 0.05$) (Table 6.2).

Table 6. 2: Marital Status and Educational level of fishermen in Lake Hayq

	Kebeles							Total	Chi-test	df	Sig
	02	012	015	017	2	027	5		207.4	21	*P<0.05*
Marital status											
Divorced	0	0	0	0	1	1	0	2			
Married	9	3	10	4	27	24	17	94			
Unmarried	10	3	7	2	43	22	15	102			
Total								198			
Education level									257.5	28	*P<0.05*
Diploma	0	0	0	0	0	7	1	8			
Illiterate	1	0	0	0	16	6	6	29			
Secondary	6	1	3	2	11	23	13	59			
Primary	12	5	14	4	44	11	12	102			
Total								198			

6. 3. 2. Fishermen categories

From a total of 198 fishermen, 118 (51%) were full time fishers who have no other means of income, whereas 78 (39%) were seasonal who have other sources of income from crop and animal farming, and 20 (10%) were part-time fishers with other sources of income from employment as a guard in private, governmental organizations and boating (boat owners) (Figure 6.1). All fishermen are working privately and there is no functional fishermen association for the past one decade in Lake Hayq.

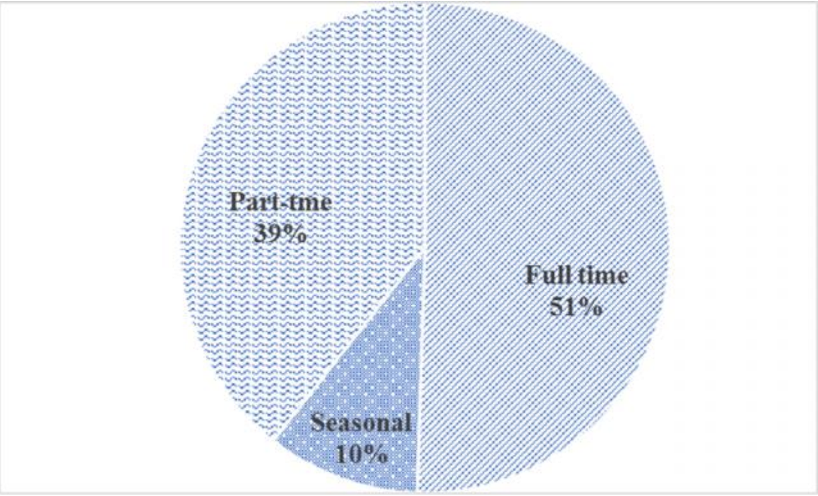

Figure 6.1 Fishermen categories in Lake Hayq, January-December, 2018

6. 3. 3. Landing sites

There are 32 landing sites around Lake Hayq which were located in 7 kebeles under two districts, Tehulederie and Worebabo. The majority (29, 90.6%) of the landing sites are found in Tehulederie District and the remaining (3, 9.4%) are found in Worebabo District. The highest and the lowest number of landing sites were found at Kebele 015 and Kebele 017, respectively (Fig. 6. 2). Among the seven Kebeles, the major landing sites (greater number of fishermen and fishing activities) are found in 015, 5, and 027 Kebeles following decreasing order

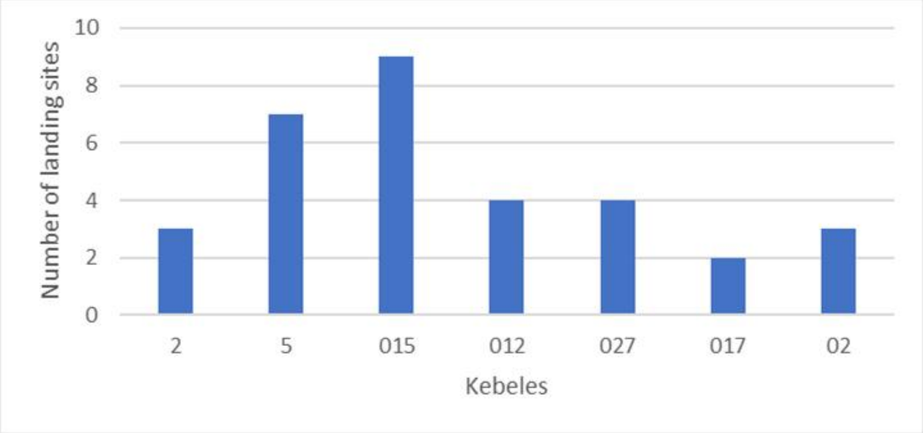

Figure 6.2: Number of landing sites in each Kebele bordering Lake Hayq

6. 3. 4. Commercially important fish species

In Lake Hayq, there are three commercially important fish species, Nile tilapia (*O. niloticus*), Catfish (*C. gariepinus*) and common carp (*C. carpio*). According to the respondents, only catfish species are native fish in Lake Hayq, the other two species (common carp and Nile tilapia) are accidentally and intentionally introduced fish species, respectively (Table 6.3).

Table 6.3: Commercially important fish species in Lake Hayq

Family name	Scientific Name	Common name	Local name
Cichlidae	*Oreochromis niloticus*	Nile tilapia	Koroso
Cyprinidae	*Cyprinus carpio*	common carp	Duba
Clariidae	*Clarias gariepinus*	Catfish	Ambaza

6. 3. 5. Fishing practices

6. 3. 5. 1. Fishing gear types

In Lake Hayq, there are three kinds of fishing gears used by fishermen, gillnets (97.4%), Hooks and lines (1.28%), and ‘’Jabeto’’(cages) (1.32%). The average mesh size of the gillnet for Nile tilapia fishing was 5 cm (< 8 cm, below the standard). Hooks and Cages are used for common carp and catfish capturing. All fishermen (100%) use traditional fishing boat made of bamboo for fishing activities. The number of fishing gears, gillnets, hooks, and boats varied with landing sites and the number of active fishermen (Fig. 6.3). The total number of gillnets (monofilaments from Egypt) and boats were 185 and 166, respectively. The number of fishing boats and gillnets decreased due to the decline in fish production over the past decades.

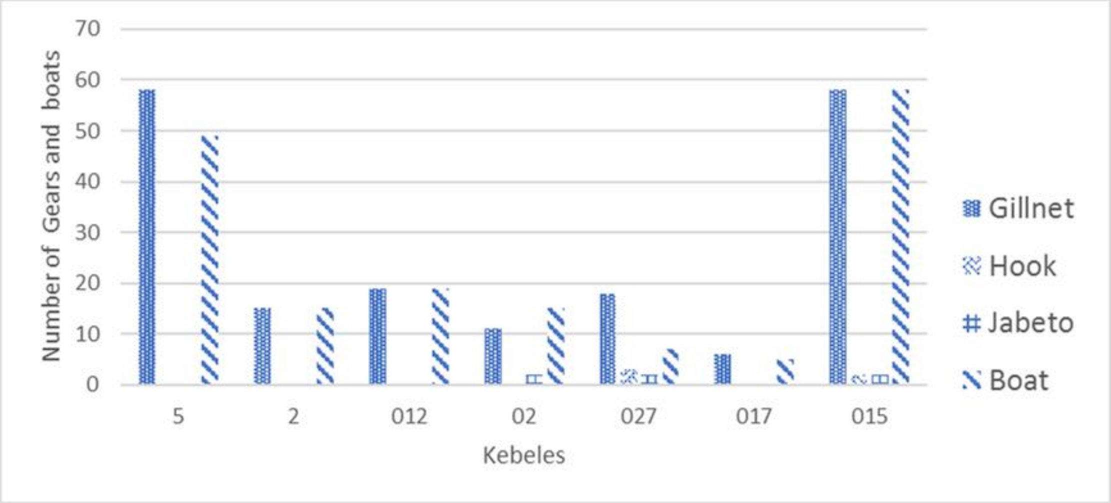

Figure 6. 3: Number of fishing gears and boats in seven selected kebeles bordering Lake Hayq

6. 3. 5. 2. Fishing methods

The fishermen of Lake Hayq capture fishes both during night and day times. Fishermen set their gillnet overnight and check fish early morning. However, most of them (70 %) capture Nile tilapia from the shore of the lake during day time using the chase and trap method. Some experienced fishermen capture bigger sized common carp and catfish using hooks and lines (Fig. 6. 4). The fishermen use gills of fishes and body parts of *Garra* species as baits to catch catfish. They use immature maize fruit (Chorka, Amharic), gills, and body parts of fishes as baits for common carp fishing.

Figure 6. 4: Bigger sized common carp (Left) and Catfish species (right) captured using Hooks and lines.

6. 3. 6. Mode of transportation of fishes

Most of the fishermen (60%) used the small vehicle ‘’Bajaj’’, some (20%) of them used boat and Bajaj to reach the market place as means of transportation, and others (20%) travel on foot to market. Those fishermen that travel on foot were mainly using the fish for their consumption.

6. 3.7. Fish processing for market and consumption

The fishermen of Lake Hayq process and sell filleted form in the market, Hotels or fish market (Asa Gebeya, Amharic) found at Hayq town. However, fishermen sell whole fish sometimes at landing sites for fish traders (Fig. 6.5). Fishermen consume about 1 kilo of raw tilapia per week. Both fishermen and other consumers prefer Nile tilapia followed by catfish and common carp for consumption. Common carp were not used for commercial purposes before 10 years around Lake Hayq. However, the scarcity of Nile tilapia forced the fishermen and the local people to consume common carp after extensive training was given on how to prepare carp dish. Today, common carp has major contribution to the income of fishermen and in the nutrition of the people living in Hayq and Dessie towns.

Figure 6.5: Gutted and filleted *C. carpio* (left to right) ready for sale in the shore of Lake hayq.

6. 3. 8. Socioeconomic contribution of fisheries

The One-way ANOVA analysis showed that there was a significant difference ($P < 0.05$) in the price of fishes, number of fishing days, fish consumption, monthly income from Agriculture and monthly income from the fishery. The price of Catfish was the highest followed by Nile tilapia. Fishermen who have other sources of income have lower fishing days per month. Fishermen consume mostly Nile tilapia, followed by common carp and catfish. The income of fishermen from fishery was more than from agriculture except in Kebele 02 in which farmers get income from horticulture (Banana, Sugarcane, Chat) (Table 6.4).

Table 6.4: Mean Price of filleted fishes (ETB), Mean monthly fish catches (Kg), Mean fishing days per month, mean monthly fish consumption (Kg), and Mean monthly income of fishermen (ETB) (Mean ± SD)

	Kebeles						
	02	12	15	17	2	27	5
Variables							
Price (ETB)							
C. carpio	50	64.0	63.8	50	55.6	50	51.6
O. niloticus	106.3	85	93.2	110	99.5	75.7	76.6
C. gariepinus	101.1	100	101.8	90	113.8	129.2	118.4
Fishing days	11.3	17	16.8	22	22.3	24.7	21.3
Catch (Kg)							
C. carpio	15	30	35	40	25	28	25
O. niloticus	5	10	10	15	10	12	10
C. gariepinus	0	5	5	10	10	5	5
Consumption (Kg)	6	4	10	8	4	5	2
Income (ETB)							
Agriculture	3000	400	800	766.7	1260.6	600	468.8
Fishery	1202.1	3584.2	3757.1	4840	3776.6	3734.9	3176.1
Total	4202.1	3984.2	4557.1	5606.7	5037.1	4334.9	3644.8

Note: ETB, Ethiopian birr ;1 USD = 30 ETB

6. 3. 9. Fish production trend

Fish production, in general has declined over the last six years in Lake Hayq (Fig. 6. 6). The fish production has a strong association with the number of active fishermen. According to the Tehulederie Agricultural office, the number of fishermen was very high (about 1500) in 2013. However, when the fish production is reduced due to overfishing, most of the fishermen changed their profession and migrated to Arabian countries. Recently the total number of fishermen of Lake Hayq was about 405 in 2018.

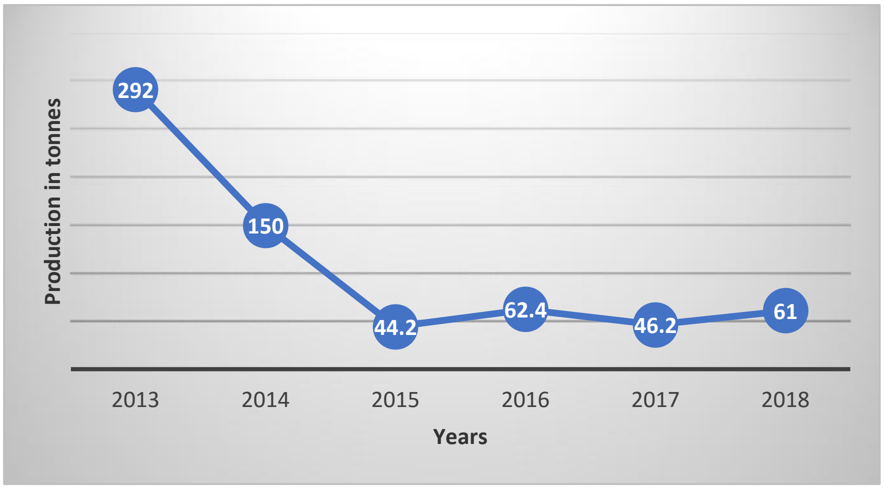

Figure 6. 6: Fish production trend for the last six years from Lake Hayq (Tehulederie District Agricultural and Rural Development Office, 2019)

6. 3. 10. Awareness of fishermen on fishery management

Most (148, 74.7%) of the fishermen in Lake Hayq have basic concepts of fishery management tools (closed breeding season and ground, mesh size regulation, gear restriction, etc.), and fishery development and utilization proclamations enacted both by the Federal and Regional governments, Federal Fisheries Development and Utilization Proclamation (Proclamation No.315/1995), the Amahara National Regional State Fisheries Development, Prevention and Utilization (Proclamation No. 92/1996), and the Amahara National Regional State Fisheries Development, Prevention and Utilization Proclamation Enforcement (Proclamation No.

50/1999). However, some (50, 25.3%) of the fishermen had no information about the aforementioned proclamations.

6. 3. 11. Implementation of the proclamations

Though better awareness has been created about the fishery development and utilization proclamations through the efforts of Wollo University and Tehulederie District Agricultural and Rural Development Office, the implementation status is very poor. The district closed any fishing activities for three months (May, June, and August) considering the breeding season and has employed a supervisor for monitoring illegal fishing activities. But the implementation was not proper. Many factors could be mentioned for the poor implementation of the proclamation; however, all fishermen agreed that increment of the number of jobless youths around the lake is the major factor for poor implementation of the proclamations.

6. 3. 12. Focus group discussion and key informants

Fish expert, fish traders, senior fishermen, Hotel owners at Hayq, and Dessie mentioned that fish production from Lake Hayq has declined dramatically for the past decade. The major factors mentioned by the participants to be responsible for the reduction were; - the increasing number of jobless youths, destruction of the buffer zone, illegal fishing gears (mesh size <8 cm, below the standard), fishing during the breeding season and breeding ground, and overfishing especially *O. niloticus*. Currently, the fish production from Lake Hayq is overfished as the result, Hotels at Hayq and Dessie are purchasing fish (*O. niloticus*) about 20-50 kg per day from other lakes such as Lakes Ardibo (Tehulederie), Lake Tana (Bahir Dar), Hashenge (Korem), and Lake Chamo and Abaya (Arba Minch).

From the PRA and discussion with key informants, the major problems of Lake Hayq fisheries have been identified and pairwise ranking was done (Table 6.5). Based on this result, major problems were identified and their solutions were proposed. The three major factors for the reduction of fish production of Lake Hayq especially for stunt growth of Nile tilapia were use of narrow sized mesh size of gillnets, fishing during the breeding season and at the breeding ground, and destruction of macrophyte which are used for feeding, breeding, refuging for the fingerlings and also threat the pollutants entering the lake.

Table 6.5: Major constraints of fisheries of Lake Hayq and proposed solution suggested by key informants and triangulated by the researcher

Constraints	**Rank**	**Causes**	**Proposed solution**
Destruction of macrophytes	3	Absence of breeding ground	Protecting and replanting macrophytes
Fishing during the breeding season and at the breeding ground	2	Overfishing beyond MSY (Maximum Sustainable yield)	Close the season and ground properly
Lack of support from the government	9	Poor fishery management system	Implementation of the fishery proclamation, creating more jobs to minimize the fishing pressure
Narrow sized gillnet of mesh size 4-6 cm	1	Small sized fish	Gillnet of mesh Size > 8cm
Lack of other fishing ground	8	High fishing pressure	Expansion of aquaculture Looking for nearby riverine fishery (Mille)
Invasive aquatic weed	5	Hinders the baby fish movement	Mechanical removal of the aquatic weeds
Point and nonpoint source of pollution	10	Degrade water quality	Integrated waste management
Sedimentation	6	Destruct fish breeding ground and kills fish eggs, larvae and baby fishes	Integrated watershed management
Open access	7	Fish Stock collapse	Establish community-based fishery management and Lake Association
Common carp invasion	4	Competition for food	Introduction of more catfish and Nile tilapia to balance the ecological competition with common carp

6. 4. Discussion

6. 4. 1 Fishing activities

The fishing activities in Lake Hayq is being done using traditional boats made of bamboo and gillnets of mesh size that ranged from 4 to 6 cm (monofilaments which are brought from Egypt). All fishermen of Lake Hayq are using these monofilaments (gillnet, 4-6 cm mesh size). The fishermen of Lake Hayq said that the reduction of the Nile tilapia fish population and stunted growth might be associated with the introduction of these monofilaments which is in agreement with the situation observed in Lake Tana (Shewit Gebremedihin *et al.*, 2018) and Lake Ziway (Lemma Abera, 2017). The fishing pressure is very high, especially for Nile tilapia. Fishermen capture fish both at night (setting the net overnight) and day time (chase and trap). The average age of fishermen was in the working force range (< 65 years) that has its own impact on resource extraction from the lake. Unlike other bigger lakes such as Tana, Ziway, Abaya, Chamo, there are no modern boats to be used for fishing purposes which might be associated with cost-benefit analysis.

6. 4. 2. Socioeconomic importance of fisheries

According to Tehulederie district Agriculture and Rural Development office (2018), about 405 fishermen are living in seven kebeles (02, 2, 5, 012, 015, 017, and 027) surrounding Lake Hayq. The average family size of fishermen was 3 and about 1215 individuals depend directly on fisheries of Lake Hayq. Some of the fishermen that have additional income sources such as crop and animal farming have better fish consumption habits that help them to balance their nutrition. Unlike fisheries of Lake Tana and Rift valley lakes, fisheries of Lake Hayq are fully controlled by males from production to marketing (Lemma Abera, 2017; Aschalew Yirga *et al*, 2016). Fisheries could be the source of employment, nutrition, and food security in Ethiopia if the sector is well developed and get recognition from the government (Selamu Abraham and Lelise Mitiku, 2018).

In Lake Hayq the demand for fish is uniform throughout the year. This is, in contrast to the situation in other lakes. For example, there is high demand during March – April, and August (fasting season) in Lake Babogaya (Lemma Abera, 2015).

6. 4. 3 Demand and supply of fishes

Currently, the fish production status of fishermen of Lake Hayq is very low compared to the demand for fishes by the people visiting Lake Hayq and getting services at lodges near the lake and for hotels that have specialized in fish dishes. From the interview made with Hotels, recently they couldn't get enough fish from fishermen and fish traders, hence they are purchasing Nile tilapia from Bahir Dar and Arba Minch (about 30- 50 kg of per day with a price of 70-180 ETB). The price of fish becomes very expensive during the fasting season especially Nile tilapia purchased from Arba Minch and Bahir Dar. However, there is no significant variation of the price for fish caught from Lake Hayq, because demand is uniform throughout the year.

6. 4. 4. Impact of fishing pressure on Nile tilapia

The intensive fishing on target fish species (*O. niloticus*) using illegal fishing activities, utilization of gillnet with 4-6 cm (monofilaments), fishing during the breeding season, and ground might cause depletion of Nile tilapia and decline of *O. niloticus* stock in Lake Hayq. In agreement with this study, Ojuok *et al*. (2007), N'sibula *et al.* (2010), Lemma Abera *et al*. (2018), and Sandun *et al.* (2018) have reported that intensive fishing selectively on target fish (*O. niloticus*), and illegal fishing such as fishing before the onset of maturation, fishing during the breeding season and at the breeding ground and fishing using very narrow sized gillnet might reduce the size at first maturity, the dominance of very small-sized fish population (95%) and early maturation. Because excessive fishing mortality (fish under stress) might increase reproduction effort, allocation of more energy for reproduction than somatic growth, r-selected life history strategy to survive stressful conditions.

Contrary to this study, Jackson *et al*. (2009) reported that fishing pressure may reduce intraspecific competition because fishing induces a reduction in population density of target stock and lead to increased yield because of reduction in intraspecific competition that release populations from density dependence resulting in faster growth and early maturation. Wolff *et al*. (2015) reported that the use of small-sized gillnet may promote sustainable fish production allowing a higher proportion of the spawning biomass to remain in the stock.

6. 4. 5. Awareness of fishermen about fishery management regulatory acts

Most of the fishermen of Lake Hayq have awareness about the Fishery Development and Utilization Proclamation ratified by the Ethiopian Federal Government (Proclamation No.315/1995) and the Amahara National Regional state Fisheries Development, Prevention and Utilization Proclamation No.92/1996) and the Amhara National Regional state Fisheries Development, Prevention and Utilization Proclamation Enforcement (Proclamation NO.50/1999). However, the implementation is very poor which is a similar problem in other Ethiopian lakes such as Lake Koka (Gashaw and Wolff, 2014), and Ziway (Lemma Abera, 2017).

6. 4. 6. Institutional support for sustainable utilization of fisheries

Currently, Haik Agricultural Research Sub-Center is involved in fishery stock assessment data collection. Wollo University conducts some basic research on fish biology and limnology of Lake Hayq, and community services, training for fishermen, and construction of some dust bins near lodges. Tehulederie District Agricultural Office is active in watershed management efforts to restore Lake Hayq. In addition to these efforts, Wollo University in collaboration with Ecohydrology Project has approved Lake Hayq Restoration Project and is working in two phases, Baseline data collection (Phase I) which is completed, and phase II (restoration of Lake Hayq and its watershed) is planned.

Bahir Dar Fish and Other Aquatic Life Research Center and Wollo University have organized a one day National Conference on June 1, 2013, with the objective to restore Lake Hayq and its fish fauna (Nile tilapia). During the conference, about 18 stakeholders were identified. Moreover, a task force entitled **‘’South Wollo Lakes Resource Management Task Force’’** was established. However, most of the stakeholders identified are not actively participating in the restoration of Lake Hayq.

6. 4. 7. Challenges on fisheries of Lake Hayq

Fisheries of Lake Hayq has faced several challenges, which include illegal fishing activities (overfishing, narrowed sized gillnet (monofilaments), fishing during reproduction and at breeding ground), destruction of macrophytes and the buffer zone, siltation, catchment degradation, land use and land cover change, expansion of invasive weed (*Ceratophylum submersum*), less support from the government and poor implementation of the fishery regulatory acts and proclamations. The present study was in agreement with what has been studied for Lake Tana (Erkie Asmare *et al*., 2016; Shewit Gebremedihin *et al.*, 2018). The present study also agrees with Mathewos Temesgen and Abebe Getahun (2016) and Selamu Abraham and Lelise Mitiku (2018) who reported about challenges of Ethiopian fisheries.

The result of the present study also was in line with Njiru *et al.* (2010) and Yongo *et al*. (2018) who reported similar challenges for Lake Victoria, and Njeru *et al*. (2017) for Lake Naivasha where overexploitation, use of illegal fishing gears and poor enforcement of regulations, pollution, catchment degradation, poor waste disposal were responsible for the overall decline in size at first maturity of *O. niloticus*. Fishing during spawning season may affect biology (physiology, behavior, and ecology) of fishes and may increase evolutionary effects on maturation and reproductive investment and risk of overexploitation of specific spawning components (Harrie¨t *et al*., 2014).

Chapter 7: General conclusions and recommendations

7. 1. Conclusions

This study addressed physicochemical water quality parameters, phytoplankton and zooplankton composition and abundance, diversity, distribution and relative abundance of fishes, some aspects of reproductive biology, length-weight relationships and condition factor of *C. carpio* and *O. Niloticus*, food and feeding ecology of *C. carpio* and *O. niloticus*, socioeconomic importance of fishes and the impact of fishing activities on *O. niloticus* in Lake Hayq. In this chapter, the main findings are summarized and recommendations are forwarded.

- The first study stated in chapter II investigated about spatiotemporal variability of physicochemical water quality parameters and phytoplankton and zooplankton community structure. Though variability in DO and water temperature was observed between sites and season, most of the parameters did not show variability that showed the lake is stable. The physicochemical water quality parameters trend in the last one decade was not changed which could be associated with less variability in climatic variables (rainfall and atmospheric temperature) and the higher depth of the lake. The depth profile data in Lake Hayq showed that the water temperature difference along the depth profile was less than 1 °C indicated the absence of stratification in the lake. The concentration of algal nutrients especially TP and SRP and Chl-*a* were lower in the present study as the result Lake Hayq is Mesotrophic. The number of phytoplankton and zooplankton taxa was higher in the present study; however, their density was lower which might be associated with lower nutrient concentration and higher grazing effect from *C. carpio* invasion. The phytoplankton species composition was dominated by green algae and diatoms. In terms of numerical abundance, *Peridinium* followed by diatoms were with the highest number in most of the sampling season and sites. The higher abundance of both taxa might be associated with atelomixis (partial or incomplete mixing) of the lake. *Peridinium* has special adaptation such as the presence of flagella and mixotrophic feeding habits to tolerate the harsh environmental conditions during partial mixing. Diatoms have a silica cell wall to tolerate the impact of atelomixis. The higher concentration of silica in the present study might have also contributed for higher abundance of diatoms. Lake Hayq was dominated by rotifers which might be also associated with partial mixing condition and lower grazing pressure from Copepods resulted from their lower density.

- The second study stated in chapter III investigated about fish diversity, distribution, and relative abundance of fishes of Lake Hayq. Lake Hayq harbors four fish species, *G. dembecha*, *C. gariepinus*, *O. niloticus*, and *C. carpio*. Small sized *C. carpio* and all stages of *O. niloticus* preferred the shore of the lake which could be associated with searching for suitable refuging and feeding habitat. The Shannon diversity index was less than 1 in most of the sampling months indicated that less fish diversity in the lake. Based on the index of relative abundance, *C. carpio* was numerically abundant followed by *O. niloticus* indicated that *C. carpio* becoming dominant fish in the lake. Most of the physicochemical parameters and algal nutrients were positively correlated with the abundance of the three commercially important fish species at the shore of the lake that indicated the shore is better habitat than the other portion of the lake.

- The third study stated in chapter IV investigated about some aspects of reproductive biology, length-weight relationships, and condition factor of *C. carpio* and *O. niloticus*. The length-weight relationships in *C. carpio* in both female and male were nearly isometric growth indicated that both length and weight grow equally that showed normal condition. However, the length-weight relationship in *O. niloticus* in both females and males was negative allometric growth patterns indicated that the growth condition was not good. The Fulton condition factor of *O. niloticus* was lower indicated that the fish was not in good condition. The lower absolute fecundity, a smaller number of females, and the smallest length at first maturity of *O. niloticus* indicated that they have stunted growth. The L_{50} values of common carp and Nile tilapia were smaller which might be associated with illegal fishing activities, and narrow-sized gillnets of mesh size of 4–6 cm. Both *C. carpio* and *O. niloticus* in Lake Hayq have similar peak breeding season between February and April which might have competition for resources and resulted in the stunted growth of *O. niloticus*.

- The fourth study stated in chapter V investigated about food and feeding ecology of *C. carpio and O. niloticus*. Both *C. carpio* and *O. niloticus* are omnivorous in Lake Hayq feeding on both animal and plant-based food items. At the smaller stage, both fish species feed on the same kinds of food items (zooplankton, insects, and phytoplankton) and live together at the shore of the lake, unlike adult *C. carpio* that prefer the deeper part of the lake. Therefore, dietary overlap and competition for habitat could be one of the factors for the current stunted growth of *O. niloticus* in Lake Hayq.

- The fifth study stated in chapter VI investigated about socioeconomic importance of fishes and the impact of fishing activities on *O. niloticus*. Despite the presence of fishery regulatory acts (Federal and Regional Fishery Development and Utilization Proclamations), the fishing activities in Lake Hayq are illegal, all the fishermen are using illegal fishing gears (monofilaments or gillnets of mesh size of 4-6 cm), they fish during breeding season and ground, and there is no fishermen association. As a result of these activities, the fishery production of Lake Hayq is decreasing from time to time, and fishermen have changed professions and migrate to Arabian Countries. The population of the Nile tilapia has significantly reduced and dominated by stunt sized population that mature at a small size (smallest size at first sexual maturity, nearly 13 cm).

7. 2. Recommendations

From this PhD research conducted in Lake Hayq on physicochemical water quality parameters, phytoplankton and zooplankton community structure, fish species diversity, distribution, relative abundance, food and feeding ecology of common carp and Nile tilapia, socioeconomic importance and Impact of fishing on Nile tilapia population, the following recommendations are forwarded

- The trophic status of Lake Hayq changed from eutrophic to mesotrophic that has its own impact on food availability, Therefore, long term monitoring system for limnological variables should be designed.

- The best place for small sized *C. carpio* and all stages of *O. niloticus* is the shore of the lake. However, the intensive agricultural activities in the shore of Lake Hayq has being caused degradation of this habitat. Therefore, the shore of the lake should be protected.

- The mesh size of the gillnets should be regulated sets at least to 8 cm, which is the national standard. Furthermore, both fishes, common carp and Nile tilapia have extended spawning seasons in Lake Hayq (February–April) with peak spawning season in April. Therefore, these intense breeding months should be used for closing seasons (no fishing activities) as one of the most important fishery management tools. Long-term monitoring on reproduction potential, spawning season, and population status of common carp and Nile tilapia should be done for sustainable fishery utilization of Lake Hayq.

- Diet over between *C. carpio* and *O. niloticus* was observed at the smaller size of the two fish species that prefer the shore of the lake. To minimize this competition, the shore of the lake should be protected through restoration of macrophytes such as *Typha latifola* species.

- To restore the fishery of Lake Hayq especially Nile tilapia, re-introduction of Nile tilapia and closing of the Lake at least for two years should be implemented. For successful implementation of these efforts, responsible stakeholders, fishermen, Tehulederie District Agricultural Office, Haik Agricultural Research Sub-Center, Wollo University, and Ecohydrology Project should work hard in creating other sources of livelihoods for the fishermen until the restocked Nile tilapia is well established.

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9. Appendices.

Appendix 1. Questionnaires used for Socio-economic Survey data collection

1.1 Questionnaires for Fishermen

Date____

Region _______ Zone ________District ______ Kebele _______

Name of Enumerator ___________________________________.

1. Age of Fisherman _____Sex of Fisherman____________________

2. Educational Background ___ A/ illiterate B/ Basic C/ Elementary D/Secondary E/Higher

3. Marital status______ A/Single B/Married C/ Divorced

4. Total number of family?___________

5. Source of Income____ A/ Animal farming B /Crop farming C/Mixed farming D/fishing E/ All F/ Other

6. When did you start fishing?_________________________

7. Type of fishing gear you use ____ A/Gillnet B/Hook C/ Fyke net D/Other

8. If you use Gillnet, what is the size of the mesh size of the gillnet?__________

   A/ < 8cm B/ 8cm C/ 10 cm D/ 12 cm

9. Types of fish You Fish

____

____

10. Which types of fish do you fish more?

____

____

11. Which type of fish do you prefer to eat?__________________________

____

12. When do you fish more fish within a year? Which type of fish?

____?

13. Price of each fish?

____

____

____

____

14. The trend of fish production_____ A/ Increasing, B/ Decreasing C/No change

15. Which fish species catch is dominant? _________

A/ Common carp B/ Nile tilapia C/ Catfish

16. When do you think common carp appears in Lake Hayq?_____________________________

17. Do you think common carp has a negative effect on other fish species?_________

A/ Yes B/No

18. If your answer to Q19 is yes, which fish species is being highly affected? ________________
Why?________________

19. The trend of fish Price - A/ Increasing B/Decreasing C/ No change

20. Do you use post-harvest technology?____________ A/ Yes B/ No

21. If you use Post harvest technology , mention techniques you use
____
____

22. Income generated from fishing in ETB? _____________________

23. What are the major problems to stay in this occupation? ________________________________?

1. 2. Questionnaires for traders

Date____

Region _______ Zone ________District ______ Kebele _______

Name of Enumerator ___________________________________.

1. Age of respondent___________________________

2. Sex A/Male B/Female

3. Where do you buy fish? ________________________________

4. Which type of fish species do you buy?

5. Which form of fish do you buy______________? A/ whole fish B/Processed

6. Price of Tilapia

A/Whole fish_______________________

B/Filleted__________________________

C/Dressed_________________________

D/Gutted __________________________

7. Price of catfish

A/Whole fish_______________________

B/Filleted__________________________

C/ Dressed_________________________

D/Gutted __________________________

8. Price of Common carp

A/Whole fish_______________________

B/Filleted__________________________

C/ Dressed__________________________

D/Gutted ___________________________

9. Which fish species and fish form do you buy more?_____________________________________

10. Is there a relation between season of the year and fish supply? A/Yes B/No

11. Where do you sell your fish ?___________________________________

12. Market distance in Km or hours it takes ____

13.Net profit from each fish per Kg or number ____

14. Net profit from fish trading per month____

15. Do you have other income source? A/Yes B/No

16. Is there any support from GOS and NGOs? _____________ A/Yes B/ No

17. What are the challenges in fish trading?____

18.What type of solution do you suggest? ____?

1. 3. Questionnaires for Hotel Owners

Date____

Region _______ Zone ________District ______ Kebele _______

Name of Enumerator ____________________________________.

1. Age of respondent___________________________

2. Sex A/ Male B/ Female

3. Do you prepare fish dish? A/ Yes B/No

4. From where do buy fish? A/ Fishermen B/ Fish shop C/ market

5. Which fish type do you buy? A/ Tilapia B/ Catfish C/ common carp D / all

6 Which form of fish do you buy? A/ Whole fish B/Filleted C/Dressed D/Gutted E/all

7. Price of Tilapia in Kg

A/ Whole fish_______________________

B/ Filleted__________________________

C/ Dressed_________________________

D/ Gutted __________________________

8. price of catfish

A/Whole fish_______________________

B/Filleted__________________________

C/Dressed_________________________

D/Gutted __________________________

9. Price of Common carp

A/Whole fish_______________________

B/Filleted___________________________

C/Dressed__________________________

D/Gutted ___________________________

10. Which type of fish dish do you prepare? ____

11. Price of each dish you prepare?____

12. Which fish type consumer prefer to consume most? ____

13. Which season of the year do you access more fish?_______________________________________

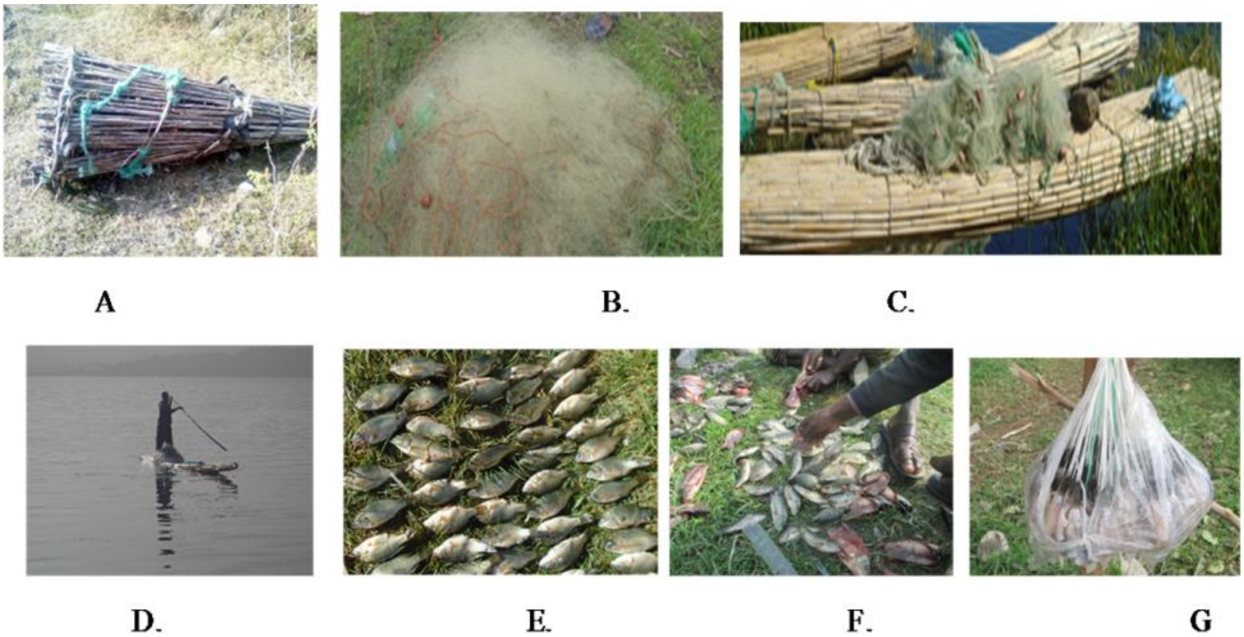
14. What is challenges associated fish business in your hotel?

____

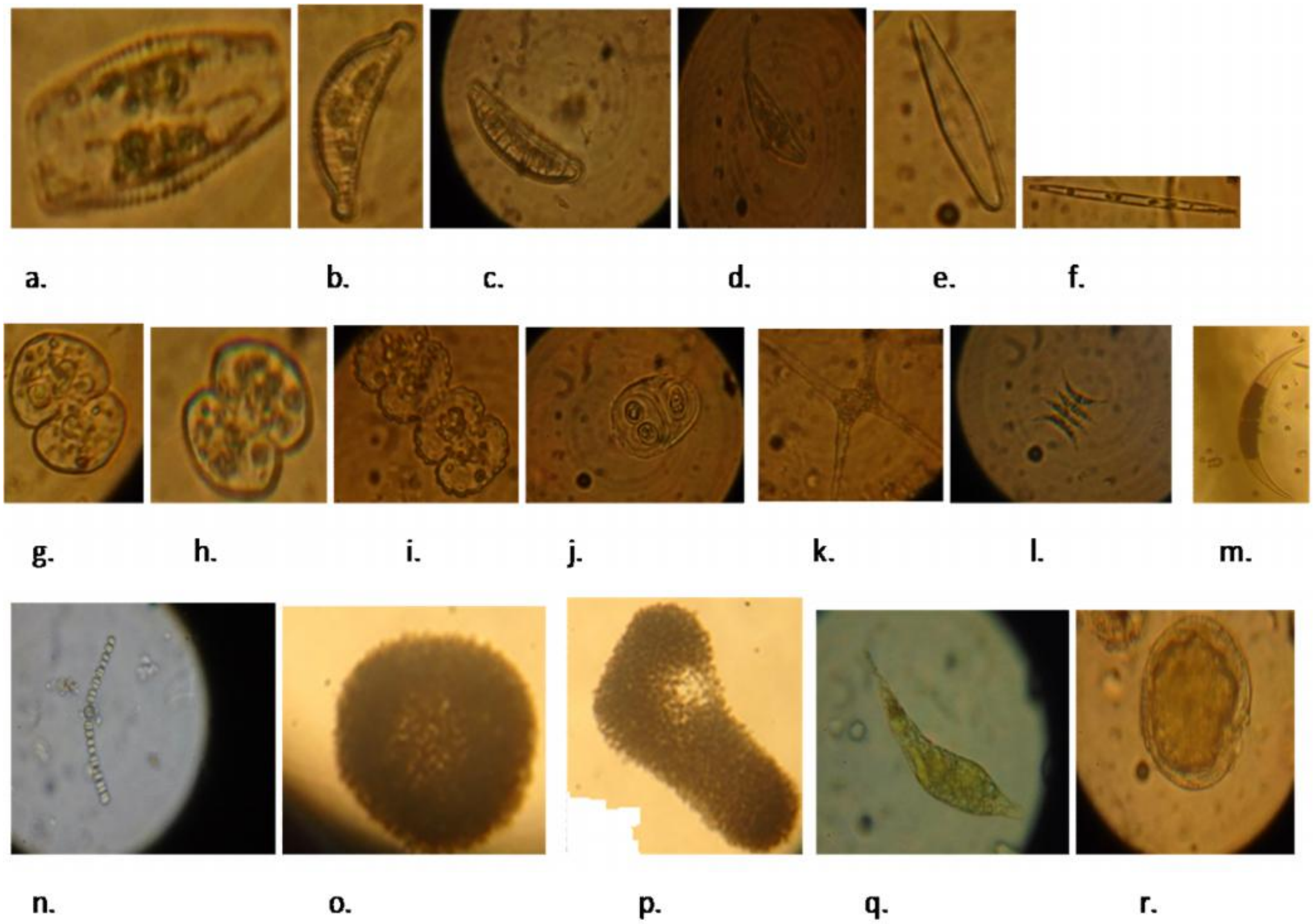
____

15. What type of solution do you suggest? ____

Appendix 2. Fishing activities in Lake Hayq, Fishing gears (A, Cage, B, Monofilaments and C, the fishing boat (made of bamboo) and D, fishing with the boat, E, Nile tilapia production, F, fish filleting activities and G, Filleted fish ready for sale.



Appendix 3: Some representative phytoplankton species in Lake Hayq, **Bacillariophyta** (a *Rhopalodia Sp*., b, *Epithemia sorex*, c, *Epithemia adnata*, d, *Cymbella Sp*. e, *Gonphonomia Sp*., f, *Nitzschia*), **Chlorophyta** (g-I, *Cosmarium Sp*. j, *Oocyst Sp*., k, *Straustrum uplandicum*, l, *Scenedesmus* sp., m, *Closterium*), **Cyanophta** (n, *Anabaena Sp*., o, *Microcyst flosaquae*, p, *Microcyst aeruginosa*), **Euglenophyta** (q , *Euglena Sp*.,), and **Dinophyta** (r, *Peridinium Sp*.)



Appendix 4: Some representative zooplankton species in Lake Hayq, **Cladoceran** (a *Ceriodaphinia cornuta*, b, *Moina micrura, C, Diaphanosoma excism*, **Copepods** (d, *Napuli*, e, *Mesocyclops aequatorialis*, f, *Thermocyclops ethiopiensis*), **Rotifers** (g, *Lepadella Sp*. h, *Anuraeopsis navicul, i. Branchionus calyciflorus*, j, *Brachionus quadridentatus*, k, Bdelloids *Sp*. l, *Trichocera pusilla* and m, *Keratella tropica*)