Fish biology and fishery management of commercial stocks in a tropical rift valley lake, Lake Langeno, Ethiopia

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A dissertation submitted to the Department of Zoological Sciences, Addis Ababa University in Partial Fulfillment for the Requirements of the Degree of Doctor of Philosophy in Biology (Fisheries and Aquatic Sciences)

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Status and trends of fish and fisheries in a tropical rift valley lake, Lake Langeno, Ethiopia"

By

Mathewos Temesgen

A Thesis Presented to the School of Graduate Studies of the Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Biology (Ecological and Systematic Zoology)

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DEDICATION

This Dissertation is dedicated to my family and my beloved wife Obse Fikiru for their outstanding guidance, motivation and helped me to achieve my vision with the help of God. I also dedicate it to my daughter Soni Mathewos, and my son Kena Mathewos, for their unreserved love and affection.

STATEMENT OF THE AUTHOR

I hereby affirm that this Dissertation "**Fish biology and fishery management of commercial stocks in a tropical rift valley lake, Lake Langeno, 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 (Fisheries and Aquatic Sciences) 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 acknowledgements 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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ABSTRACT

The study of status and trends of fish and fisheries in Lake Langeno (also known in the literature as Langano), Ethiopia was conducted from March 2014 to February 2016. The basis for this study was that fish stocks were subjected to uncontrolled fishing over many years and available data on the status and trends of fishes in the lake has become unreliable for management and sustainability of the sector. In order to examine the diversity, habitat preference and seasonal distribution, spatial and seasonal data were collected from six different sampling sites by using gillnets of various mesh sizes and long lines. Data were analyzed by Canonical Correspondence Analysis (CCA), SPSS software and by various descriptive statistics. The results indicate physico-chemical parameters showed no significant spatial variation, but high seasonal variation. A total of seven fish species dominated by family Cyprinidae were identified (H'=1.264). *Carassius carassius*, was not reported in previous studies, now comprise 0.64% of the total collected specimens. All the fish species were collected from all of the sampling sites, except at one site (Middle), where *Carrasius carassius* and *Garra dembecha* were absent. Index of relative importance (IRI) was essentially similar for all the sampling sites, but differed in the relative importance of each species with the high importance of *Oreochromis niloticus*. Principal Component Analysis (PCA) did not produce distinct habitat-associated species patterns across the sampling sites. However, temperature and depth seemed to be the key environmental factors determining fish community structure in the lake. The results showed that the composition of the fishes has undergone some changes during data collection from what was reported in the literature. The Length-weight relationships of *O. niloticus*, *E. paludinosus*, *C. gariepinus*, *L. intermedius* and *C. carpio* were curvilinear (b=2.872, 2.554, 2.823, 2.771 and 2.919, respectively), and statistically significant ($p>0.05$) except for *Enteromius paludinosus*. For both sexes, the mean Fulton Condition Factor values of *Oreochromis niloticus*, *B. paludinosus*, *Clarias gariepinus*, *Labeobarbus intermedius* and *C. carpio* were 1.77±0.37, 1.06±0.44, 0.60±0.5, 1.33±0.44 and 1.47±0.83, respectively. A better body condition was recorded in the dry seasons for all species except for *O. niloticus*. All fish species had relatively smaller maximum size and poor body condition than what was reported for fishes in most of the Ethiopian water bodies. Females were more abundant than males for all fish species, and the sex ratio of *O. niloticus* (1.13:1)and *E. paludinosus* (1:.24:1) was significantly different from the hypothetical distribution of 1:1 (χ^2, $p<0.05$. The identified peak breeding time was April-June, May-July, June-July and March-May for *O. niloticus*, *C. gariepinus*, *L. intermedius* and *C.*

carpio, respectively. Their respective length at L_{50} for females and males during these breeding times were 16.4 cm & 15.8 cm TL, 28.5 cm & 29.5 cm TL 30.5 cm & 29.5 cm FL and 28.2 cm & 27.6 cm FL. The mean fecundity of these fish species were 463.83±114, 141,466±40,982, 3,055±2,234 and 105,631±46,680, respectively. The results also showed significant seasonal variations of GSI for all fish species (ANOVA, P< 0.05). In addition, seven food items, namely phytoplankton, zooplankton, insects, detritus, macrophytes, fish parts and nematodes were identified from the stomach contents of *O. niloticus*. Phytoplankton was the main food grazed followed by detritus, zooplankton and macrophytes. The other food items were occasionally and randomly consumed. The volumetric contribution of these food items showed high variation in the study months (p<0.05). Phytoplankton and detritus were the dominant food items in the dry season and zooplankton and macrophytes were the highest in the wet months. The contribution of phytoplankton, zooplankton and insects were slightly high in small sized groups (<10 cm), whereas detritus, macrophytes and fish parts were the highest in larger size groups (>20 cm). Generally, food items of plant origin dominated the stomach contents, typically associated with less protein content than food item of animal origin. The result also showed that the lake supported small-scale beach seine fishery for small income generation and alternative employment opportunity of fishermen. The catch composition was dominated by *O. niloticus* (87.58%) followed by *C. gariepinus* (5.89%). Fisheries value chain was also developed and major related issues were addressed, fishers' perceptions about the resources condition and management status were identified and discussed. Generally, the total annual fish production from the lake was estimated to be 1,137.67 tonnes/ year, and the mean gross annual revenue was about 8,622,158 ETB. Extrapolation of annual production and annual revenue from the sector showed a significance variation among the landing facility owners and those that do not have landing facilities (ANOVA, p<0.05), and between the fulltime and part time fishermen (ANOVA, p<0.05). The estimated annual per capita consumption of fish/ person was about 23.65 kg. The majority of the fishermen had positive attitude towards the fish resources, but due to lack of knowledge and follow up, the current harvest system and fishing methods put these resources at risk. Therefore, appropriate management action should be in place in order to sustain the fish resources in Lake Langeno.

Key words: *Fish; Fishery; Fish biology; Ethiopia; Lake Langeno; Feeding habits; Fish reproduction; Length-weight relationship*

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ACRONYMS AND ABBREVIATIONS

ACP	Africa Caribbean and Pacific
ARIMA	Auto regressive Moving Average
CMA	Central Moving Average
CSA	Central Statistical Agency
DCA	Detrended Correspondence Analysis
DO	Dissolved Oxygen
FCF	Fulton condition factor
FL	Fork Length
GII	Geometric Importance Index
GSI	Gonado Somatic Index
IP	Index of preponderance
IRI	Index of Relative Importance
ITCZ	Inter-tropical Convergence Zone
LFDP	Lake Fishery Development Project
LWR	Length-weight relationship
MANOVA	Multivariate analysis of variance
MoARD	Ministry of Agriculture and Rural Development
MoLF	Ministry of Livestock and Fishery
OFSDPPC	Oromia Food Security Disaster Prevention and Preparedness Commission
PCA	Principal Component Analysis
RDA	Redundancy Analysis
RMS	Recommended Mesh Size
SL	Standard Length
SSA	Sub-Saharan Africa

SWDI	Shannon-Weiner Diversity Index
TL	Total Length
TW	Total Weight
ZFRRC	Zeway Fishery Resources Research Center

TABLE OF CONTENTS

Contents **page**

LIST OF TABLES

Contents pag

LIST OF FIGURES

Contents pag

CHAPTER ONE

1. GENERAL INTRODUCTION

1.1 Background of the study

Providing adequate food for rapidly increasing human population is one of the greatest challenges in the world (FAO, 2016). The problem is acute in developing countries, where population growth, natural and manmade calamities have aggravated the problem (Arthur*et al.,* 2013). Small-scale agriculture, livestock husbandry and fisheries are the major livelihood activities for the people living near aquatic environments (Castine *et al*., 2013). To meet the demand of many people, over 4,000 species of aquatic animals approaching 120 million metric tonnes including fish are being harvested annually both from natural and man-made aquatic environments worldwide (Lackey, 2005). Freshwater ecosystems support a large number of these aquatic diversities, which are essential for human life (Dudgeon *et al*., 2006). Fish comprises about 13-15% of the 100,000 freshwater animal species currently known (FAO, 2010).

Fish is providing around 15% of the animal protein for about 4.3 billion people in the world (Villaprudente, 2012). Currently, it is the fastest growing source of food, where 89% of the production by volume is from Asia (FAO, 2010). In Sub-Saharan Africa (SSA), fish and fishery related activities are serving as a means of life directly or indirectly for more than 40 million people engaged in the sector (Tacon and Mentia, 2009). It is contributing about 25% of the total annual animal protein supply in the region (FAO, 2010; Tacon and Mentia, 2009). Perhaps, over 60% of the supply comes from artisanal fisheries for both domestic and international markets (FAO, 2010; Mohammed and Uraguchi, 2013).

Each continent has its own distinctive diversities of fish fauna (Leveque *et al.,* 2008). Tropical and subtropical regions encompass the greatest number of fish diversities due to the accessibility and suitability of water bodies throughout the year (Revenga and Kura, 2003). Moreover, fish species are extremely diverse in tropics, and these diversities are not fully characterized (Leveque *et al.,* 2008). However, there is an overall reduction in diversity towards the temperate and polar regions (Potts *et al.,* 2015).

Aquatic environments variability is the greatest challenge to assessing the biological consequences of fishery management options, such as adjusting harvest level, changing gear regulations, or placing a moratorium on fishing (Lackey, 2005). Operation of fishing gears within different frameworks, implementation of their guidelines and their management system are also other challenges being observed (Villaprudente, 2012). In addition, human interaction with freshwater ecosystems for the pursuit of profit is altering the ecological structure and function of aquatic biota (Benejam *et al*., 2010). The harvesting trends and fishing conditions also put the attributes of the fishery industry at risk (Garrity, 2010). Climatic and water level changes are also altering the productive capacity of aquatic environments over the long-term (Jalal *et al*., 2012).

Ethiopia is the second most populous country in SSA, which has more than 104 million people living in it, and has one of the fastest-growing economies in the world (Selamta, 2018). The foundation of its economy is agriculture, which employs more than 80% of the population (Burney *et al*., 2014; Berara Endalew *et al*., 2015). The ecological diversities and climatic variation of the country is largely explained by its high variation in topography (Yilma Delelegn and Geheb, 2003). With the high variability of its geological formations and climatic condition, Ethiopia is endowed with considerable water resources and wetland ecosystems (FAO, 1995; Gashaw Tesfaye and Wolf, 2014). More than 20 natural lakes, 12 large river basins, over 75 wetlands, and 15 manmade reservoirs are found scattered in the country (Alayu Yalew *et al*., 2015). There is an estimated 7,334 km^2 of major lakes and reservoirs, 275 km^2 of small water bodies and 7,185 km length of rivers in Ethiopia (Gashaw Tesfaye and Wolf, 2014). Minor water bodies, such as crater lakes and reservoirs also make up about 400 km^2 (Mebrat Alem, 1993; Tesfaye Wudneh, 1998). These water bodies are supporting a diverse aquatic life including different fish species, which is estimated to be more than 200 species (Golubtsov and Darkov, 2008; Redeat Habteselassie, 2012). Despite having these resources, food security is still a big challenge in the country. Nearly one third of the population lives below the poverty line, and majority of them are relying on subsistence agriculture for their livelihood (Berara Endalew *et al*., 2015; Burney *et al*., 2014). About 10% of Ethiopians are chronically food insecure, and this figure rises to more than 15% during frequent drought years (Burney *et al.,* 2014). Thus, fish resources could undoubtedly offer one solution to the problem of food shortage in the country (Asefa Mitike, 2014; Gashaw Tesfaye and Wolf, 2014).

Ethiopian rift valley is characterized by a chain of lakes and wetlands, with unique hydrological and ecological characteristics (Hengsdijk and Jansen, 2006). It consists of three major drainage basins from Northeast Ethiopia to Southwest Ethiopia. These are: Awash River drainage basin in the north (includes Koka Reservoir, L. Beseka, L. Gemari and L. Abhe), central Ethiopian rift valley basin (Zeway-Shalla Basin) and southern rift valley basin (Lake Hawassa, Lake Abaya, Lake Chamo, Lake Turkana and Lake Chew-Bahir) (Tamiru Alemayehu *et al.,* 2006). Chew Bahir basin, Lake Turkana and lower reaches of Omo River are found in between the northern Ethiopian rift valley and Kenya (Tadlo Awoke, 2015) (Fig. 1.1). Very interesting feature of the northern and central part of the Ethiopian rift valley is the existence of open and closed lakes situated within the large depressions (Kassaye Bewketu, 2015). However, the increasing population and expansion of irrigation projects are putting pressure on these lakes (Kassaye Bewketu, 2015; Tenalem Ayenew, 2004).

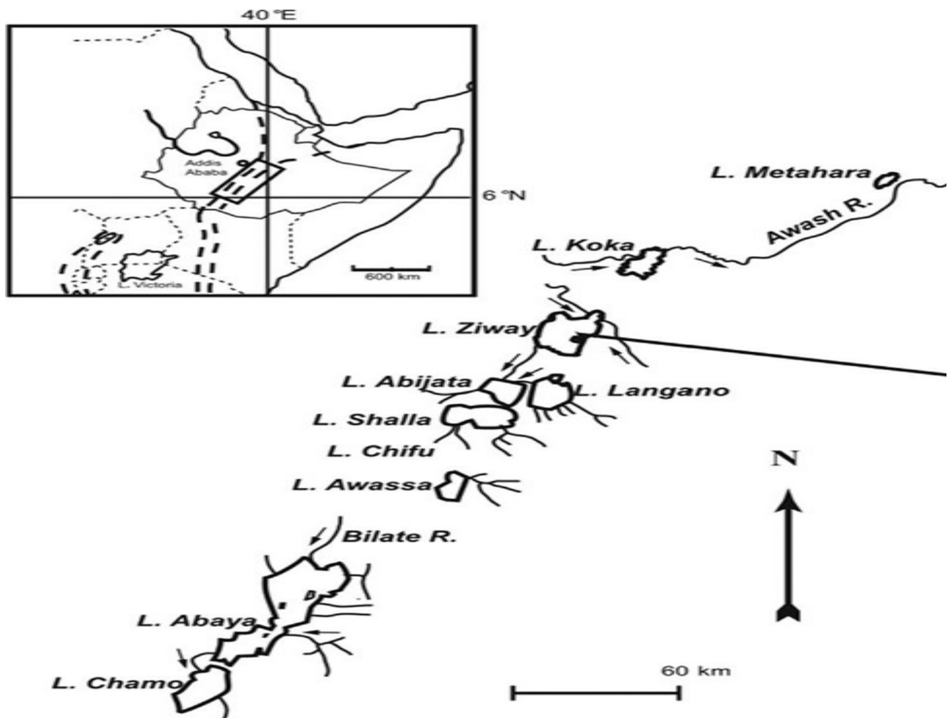


Figure 1.1: Distributions of Ethiopian rift valley lakes (Girma Tilahun and Ahlgren, 2010).

The fish fauna of the Ethiopian rift valley and Awash River basin is characterized by a lower number of species diversity as compared to all other basins (Golubtsov *et al*., 2002; Golubtsov and Mina, 2003; Vijverberg *et al.,* 2012). This could be due to the physical isolation of the rift valley basin from each other and from the adjacent river systems, and the instability of hydrological conditions determined by the paleo-climatic fluctuations, which increase the volcanic and tectonic activities in the region (Tadlo Awoke, 2015). The fish species diversity is highest in southern part of the basin, lowest in the central part and intermediate in the northern part. The highest diversity in southern rift valley basin could be due to their former connections to the Omo-Turkana basin and White Nile system (Abebe Getahun and Stiassny, 1998; Tadlo Awoke, 2015). Currently, over 35 fish species inhabiting the northern and central portion and 22 fish species from the southern portion have been described (Golubtsov *et al*., 2002; Golubtsov and Mina, 2003). These fish species are dominated by *Oreochromis niloticus*, *Clarias gariepinus* and a few species of the family Cyprinidae, mainly *Labeobarbus* spp. (Reyntjens and Tesfaye Wudneh, 1998). In addition, rift valley basin is the region with the highest number of introduced fish species (Golubtsov *et al.,* 2002; Tadlo Awoke, 2015).

1.2 General description of the study area

1.2.1 Location and socio-demographic characteristics of Lake Langeno

Lake Langeno is one of the Ethiopian rift valley lakes located in Oromiya Regional State, between Western Arsi and East Shoa zonal administration at 200 km from Addis Ababa towards the south. It is bordered by Arsi Negelle District from the south, west and east, and by Adami Tullu Giddo Kombolcha District from the north, between $7^0$36’N and $38^0$43’E at an altitude of 1585 m above sea level. Totally, 12 peasant associations are surrounding the lake. Three of them are located in Adami Tullu Jido Kombolcha District (Hurufa lole, Habule Gutema and Hoitu Besuma), and 9 of them are in Arsi Negelle District (Deka Hora-Kelo, Deka Argemo, Hadibossa, Keraru, BukuWelda, Dawi, Simbirorogicha, Hamba Goda Sadeni and Tufa) (Fig. 1.2). The total population of the two districts are estimated at 141,405 (71,167 men and 70,238 women) and 260,129 (128,885 men and 131,244 women), respectively. Majority of the inhabitants are Muslims (82.65% and 68.86%) followed by Ethiopian Orthodox Christians (11.61% and 20.2%) in Arsi Negelle and Adami Tullu Giddo Kombolcha District, respectively, whereas Protestants is a minor religious group. Oromo (78.69%), Amhara (8.53%), Soddo Gurage (2.87%), Silte

(2.81%), and Sebat Bet Gurage (1.19%) are the five largest ethnic groups living in these two districts. Afan Oromo is the most spoken language in the two districts (CSA, 2014).

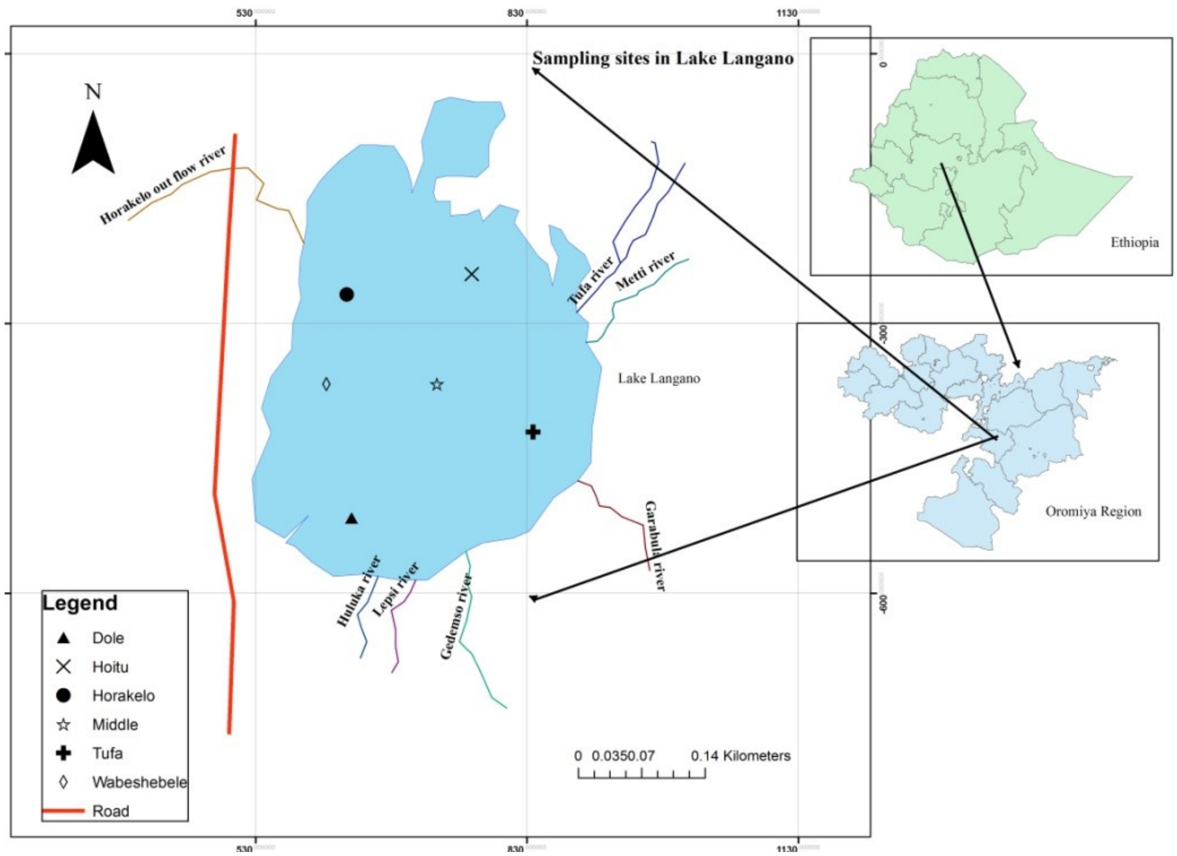


Figure 1.2: Sampling sites for collection of fish samples from Lake Langeno, Ethiopia

1.2.2 Morphology, topography and hydrology of Lake Langeno

Lake Langeno is considerably deep with about 48m maximum depth and 17m average depth. It has surface area of about 240 km^2 (Table 1.1). The eastern part of the lake is surrounded by eastern Langeno Nature Reserves known as Munesa Forest. The lake is known with only small variation of seasonal water level, which is less than 2m (Kassaye Bewketu, 2015; Tenalem Ayenew, 2001). According to Tenalem Ayenew (2001), the absence of considerable water abstraction and large groundwater inflow from the springs could be the factors for the relative stability of the lake level. However, it is affected in recent years due to the diversion of water at its feeder tributaries for small-scale irrigation in Arsi highlands (Tenalem Ayenew, 2009). Runoffs, perennial small rivers and hot springs feed the lake. The feeder rivers coming from the highlands of Arsi Mountains include Lepis, Gedemso, Garabula, Metti, Tufa and Sedesedi Rivers. On the western side, River Hora-Kelo drains Lake Langeno to join Lake Abijata (Mathewos Hailu *et al*., 2010; Lemma Abera, 2012a). From these rivers and hot springs, the inflow water volume is estimated to be about 533.4 million m^3, and outflow is about 527.9 million m^3 per year (Tenalem Ayenew, 2004).

Table 1.1: Morphometric parameters data of Lake Langeno, Ethiopia (Zinabu Gebremariam *et al.,* 2002)

Parameter	Measure
Surface area (km^2)	240
Catchment area (km^2)	1600
Length (km)	23
Width (km)	16
Maximum depth (m)	48
Mean depth (m)	17
Volume (km^3)	5.3

1.2.3 Climate

Lake Langeno region has a tropical lowland climate with high temperature. The region is characterized by a semi-arid to sub-humid climate with monthly rainfall ranging between 2 mm and 171.2 mm (Ethiopian Meteorological Agency, 2016). The area enjoys bi-modal rainfall influenced by the annual oscillation of inter-tropical convergence zone (ITCZ). The months from June to September are considered as the main rainy season, while the months from November to February are the driest season. The main rainy season accounts for 70-90% of the total annual rainfall (Kassaye Bewketu, 2015). In addition, minor rainfall, which originates from moist southeasterly winds, occurs between March and May. Monthly minimum air temperatures range from 14.32ºC to 16.69°C, and maximum air temperatures range from 24.48ºC to 31.98°C, respectively (Ethiopian Meteorological Agency, 2016) (Fig. 1.3). The weather condition of the lake region is frequently windy to stormy. Strong wind-induced water current, especially in the afternoon is a common phenomenon. The lake is highly turbid, with a Secchi depth of less than 25 cm due to suspended sediment particles and high algae composition (Kassahun Wodajo and Amha Belay, 1984). The seasonal rainfall cause the lake level to fluctuate regularly with an average difference between minimum (May-June) and maximum (September-October) lake level of approximately 2 m (Kassaye Bewketu, 2015).

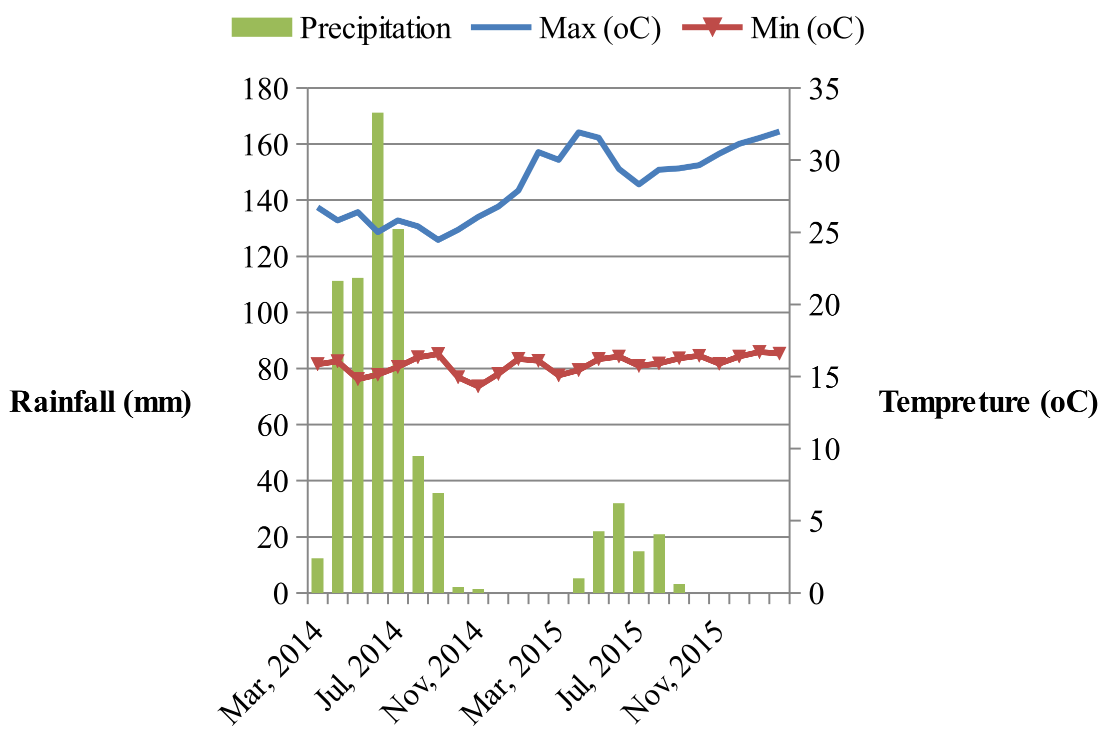


Figure 1.3: The mean monthly temperature and total rainfall of Lake Langeno area from March 2014 to January 2016 (Ethiopian Meteorology agency, 2016).

1.2.4 Water chemistry of the lake

Water chemistry of the lake is similar to other Ethiopian rift valley lakes, where Na^{+} and CO_3^{2-} are the dominant cations and anions, respectively (Kassahun Wodajo and Amha Belay, 1984; Zinabu Gebremariam *et al.,* 2002). The color of the water is reddish brown due to high colloidal suspension of inorganic silt, which reportedly contributed 94-98% of light attenuation (Kassahun Wodajo and Amha Belay, 1984). The mean conductivity of the lake is about 1632 μScm^{-1}. Salinity of the lake is also high about 9.4 g L^{-1} (Zinabu Gebremariam *et al.,* 2002) (Table 1.2).

Table 1.2: Physico-chemical features of Lake Langeno, Ethiopia (Elizabeth Kebede *et al.,* 1994; Zinabu Gebremariam *et al.,* 2002).

Physico-chemical parameters	Values
Alkalinity (meq L^{-1})	12.5
Salinity (g L^{-1})	9.4
Total N (mg L^{-1})	0.01
Total P (mg L^{-1})	99
Chlorophyll-*a* (µg L^{-1})	5.9
Cations (meq L^{-1})	18.8
Anions (meq L^{-1})	17.5
Na^{+} (mg L^{-1})	16.3
K^{+} (mg L^{-1})	0.5
Ca^{++} (mg L^{-1})	0.3
Mg^{++} (mg L^{-1})	0.2
Alkalinity (meq L^{-1})	12.3

Cl^- (mg L^{-1})	4.8
SO_4 (mg L^{-1})	0.4

1.2.5 Biodiversity

The Lake Langeno is serving as a home to diverse animals and plants. Most of the natural vegetations surrounding the lake are *Acacia* spp. (Mathewos Hailu *et al.,* 2010). The eastern side of the lake, where the streams enter, retains some trees, especially *Ficus* spp. and small *Sesbania* spp. On the southern and south-eastern shores, there are dense thickets of *Acacia*, other spiny bushes, climbers and large *Ficus vasta* and *Ficus sycomorus* trees. The surrounding slopes, within Munessa State Forest, are dominated by *Podocarpus falcatus*. The lake is also serving as a home to varieties of fishes and birds (Tafesse Kefyalew, 2008). The most common species are *Pelecanus onocrotalus*, *Scopus umbretta*, *Threskiornis aethiopicus* and *Leptoptilos crumeniferus*. The lake's ecosystem serves as breeding and wintering ground and as a migration stopover habitat for several resident and migratory bird species (Tafesse Kefyalew, 2008; Yared Beyene *et al.,* 2014). Dense phytoplankton blooms, mainly Cyanophyta, also characterize the lake (Elzabeth Kebede, 1996; Kassahun Wodajo and Amha Belay, 1984). The major phytoplankton genera of *Microcystis* spp. and *Cyclotella* spp. are dominant in the lake (Elizabeth Kebede, 1996). However, phytoplankton biomass (1.6 mg L^{-1}) and productivity (Chl-*a*=2 μgL^{-1}) of the lake is very low (Amha Belay and Wood, 1984). In addition, *Craticula halophila*, *Cymbella excisa*, *Denticula elegans* and *Gomphonema bergii* are the dominant diatoms species in Lake Langeno (Alebachew Tadie, 2014). Sedges and rushes fringe some parts of the lake and cover many of the small swampy bays. *Ceratophyllum demersum* and *Potamogeton* spp. are important submerged aquatics plants. In addition, four family of zooplankton were reported from the lake, where Cladocera and Copepoda dominate the zooplankton assemblages (Kassahun Wodajo and Amha Belay, 1984).

1.2.6 Socio-economic importance of the lake

Lake Langeno is one of the most attractive lakes serving as a recreation site in Ethiopia. This is due to its beautiful nature and presence of attractive birds in its wetlands (Mathewos Hailu *et al*., 2010). Agriculture, charcoal trade and fishing are the major means of income generation in the area. During the fasting period, most of the people living around the lake (34%) participate in fishing (Dawit Garoma *et al*., 2014; Mathewos Hailu *et al.,* 2010). The lake is also serving as a source of drinking water for human and livestock. However, it is not used for irrigation due to the water's high salinity and unsuitable topography of the area.

1.2.7 Fisheries

Lake Langeno is harboring very important fish species (Gashaw Tesfaye and Wolff, 2014; Lemma Abera, 2012a). It is the fifth most important lake contributing high capture fishery (7%) to the national and local markets (Gashaw Tesfaye and Wolff, 2014). Both Arsi Negelle and Adami Tullu Giddo Kombolcha District administer the fishery of the lake. The fish catch from the lake is almost exclusively *O. niloticus* (Lemma Abera, 2012a). Fishing is being carried out with beach seine, gillnets, and hooks and lines (LFDP, 1997). Similar to other lakes in the country, fishing has seasonal pulse on Lake Langeno, with high fishing activity during January-March (Asefa Mitike, 2013). Gashaw Tesfaye and Wolff (2014) estimated the production potential of the lake as 1293 tonnes year^{-1}. The fish catch from the lake is has increased dramatically since the year 2000, although showed drastic decline in 2007, which later on revived, due to reason of many people engaged in the lake's fishery and increasing of fish demand in the country (Fig. 1.4).

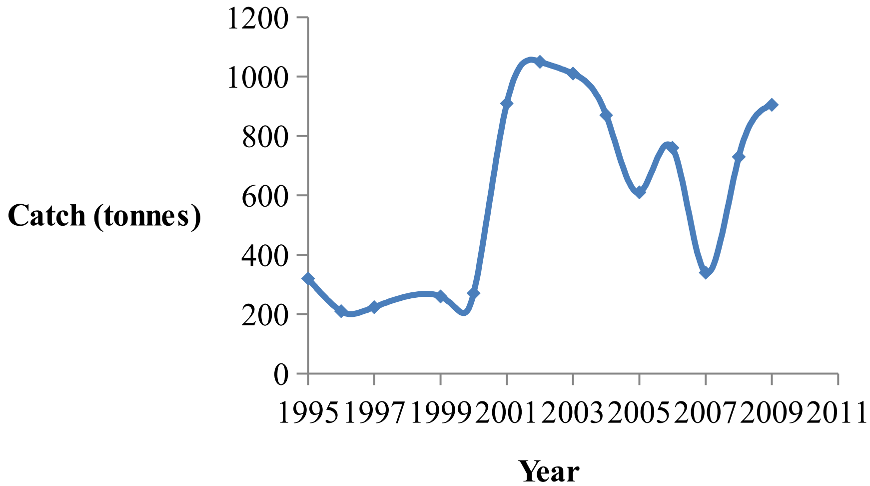


Figure 1.4: Trends of yearly fish harvest from Lake Langeno from 1995 to 2010 (FAO, 1995; Gashaw Tesfaye and Wolff, 2014; LFDP, 1997)

1.3 Justification and research questions

Agricultural development strategy is one of the major objectives of Sustainable Development and Poverty Reduction (SDPR) program in Ethiopia (Demese Chanyalew *et al.,* 2010). Fishery is one of the agriculture sector, expected to enhance the food security and provide alternative source of income to the rural society (Hussen Abegaz, 2010a). The former Ministry of Agriculture, now Ministry of Livestock and Fishery, is running a fishery development program starting from 2003 to achieve the objective of enhancing food security and employment, and provide alternative sources of income to improve the livelihood of rural societies (Vijverberg *et al.,* 2012). However, there is a lack of scientific information regarding the state of fisheries in different parts of the country. Thus, fishery assessment needs to be done for each water body to know the actual status of the fishery, and to optimize management measures for sustainable use of the resources (Gashaw Tesfaye and Wolff, 2014).

Located in the central Ethiopian rift valley, Lake Langeno is contributing a significant commercial catch of wild fishes (Gashaw Tesfaye and Wolff, 2014; Lemma Abera, 2012a). After the introduction of improved fishing technologies by Lake Fisheries Development Project (LFDP) in late 1980s (LFDP, 1997), however, a sign of overexploitation with the average sizes reduction have been observed (Lemma Abera, 2012a; Mathewos Hailu *et al.,* 2010). The fishing activities are being undertaken both by legal and illegal fishermen (Dawit Garoma *et al*., 2013; LFDP, 1997). However, there is still no adequate scientific report on the basic fishery data, such as status of fish resources in the lake, their trends, biology of important fish species, the role of fishery in the livelihood of fishermen living along the shores of the lake and the management systems in place. Thus, this study aimed at assessing the fish biology and fishery management of commercial stocks in Lake Langeno, Ethiopia.

Based on these facts, the following research questions were addressed in this study.

1. What is the fish species composition in the lake?
2. How are the fish communities of the lake compared with lakes of similar dimensions in other parts of the country?
3. What are the factors affecting distribution and abundance of fish communities in the lake?
4. Is there any spatial and seasonal difference in diversity, distribution and abundance of fish species in the lake?
5. What does the length-weight relationship and body condition of commercially most important fish stocks in the lake look like?

6. What does the reproductive biology of commercially important fish species in the lake look like?
7. Is there a seasonal and length based variation of food composition in the diet of *O. niloticus*?
8. What is the role of fisheries in the livelihood of surrounding community?
9. What types of fishery management systems are in place in and around Lake Langeno?
10. What are the major constraints being observed in the management of the fisheries in the lake?

1.4 Overall objective of the study

1.4.1 General objective

The general objective of the study is to provide scientific information on the fish biology and fishery management of commercial stocks of Lake Langeno, Ethiopia.

1.4.2 Specific objectives of the study

- To examine the diversity, distribution and relative abundance of fish species in the lake
- To evaluate the impact of physico-chemical parameters, spatial and seasonal variations of the lake on fish species composition and distribution
- To examine the length-weight relationship and condition factor of fish species in the lake
- To determine breeding season, fecundity and L_{50}% of commercially important fish species in the lake
- To examine the seasonal and length based variation of food composition of *Oreochromis niloticus* (Linnaeus, 1758) in the lake
- To assess the annual production, socio-economic characteristics, management system and major constraints of fisheries in the lake

1.5 Structure of the Dissertation

This work is organized into seven principal chapters. The **first chapter** is an introduction part of the dissertation, which gives a brief outline on background of the study, short introduction of the study area, which includes the location, morphology and topography, climate, water chemistry, biodiversity, socio-economic importance and fishes of the lake. The **second chapter** of this dissertation covers the reviews of related literatures. The **third chapter** deals with the diversity, distribution, abundance of fish species in the lake with respect to physico-chemical parameters, spatial, seasonal and environmental factors. The **fourth chapter** focuses on the length-weight relationship and condition factor of commercially important fish species in the lake. The **fifth chapter** discusses about reproduction biology of commercially important fish species in the lake, which includes the breeding season, sex ratio and fecundity. The **sixth chapter** deals with the feeding biology of *O. niloticus*, which is the dominant fish species in the lake. The **seventh chapter** is about socio-economic characterization and management systems of fisheries in the lake, which could help to develop a new policy framework for the resource management. Finally, the **last chapter** includes the conclusion and recommendation of the study**,** which provides summary and suggestions for future studies.

CHAPTER TWO

2. REVIEW OF RELATED LITERATURE

Fishery is a set composed of particular stocks and the fishing activities related to its harvest, gears and facilities inclusive of fishermen (Kevern, 2002). It is very important for any society as they are central components of human food and source of income (Villaprudente, 2012). Small-scale capture fishery contributes a high percentage to global fisheries, particularly in developing countries, where other livelihood options are often very limited (Mohammed and Uraguchi, 2013). Over the past decades, however, several fish stocks have been showing a declining trend due to different factors, such as change in riparian structure, chemical and organic pollution, overfishing, use of destructive fishing practices, alterations in hydrological regimes, global climatic changes etc. (Winker *et al.,* 2011). Thus, proper assessment and ecosystem-based management of fish and fishery seem to be imperative to sustain the resources and their benefits (FAO, 2010).

2.1 Fish and fisheries in Ethiopia

2.1.1 Diversity and distribution of fishes by drainage basin

Today, more than 200 fish species have been reported from all drainage basins (Redeat Habtasillasie, 2012; Tadlo Awoke, 2015). These fish fauna is a mixture of Nilo-Sudanic, East African highlands and endemic forms (Abebe Getahun and Stiassny, 1998; Golubtsov and Mina, 2003; Redeat Habtasillasie, 2012). The Nilo-Sudanic forms are those related to West African fish species, which include genera, such as *Alestes, Bagrus, Citharinus, Hydrocynus, Hyperopisus, Labeo, Mormyrus* etc. These are the dominant forms in terms of diversity, which are founddistributed in Gibe-Omo, Baro-Akobo, Tekeze and Abay basins. Some of these forms are also found in the southern rift valley lakes (L. Abaya and L. Chamo) and Shebelle-Genale basin. However, they are entirely absent from Awash and northern rift valley lakes (Abebe Getahun and Stiassny, 1998; Golubtsov and Mina, 2003). On the other hand, the East African highland forms are those related to Eastern and Southern Africa forms, which include genera, such as *Labeobarbus, Clarias, Garra, Oreochromis* and *Varicorhinus*. These are found distributed in Northern Ethiopian rift valley lakes (L. Hawassa, L. Zeway, L. Langeno and Koka Reservoir), Awash drainage basin, highland lakes (L. Tana and L. Hayq) and their associated rivers (Abebe Getahun and Stiassny, 1998).

The diversity and distribution of fish species in different drainage systems is extremely uneven (Golubtsov and Mina, 2003; Vijverberg *et al.,* 2012). Baro-Akobo is the most diverse basin (113 spp. in 60 genera and 26 families) in Ethiopia followed by Blue-Nile and Gibe-Omo basins. The Gibe-Omo and Blue Nile basins have more or less comparable species richness. The former has 76-79 species (42 genera and 20 families) and the latter has 77 species (37 genera and 16 families). Tekeze-Atbara and Shebelle-Juba drainage basins have 34 (22 genera and 10 families) and 33 (21 genera and 12 families) fish species, respectively (Abebe Getahun and Stiassny, 1998; Golubtsov and Darkov, 2008; Tadlo Awoke, 2015). However, the rift valley lakes and Awash River basin are poor in its ichthyofauna (Golubtsov *et al.,* 2002) (Annex 1 inTable 1).

Family Cyprinidae is the most diverse form found distributed in all drainage basins followed by certain families of Siluriformes (Mochokidae and Alestidae) and elephant fishes (Mormyridae) (Abebe Getahun and Stiassny, 1998; Golubtsov and Mina, 2003; Tadlo Awoke, 2015). The high tolerance of Family Cyprinidae to low water pH, high water temperature, their effectiveness in wide habitat exploitation and the ability to live in torrent flows (Mayden *et al.,* 2008), may have made them more abundant in all water bodies. In addition, about eleven exotic fish species

namely; *Coptodon zillii, Tilapia rendalli, Salmo trutta, Oncorhynchus mykiss, Ctenopharyngodon idella, Hypophthalmichthys molitrix, Cyprinus carpio, Carassius carassius, Carassius auratus, Gambusia holbrooki* and *Esox lucius* have been introduced into the different water bodies of the country (Shibiru Tedla and Fesseha Hailameskel, 1981).
Endemisim is reported to be the highest in Blue Nile drainage basin, but less in Baro-Akobo and Gibe-Omo basins despite its highest diversity. The highest species endemism is attributed to the high endemic Cyprinidae (about 18 spp.) from Lake Tana (Golubtsov and Darkov, 2008). This may be due to the geographical barrier that isolates Lake Tana from the lower parts of Blue Nile basin (Golubtsov and Mina, 2003). In other words, the lower species endemism in Baro-Akobo and Gibe-Omo could be due to the interconnectivity of the basin (Golubtsov *et al*., 2002; Golubtsov and Mina, 2003). Shebelle-Juba system has also been reported to have 10-12 endemic species (Abebe Getahun, 2007).

2.1.2 The production potential and status of fishery in Ethiopia

Ethiopia is depending only on inland water capture fisheries (Abebe Ameha and Alemu Assefa, 2004). The total production potential of all water bodies is estimated to be about 94,541 tonnes year^{-1} (Gashaw Tesfaye and Wolff, 2014) (Annex 1 in Table 2). However, only less than 50.42% of this potential is being exploited, where Lake Tana takes more than half of the estimate (MoLF, 2016).

The dramatic changes have occurred in the fisheries of most lakes since the start of the second phase of Lake Fishery Development Project (LFDP II) in 1980 (Reyntjens and Tesfaye Wudneh, 1998). In 1993, the annual fish production from major lakes, reservoirs and rivers was estimated to be 8,000 tonnes (Felegeselam Yohannes, 2003). Between 1994 and 2001, total landings fluctuated between 7,700 and 16,224 tonnes year^{-1}. From 2004 to 2008, the total landing increased from 10,005 to 16, 770 tonnes year^{-1} (Ward and Tesfaye Wudneh, 2011). In 2010, the total production reached about 18,058 tonnes year^{-1} (Aytegeb Anteneh, 2013). This indicated that the catch has increased by more than five-fold over the past three decades (Fig. 2.1). Nevertheless, some lakes are showing the signs of overfishing for the commercially important fish species, like Nile tilapia due to uncontrolled fishing practices and lack of effective management (Gashaw Tesfaye and Wolff, 2014).

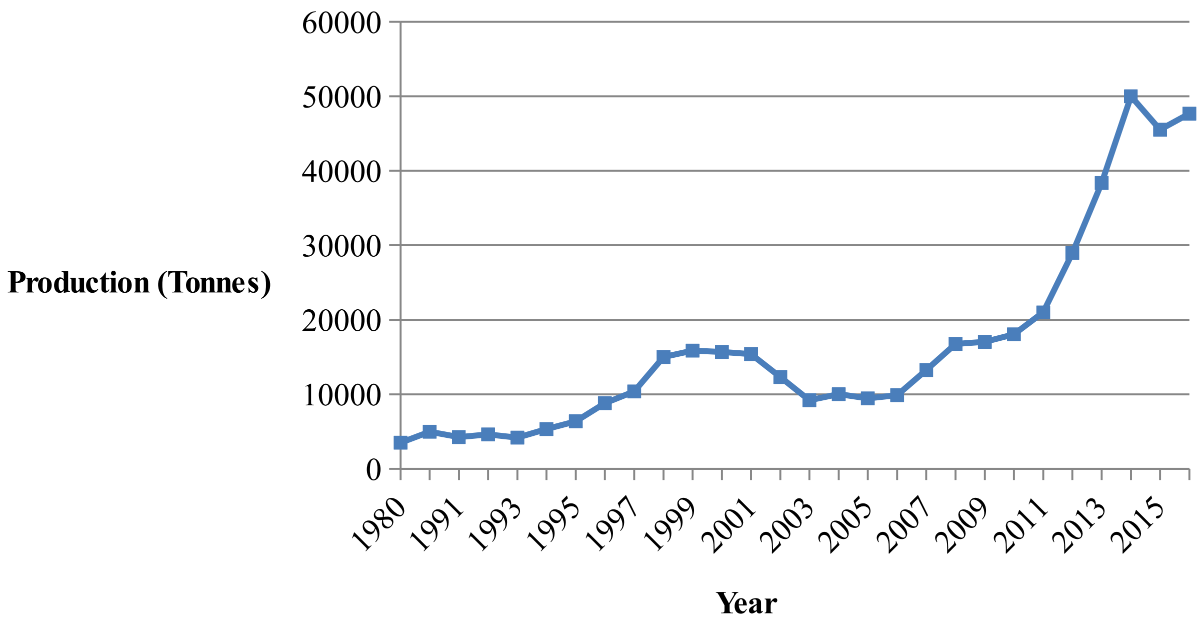


Figure 2.1: Total annual production of capture fisheries (in tonnes) in Ethiopia from 1990 to 2012 (Aytegeb Anteneh, 2013; Brook Lemma, 2012; FAO, 2012; FAO, 2016; MoLF, 2016)

2.1.2.1 Fish production by water bodies

Except for some remote and inaccessible water bodies, artisan fishing is being carried out in all water bodies (Felegeselam Yohannes, 2003). However, the commercial fisheries are mainly concentrated in the central and southern rift valley lakes (40%) and Lake Tana (50.2%) (Gashaw

Tesfaye and Wolff, 2014). Lake Chamo, Lake Zeway and Lake Tana provide the highest catches, and contribute more than 65% of the total annual catch (Asefa Mitike, 2014; Gashaw Tesfaye and Wolff, 2014) (Annex 1 in Table 3). Convenient road connections and proximity to the capital city had given these lakes the opportunity in their fishery development (Asefa Mitike, 2014).

In addition, fishing is highly practiced in two large reservoirs, namely, Fincha-Amerti and Koka Reservoirs (Asefa Mitike, 2014; Gashaw Tesfaye and Wolff, 2014). Riverine fisheries are also being performed in River Baro (Gambella), Blue Nile River, River Awash, River Omo and their tributaries (Brook Lemma, 2012; Tadlo Awoke, 2015). Most of the riverine fishes are being exploited for subsistence except from River Baro, where small-scale commercial fisheries are developing (Alayu Yalew *et al.,* 2015; Hussein Abegaz *et al.,* 2010a).

2.1.2.2 Fishery production by species

Themost commercially important fish speciesin Ethiopia are *O.niloticus, Labeobarbus* spp., *L. niloticus, C. gariepinus, B.docmak* and *C.carpio,* where Nile tilapia contributes more than 80% of the annual average catch (Gashaw Tesfaye and Wolff, 2014). Tilapia is not only the most important in production volume, but also one of the most preferred by consumers and economically the most important fish species (Asefa Mitike, 2016; Hussien Abegaz *et al.,* 2010b). Nevertheless, tilapia catches have apparently been declining due to the high fishing pressure in some lakes (Gashaw Tesfaye and Wolff, 2014). *Clarias gariepinus* was formerly the least preferred fish species in Ethiopia, but it has become now as commercially important like Nile tilapia (Abdurhman Kelil, 2002; Gashaw Tesfaye and Wolff, 2014). Lake Abaya and Lake Chamo are the main sources of *L. niloticus*, *B. docmak* and *Labeo* species, while Lake Tana is the source of *Labeobarbus* and Nile tilapia (Gashaw Tesfaye and Wolff, 2014).

2.1.3 Socio-economic contribution of the fishery sector in Ethiopia

Fishery is serving as a means of livelihood for many people in Ethiopia particularly for those who are residing in the vicinity of major water bodies. The sector provides a substantial employment and an alternative source of income for many poor people, thereby improving the livelihoods of the society (Asefa Mitike, 2016; Gashaw Tesfaye and Wolff, 2014). In 2014, for instance, nearly 45,000 fishers were employed in the primary sector with 30% employed fulltime, in addition to nearly 700 people engaged in aquaculture (FAO, 2015). This activity is closely linked to other activities like farming and rearing of livestock (Aytegeb Anteneh, 2013; Gashaw Tesfaye and Wolff, 2014). It is also serving as the main source of protein supply for many people (Gashaw Tesfaye and Wolff, 2014; Hussien Abegaz *et al.,* 2010a; Hussien Abegaz *et al*., 2010b). However, its contribution to the GDP is very small (about 0.05%) (Gashaw Tesfaye and Wolff, 2014). Similarly, the national per capita fish consumption is extremely low (240 g), which is significantly below the mean 2.6 kg year^{-1} for the East African sub-region (FAO, 2012). This show that in most parts of Ethiopia, fish food has not been integrated into the diet of population (Asefa Mitike, 2014).

2.1.4 Fish markets and market channels

The spatial distribution of overall production showed that fish production is mainly concentrated in few lakes, which have a better infrastructure and good market outlets (Brook Lemma, 2012). Many different actors, such as Ethiopian fishery corporation enterprises, local and regional merchants, retailer shops, supermarkets and hotels are involving in the fish markets, and this partly explains the recent sharp rise in fish price as each actor only focuses on profit maximization (Fig. 2.2). However, the fish market chains differ from state to state. In most parts, the distribution of market's network for fish trading is not more than 60 km radius from landing sites except the fishery from some rift valley lakes and Lake Tana (Dereje Tewabe and Goraw Goshu, 2010; Hussien Abegaz *et al.,* 2010b).

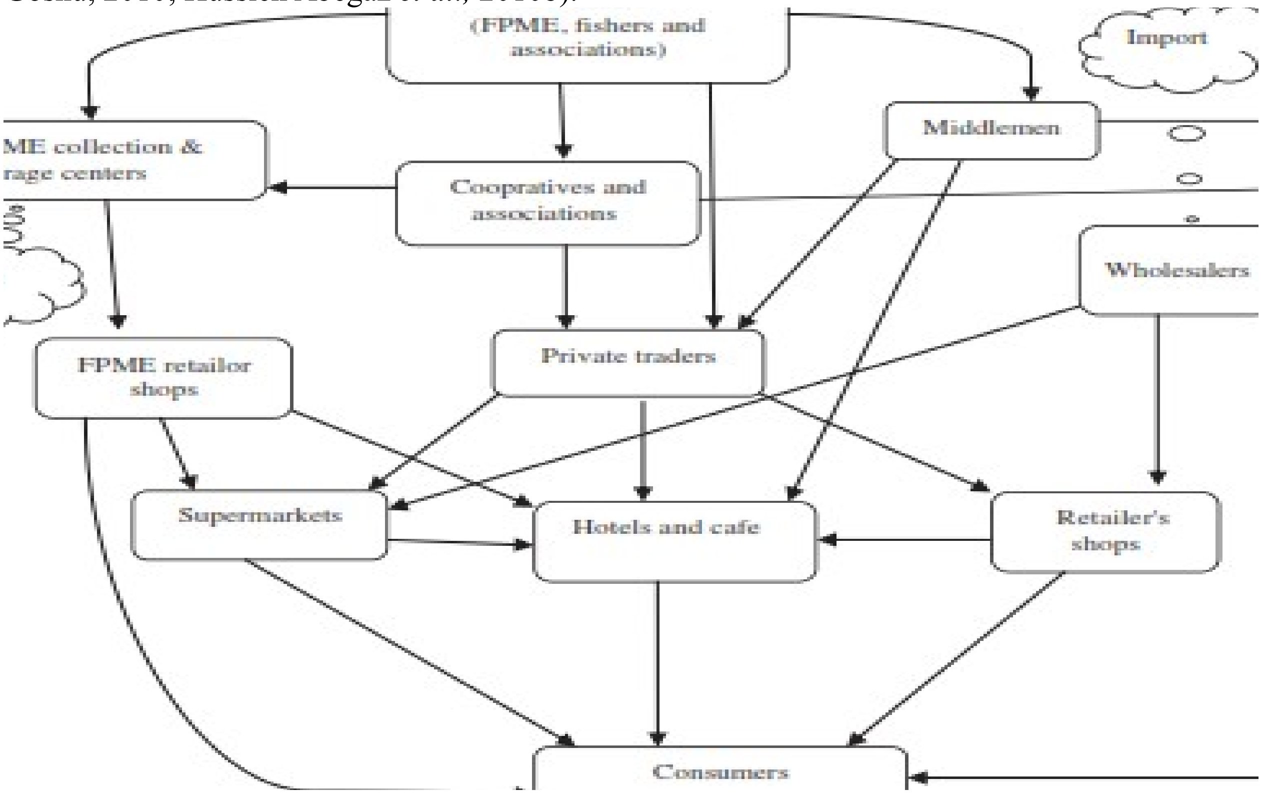


Figure 2.2: Schematic diagram showing the general fish market chain in Ethiopia (Brook Lemma, 2012).

2.1.5 Fisheries policies and institutional arrengements in Ethiopia

The first fishery legislation entitled ''Ethiopian fishery legislation'' was drafted by assistance of FAO in 1983 for management, development and establishment of advanced fishery sector (FAO, 1995). Unfortunately, the draft had not accepted and implemented by fishermen due to the absence of follow-up (FAO, 1995; LFDP, 1997). In 1991, the new economic policy promulgated by transitional government of Ethiopia emphasized the need to revitalize economy and create a favorable environment for fishery development (FAO, 1995). However, the policy left the resources open for fishermen. From 2001-2005, the second five-year agricultural development plan of the federal government laid down a number of targets to improve fish production in the country (Abebe Ameha and Alemu Assefa, 2004).

Based on this, in 2003, by recognizing the danger posed on most water bodies, ‘’National Fisheries Development and Utilization Proclamation No. 315/ 2003’’ was ratified by the Federal parliament to provide broad guideline related to resource conservation, food safety and aquaculture development (Vijverberg *et al.,* 2012). The objectives of this proclamation was to conserve fish biodiversity and its environment as well as prevent and control overexploitation of the fish resources, increase the supply of safe and good quality fish, and ensure a sustainable contribution of the fisheries toward food security, and expand the development of aquaculture (Hussien Abegaz *et al*., 2010b). This proclamation constitutes the principal legal tool available at the federal level for the management of fisheries in Ethiopia, which contains 21 articles that describe procedures and rules to be enforced in order to utilise the country's fishery resources and to develop aquaculture (Negarit Gazeta, 2003). Article 5(10) states, that any person who wishes to import or export any type of exotic live fish species must have a permit from the Biodiversity Institute first. Article 5(10) also states that any person who wishes to transfer live fish that have been imported or an indigenous species from one regional water body to another regional water body, must have a permit from the ministry. Similarly, article 6 contains provisions that deal with how to obtain permits to establish aquaculture farms, the control of fish disease, and standards for the establishment and operation of aquaculture facilities (Alayu Yalew *et al.,* 2015; Negarit Gazeta, 2003). Consistent with the proclamation, two regional states (Amhara and Southern Nation, Nationalities and People (SNNP) regional states), which have major water bodies, produced their own proclamation for the management of fisheries under their jurisdiction (ACP Fish II, 2013; Breuil and Grima Damien, 2014).

In 2009, MoA also developed a National Aquaculture Development Strategy Framework, with the support of FAO. The overall objective of the National Strategy is "to define a regulatory framework and to build a strong basis for the development of aquaculture in the country". In particular, the National Strategy aims to provide a framework in which the aquaculture industry can be developed in an economically, socially and environmentally sustainable manner, with aquaculture targeted as an activity to ensure food security, alleviate poverty of rural farmers and to provide fish for domestic consumption and industry (ACP Fish II, 2013). According to ACP Fish II (2013**),** the 2009 National Strategy was designed based on four fundamental principles: (i) development should be concentrated in areas of high potential to be successful; (ii) stakeholders must contribute to development where they have a comparative advantage, these advantages being redefined for various public and private sector partners; (iii) aquaculture should be profitable; and, (iv) producers must have a voice in the management of the sub-sector.

Today, fishery legislation is available at the federal and at some regional levels (at Amhara and SNNP states), under the follow up of Ministry of Livestock and Fishery. The legislation provides broad guidelines relating to control overfishing, fishing gear, introduction of exotic species and regulate the fish market. It also puts considerable emphasis on regulation, permission and the role of fishery inspector (Hussien Abegaz *et al*., 2010a).

2.1.6 Fisheries management practices in Ethiopia

The central government of Ethiopia formulated policies for management of inland water fisheries prior to 1992 (Abdurahan Kelil, 2002). However, the involvement of central government to issuing nationwide fisheries law, and provision of technical and professional support is very low

(Abduraham Kelil, 2002; Ward and Tesfaye Wudneh, 2011). In addition, the sector is not given due attention equal to other agricultural sectors (Felegeselam Yohanis, 2003; Hussien Abegaz, 2010a). The less priority given for the fishery sector as compared to the other agricultural sectors is resulting in uneven efforts regarding fishery management (Chalachew Aragaw, 2010). Low level of economy, in-effective administration setup and lack of expertise are also the other challenges (Asefa Mitike, 2014). Thus, fisheries remain open access where anyone at any time can fish from water bodies (Abduraham Kelil, 2002; Chalachew Aragaw, 2010). As a result, several water bodies have suffered from overexploitation due to unwise use and untimely capture of fishes (Ward and Tesfaye Wudneh, 2011).

Encouraging fishery cooperation is the principal method being employed in the fishery management process (Dawit Garoma *et al.,* 2014). Fishery cooperation associations have a mandate of preserving and developing indigenous fish varieties and go for exotic varieties without affecting the ecological balance. Sometimes, they adopt direct limits on catch quantity or size, but these actions are fairly rare (Dawit Garoma *et al.,* 2014; Asefa Mitike, 2014). However, because they operate on a small-scale fishery, they often lack sufficient capital to purchase fishing gears. This enforced them to use low cost and traditional fishing materials, which have an adverse effect on fish populations (Gashaw Tesfaye and Wolff, 2014).

Another method called fishery co-management was also developed for most lakes and reservoirs in 2013 (Asefa Mitike, 2014). Management measures like prohibition of destructive gears, standardization of net dimension, and close some area and seasonal fishing have been implemented in some areas (Hussien Abegaz, 2010a). However, the management in place follows the traditional command and control (top-down) approach rather than real co-management approach, and the existing fishery co-management is very weak (Asefa Mitike, 2014; Ward and Tesfaye Wudneh, 2011).

2.2 The study of fish biology as an important aspects in fishery management

One of the key factors to successful fishery management is to understand the fundamental biological aspects of fishes. It is also necessary to understand which kinds of factors are related to the biological changes of these resources (Hart and Reynolds, 2002).

2.2.1 Length-weight relationship (LWR) and condition factor of fishes

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

Condition factor is a measure of various ecological and biological factors, such as the degree of fitness, gonad development and the suitability of environment (Weatherly and Gill, 1987). It is also affected by biotic and abiotic factors, ecology, stress, sex, season, availability of foods, and other water quality parameters (Froese, 2006). The study of condition factor assumes that heavier fish of a given length are in better physiological condition (Bagenal and Tesch, 1978). The earliest condition factor developed was Fulton's condition factor (K), which assumes isometric growth in the form of $W=aL^b$, where W is fish weight, L is fish length, ‘a’ is regression intercept and ‘b’ is regression slope. It is still one of the most commonly used indices (Froese, 2006). The other type of condition factor is relative condition factor, which dependens on the measure of total weight of the fish in relative to total weight of the whole sampled fish (Weatherly and Gill, 1987).

2.2.2 Reproductive Biology of fishes

Reproductive biology is one of the fundamental aspects in the study of fish biology and population dynamics (Hunter *et al.,* 1992). It is used for a better understanding of observed fluctuations in reproductive output and enhances our ability to estimate recruitments (Shalloof and Salama, 2008). It is also used to form a basis for developing strategies and formulating policies, which is used for effective management of the fish resources (Agbugui, 2013). Of these, the study of breeding season is the most important biological aspect that is used in fishery management. To identify breeding season, each individual fish should be identified as reproductive or non-reproductive in all seasons (Yaragina, 2010). The breeding season of fish is influenced by food availability and environmental factors, such as dissolved oxygen, rainfall, pH and temperature (Tesfaye Wudneh, 1998).

Fecundity assessment is the other most important reproductive aspect in fish biology. It is the spawning potential of fish for a particular season or the number of ripening eggs in a female prior to the next spawning period (Bagenal, 1978). The intensity of reproduction is determined by the average number of eggs per brood, and how often the eggs are laid by the female per unit time. A marked difference in fecundity often reflects the difference in reproductive strategies (Hunter *et al*., 1992). This is very essential for evaluating the commercial potentialities of fish stock, life history, practical culture and actual management of the fishery. It also used to calculate eggs and fry survival, and ultimately recruitment rates (Azhari, 2014). The fecundity of an individual female varies based on season, food supply, environmental conditions (temperature and stress) and fish size (Jakobsen and Fogarty, 2015; Nandikeswari and Anandan, 2013). It is mainly temperature and food that influence the fecundity through their effects on the body size of fishes (Yoneda and Wright, 2005). For instance, females of older fishes are less fecund as compared to young fishes because fecundity increases with body weight and growth (Njiru *et al*., 2004a; Yoneda and Wright, 2005).

The study of age and length at first reproduction has also a broad implication for studying population dynamics and community ecology (He and Stewart, 2001). The biological relationship of the two are very important to control the dynamic of ichthyologic populations, and study the longevity, catchable size and other life history problems in fish (Cailliet and Goldman, 2004). It is also an important management parameter used to monitor whether enough juveniles in an exploited stock is mature and can spawn. Mainly, fishery biologists prefer to conceive size at first maturity as the average size at which 50% of the individuals are getting mature (Roa *et al.,* 1998). In various populations, this is related closely to the maximum length (L_∞) at which the fish of that population would reach if they would continue to grow indefinitely (Stamps *et al*., 1998). This is based on the model of relation between body size and the number of individuals that are mature from a total number at each of many size intervals. To estimate L_{50}, a sample of organisms known to have just reached sexual maturity could be available and their arithmetic mean size can be used as an estimator (Roa *et al*., 1998; Stamps *et al*., 1998). This is usually derived through either linear interpolation, probit analysis, fitting of a logistic curve, or estimated from a plot of percent mature specimens over length. Linear interpolation is a method of curve fitting using linear polynomials to construct new data points within the range of a discrete set of known data points. It is a mathematical and statistical tool used to estimate values between two points. Probit analysis is a method of analyzing the relationship between a stimulus and the quantal response. Quantitative responses are almost always preferred, but in many situations they are not practical. Fitting of a logistic curve is an apparent relationship by simply plotting y versus x and choosing the particular values of ‘a’ and ‘b’ that produces a line that comes as close as possible to the observed data (Roa *et al*., 1998).

In other way, studies on sex ratio would provide information on the proportion of male to female in a population (Vicentini and Araujo, 2003). It also indicates the dominance of sex in a given population and basic information necessary for fish reproduction and stock size assessment (Agbugui, 2013; Vicentini and Araujo, 2003). Environmental sex determination has become a widely used tool in fish production (Cnaani and Levavi-Sivan, 2008). According to the sex ratio model of Fisher (1930), animals should produce offspring of a balanced sex ratio (1:1). Population with an imbalanced sex ratio due to unusual environmental condition can be considered as a disturbed or maladapted for the given condition (Bohlen *et al*., 2008). In many species, unusual ecological condition change can create shifts in the sex ratio of fishes (Devlin and Nagahama, 2002). Moreover, it is subject to modification by external factors like temperature, which can interact with hormonal or genetics to alter fish sexual development (Budd *et al.,* 2015).

In Ethiopia, the study of reproductive aspects of different fish species were conducted in different water bodies (Dereje Tewabe, 2014; Elias Dadebo *et al*., 2011; Fasil Degefu *et al.,* 2012; Lemma Abera, 2012b; Lemma Abera *et al*., 2014; Lemma Abera *et al*., 2015; Tadlo Awoke *et al*., 2015; Wassie Anteneh *et al*., 2007; Yirgaw Teferi *et al*., 2001; Zenebe Tadesse, 1997). The studies revealed that the reproductive biology of fishes such as sex ratio, length at first sexual maturity, reproductive season and fecundity of many fish species are varrying depending on the water temperature, elevation, water chemistry, food availability and seasonal variation (Elias

Dadebo *et al*., 2011; Fasil Degefu *et al.,* 2012). Mainly, the seasonal variation and food availability in the water are highly determining the reproductive aspects of many fish species (Elias Dadebo *et al*., 2011; Tadlo Awoke *et al*., 2015). For instance, majority of the fish species available in Ethiopian rift valley lakes has more or less similar reproductive behavior due to the similarity of the habitats and food availability in the area (Elias Dadebo *et al*., 2011; Lemma Abera, 2012b; Lemma Abera *et al*., 2014; Lemma Abera *et al*., 2015). On the other hand, those fishes live in Ethiopian high land water bodies are a bit different in their reproductive system from those found in rift valley lakes due to their ecological differences (Dereje Tewabe, 2014; Fasil Degefu *et al.,* 2012; Tadlo Awoke *et al*., 2015; Wassie Anteneh *et al*., 2007; Yirgaw Teferi *et al*., 2001; Zenebe Tadesse, 1997).

2.2.3 Feeding biology

Fish distribution and abundance in different habitats are associated with availability and abundance of food in a particular habitat (Welcomme, 2011). The quality and quantity of food are among the most important exogenous factors directly affecting growth, maturity and mortality of fishes (Wootton, 1998). Dietary studies have traditionally relied upon stomach content analysis (Hyslop, 1980). Scientific knowledge on food and feeding habits of fish is an important condition for successful fisheries management programme and fish culture (Fatema *et al.,* 2013). It is also used for assessment of resource partitioning within and between-species competition, prey selection, predator-prey size relationships (Scharf *et al*., 2000), distribution of feeding types with latitude, ontogenetic diet shifts and habitat selection (Pauly, 2000).

In Ethiopia, many authors have reported that Nile tilapia feeds on variety of food items including phytoplankton, zooplankton, insects, detritus, macrophytes, fish parts and nematodes (Alemayehu Negassa and Prabu, 2008; Flipos Engdaw *et al.,* 2013; Getachew Tefera, 1993;

Mulugeta Wakjira, 2013; Workiyie Worie and Abebe Getahun, 2015; Yirgaw Teferi *et al.,* 2000; Zenebe Tadesse, 1999). However, in terms of prey importance, the foods of plant origin (mainly phytoplankton) are the most frequently consumed food types by the fish in all of the water bodies. For instance, the studies carried out in some rift valley lakes (e.g. Lake Hawassa (Zenebe Tadesse, 1999), Lake Chamo (Yirgaw Teferi*et al*., 2000), Lake Zeway (Alemayehu Negassa and Prabu, 2008) and Koka Reservoir (Flipose Engdaw *et al*., 2013)), some high land lakes (e.g Lake Hayq (Workiyie Worie and Abebe Getahun, 2015)), in lower Omo basin (e.g. Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013) and River Omo (Mulugeta Wakjira, 2016)) indicated that phytoplankton is the most frequently consumed food prey by Nile tilapia. In addition to phytoplankton, the highest contribution of detritus was also reported in some rift valley lakes (e.g. Koka Reservoir (Flipose Engedaw *et al.,* 2013)), and in other water bodies like Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013) and Tekeze Reservoir (Tsegay Teame *et al.,*2016). The occurrences of macrophytes were also found slightly high in the diet of Nile tilapia in some of the rift valley lakes (Alemayehu Negassa and Prabu, 2008; Flipose Engedaw *et al.,* 2013; Yirgaw Teferi *et al.,* 2000).

CHAPTER THREE

3. DIVERSITY, DISTRIBUTION AND ABUNDANCE OF FISH SPECIES IN LAKE LANGENO, ETHIOPIA

3.1 Introduction

Fishery is one of the important production sectors, which plays a key role in the economy of many nations and fishes serve as the diet of many poor people in the world (Tacon and Metian, 2009). However, environmental changes due to human activities and some natural factors like climate change have been causing adverse effects on fish resources (Mohammed and Uraguchi, 2013). Moreover, human activities, such as overexploitation, habitat alteration, pollution from industrial and agricultural discharges, and introduction of exotic fish species are highly contributing to the declining level of aquatic biodiversity both in freshwater and marine environments (Leveque *et al.,* 2008).

Studies of fish species composition and their spatial and/or seasonal distribution are useful to examine factors influencing the structure of fish communities, because fish species diversity is influenced both by biotic and abiotic processes that function across various scales of space and time (Galactos *et al.,* 2004). Mainly, diversity and distribution of freshwater fish species is highly influenced by the types of river basin (Tesfaye Wudneh, 1998; Vijverberg *et al.,* 2012), physical factors (temperature, depth, topography, water current and physical barrier) and chemical properties of water (Leveque *et al.,* 2008). In addition, various biological factors, such as food availability, breeding sites, density, competition, predation and composition of aquatic plantsin each habitat influence the diversity and distribution of fish species (Harris, 1995).

Conservation of aquatic biodiversity is based on the knowledge of fish stock and their distribution, because site-specific management is based on the knowledge of fish community difference per site and water body (Vijverberg *et al.,* 2012). Assessing the fish biodiversity and their interaction with biotic and abiotic factors would also give a broader understanding of the functions and ecological values of these ecosystems (Blay *et al*., 2011). Thus, knowledge of fish diversity, distribution, stock sizes and the means of exploitation should have to be known for each water body (Sileshi Ashine, 2013).

Ethiopia has a large variety of freshwater fish biodiversity, but except for some lakes, fish communities were rarely studied in a quantitative way (Tadlo Awoke, 2015; Vijverberg *et al.,* 2012). The studies show that there is a reduction in species diversity from northern and central highlands to the rift valley lakes, which vary from 40 to 85% (Abebe Getahun and Stiassny, 1998). Additionally, the Ethiopian rift valley contains a system of small to medium-sized lakes, some of which are saline (Gashaw Tesfaye, 2011; Tadlo Awoke, 2015).

Lake Langeno is one of the Ethiopian rift valley lakes harboring commercially important fish species (Vijverberg *et al.,* 2012). The commercial catch in central Ethiopian rift valley is mainly harvested from Lakes Zeway and Langeno (Mathewos Hailu *et al.,* 2010). Lemma Abera (2012a) and Vijverberg *et al.* (2012) conducted a preliminary research on fish biodiversity assessment in Lake Langeno. However, still there is no complete data on fish biodiversity and their distribution across spatial and seasonal scales and with respect to physico-chemical parameters of the lake. Therefore, the present study on fish diversity was carried out with the notion to assess the influence of physico-chemical variations on fish community structure of the lake; identify the fish biodiversity and their distribution across spatial and seasonal scale; examine the relative abundance of fish species in the lake; and search for factors that affect the diversity, distribution and abundance of fish species in the lake

3.2 Materials and methods

3.2.1 Study design and sample site selection

The study was conducted from March 2014 to February 2016. Before starting data collection, preliminary survey was conducted from January to March 2013. This helped to identify boundary of the lake, to have a general understanding of the overall situations of fishes in the lake, and to fix the sampling sites for data collection. Based on the population of the fishermen in the area, distance from the shore, depth of the lake, distance from the road and human activity in the catchment area, six sampling sites were selected (one site from the middle and five sites from shore areas). Morphometric variables of the lake, including the depth of the lake were measured at each sampling site both in wet and dry seasons by a weighted and graduated rope. Global Positioning System (GPS) was used to determine the locations of the sampling sites (Table 3.1).

Table 3.1: Geographic Positioning System (GPS) record of the sampling sites and their descriptions

Site	Depth (m)	Latitude and longitude	Relative location	Distinctive characteristics of the site
Hora-Kelo	8.7	7°39'13.7"N 38°43'37.9"E	North-Western part	Visited by large number of fishermen next to Dole site, presence of out flowing river here, the site is protected by wetlands and there are agricultural farm lands beyond the site
Hoitu	10.2	7°38'40.4"N 38°46'17.4"E	Northern part	Supporting large number of fishermen with majority of them fully licensed, on-shore hot springs are feeding the site, outer part of the site do not support agriculture
Tufa	12.3	7°35'02.3"N 38°48'21.0"E	Eastern part	The 4th in supporting a large number of fishermen, most of the fishermen fishing from this site are not legally licensed, no agriculture at the outer part of the lake by this side and have many inlet tributaries
Wabishebele	19.7	7°36'44.0"N 38°43'13.2"E	Western part	This site is serving as a tourists' center, there are many farm lands along the site, it supports less fishermen
Middle	43.5	7°35'24.4"N 38°45'40.3"E	Middle part	This site is supporting only a few fishing activities and far away from human activities
Dole	11.5	7°32'23.1"N 38°44'17.5"E	Southern part	This site is visited by large number of fishermen next to Hoitu, the southern shores are protected by wetlands, beyond which farm lands are found, presence of inlet tributaries like Lepis, Gedemso, Garabula, Metti, Tufa and Sedesedi Rivers

3.2.2 Collection and measurement of physico-chemical parameters

At each sampling site, depth integrated water samples were collected monthly from three depths (surface, middle and near the bottom depending on the total depth of the specific site) by Kemmerer tube sampler (Bartram and Balance, 1996). The collection of water samples and measurements of physico-chemical parameters was done between 09:30 and 1:30 am. Measurements of pH, temperature, electrical conductivity, dissolved oxygen and water transparency were done *in situ* (Table 3.2). For chlorophyll-*a* content analysis, pre-treatment and filtration were carried out immediately in the field by Whatman filter paper with 42 µm mesh size (McCarthy *et al*., 2011). The filters were folded in, dabbed between 2 pieces of blotting paper, and wrapped with aluminum foil to avoid light. The samples were frozen at $<-4^0$C and transported to the limnology laboratory at Addis Ababa University for further analysis.

Table 3.2: Instruments used for physico-chemical parameter measurements

No.	Parameter	Determination method and instruments
1	Secchi depth	30 cm diameter of Secchi disk
2	Dissolved oxygen	Dissolved Oxygen Meter (PN# DK0600)
3	Temperature	Conductivity meter (HANNA pH211)
4	pH	Digital pH meter (Hanna 9024)
5	Total dissolved solid	Conductivity meter (HANNA pH211)
6	Electrical conductivity	Conductivity meter (HANNA pH211)
7	Chlorophyll-*a*	Spectrophotometer (APHA, AWWA and WPCF, 1998)
8	Water sample collection	Kemmerer tube sampler
9	Water depth	Labeled rope tied to stone

3.2.3 Fish sampling method

Because of the gear-specific selectivity associated with fish size, species and sampling location, varied mesh sizes of gillnets (6 cm, 8 cm, 10 cm and 12 cm) with 25 m panel length and 1.5 m depth were used to get representative samples of fishes (Vijverberg *et al.,* 2012). In addition, long-lines with number 9 and 11 hook sizes were used to catch large sized fish species.

From the six selected sites, fish samples were collected monthly for two years (March 2014 to February 2016). Gillnets were set in the afternoon between 5 and 6 pm, left overnight, and catches were collected the following morning two hours after sunrise (between 6 to 7 am) (Imam *et al.,* 2010). The number of fish caught was recorded for each sampling site. Total length (mm) and total weight (g) of fish were immediately measured using measuring board to the nearest 0.1 cm, and sensitive balance with sensitivity of 0.1g. In addition, dial caliper was used to measure the morphological parts of fishes. The representative fish samples were placed in plastic jars containing 10 % formalin, labeled, and transported to Zeway Fishery Resources Research Center (ZFRRC) for further analysis.

3.2.4 Laboratory study

The fish specimens transported from the field were soaked in tap water to wash off the formalin. After a few days, the specimens were transferred to 75% ethanol for two days before species identification was made. Then, the fishes were identified to species and genera levels at the ZFRRC based on Golubtsov *et al*. (1995), Okaronon *et al.* (1998) and Redeate Habtasillasie (2012). Chlorophyll-*a* analysis was also done spectrophotometerically according to Bos (2008).

3.2.5 Data analysis

Microsoft Excel was used for data management. Univariate analysis was used was done in order to get the descriptive statistics of the collected data such as mean and standard deviation of the environmental parameters and percentage composition of the collected fishes. Multivariate analysis of variance (MANOVA) was used to test a significant physic-chemical parameters variation between the sampling sites and sampling months (Anderson, 2001). When significant spatial differences were observed, specific environmental variables that contributed to variations between study sites were determined using pared t-test. Data were $\log_{10}$ transformed prior to analyses to improve normality of the data (Hammer *et al.,* 2001).

Detrended Correspondence Analysis (DCA) was employed to check the response of the species data matrix (dependent set) to the environmental data matrix (independent set) and to determine if species response followed linear or unimodal model (Lepš and Smilauer, 2003). A principal component analysis (PCA) triplot of species, sites and environmental variables data were used to discern variations in community structure that could be explained by the measured environmental variables. The extent of variability in fish assemblages explainable by each environmental variable was explored with Redundancy Analysis (RDA), a constrained ordination technique, using forward selection for appropriate variables (Lepš and Šmilauer, 2003).Monte Carlo permutation test was done to assess the strength of fish assemblage variability among the study sites explainable by the environmental variables. CANOCO 4.5 and PAST version 3.08 softwares were used to run all of the descriptive and statistical analysis.

Species abundance at each sampling station and month was presented as a numerical contribution by each species. This was determined by calculating the percentage of each species represented in the total catch for each station and month. Shannon diversity index (H') was used to evaluate the diversity index of fish species in the lake to explain varieties and relative abundances of fish species (Shannon and Weaver, 1963).

$H' = - \Sigma Pi \ln Pi$

Where: - H' = diversity index, $Pi = n_i/N$ = number of individuals within species (n_i)

N= total number of individuals (N) and ln = normal log.

The non-parametric Chi square test was computed in order to assess the heterogeneity of Shannon diversity index (H') value among the study sites for a single variable. An Index of Relative Importance (IRI) was also calculated to measure the relative abundance of fishes based on head-counts and weights of individuals in batches of catches, and their frequency of occurrence at each sampling site (Kolding, 1989). This was calculated as:

$$\%IRIi = \frac{(\%Wi + \%Ni)X\%FiX100}{\sum_{j=1}^{s=1}(\%Wj + \%Nj)X\%Fj}$$

Where: % Wi = percentage weight of each fish of total catch

% Ni =percentage number of each species of total catch

%Fi = percentage of frequency of occurrence of each species in total number of settings

% Wj = percentage weight of total species of total catch

%Nj = percentagenumber of total species of total catch.

% Fj= percentage frequency of occurrence of total species in total number of settings

S = total number of species

Finally, Auto regressive Moving Average (ARIMA) time sereous forcasting model was used to assess the seasonal variation of fishes catch composition (Hair *et al.*, 2012).

3.3 Results

3.3.1 Physico-chemical parameters of Lake Langeno

The average Secchi depth, dissolved oxygen (DO), water temperature, pH, total dissolved solid (TDS), electrical conductivity (EC) and chlorophyll-*a* content recorded from Lake Langeno are presented in Table 3.3.

Table 3.3: The physico-chemical parameters obtained from different sampling sites in Lake Langeno, Ethiopia (Mean ± SD) from March 2014 to February 2016 (Secchi=Secchi depth, DO=Dissolved oxygen, Temp. =Temperature, TDS= Total dissolved solids)

Site	**Secchi (cm)**	**DO (mg L^{-1})**	**Temp (°C)**	**pH**	**TDS (mg L^{-1})**	**Conductivity (µS cm^{-1})**	**Chlorophyll-*a*** (µg L^{-1})
Hora-kelo	15.5±2.3	5.1±0.8	23.5±1.2	9.46±0.1	1526±156	1785±98	6.4±0.5
Hoitu	15.9±2.1	5.0±0.9	23.8±1.3	9.44±0.4	1510±926	1797±98	6.2±0.3
Tufa	15.9±2.2	5.5±0.9	23.4±1.2	9.45±0.1	1499±131	1773±95	6.3±0.4
Wabishebele	15.4±1.9	5.2±1.2	23.6±1.2	9.48±0.1	1534±77	1791±108	6.4±0.6
Middle	15.8±2.8	5.2±1.2	23.5±1.2	9.43±0.1	1486±146	1767±94	6.2±0.3
Dole	15.7±2.3	5.1±0.9	23.4±1.1	9.46±0.2	1522±149	1779±92	6.4± 0.3
Total mean	15.7±0.2	5.2±0.2	23.5±0.2	9.46±0.1	1510±19	1781±12	6.3±0.1
p-value	0.93	0.91	0.96	0.4	0.86	0.29	0.43

The Secchi depth of the study area ranged from 11.5 cm in July to 21.2 cm in February with the mean depth of 15.7 cm. The minimum DO concentration was recorded in February (4.8 mg L^{-1}), and the maximum result was recorded in August (7.2 mg L^{-1}) with the mean DO content of 5.18 mg L^{-1}. The minimum water temperature was recorded in August (20.8°C), and maximum temperature was recorded in February (25.6°C) with the mean temperature of 23.5°C. The minimum (9.41) and maximum (9.6) pH values was recorded in July and February, respectively with the mean pH of 9.5. The TSD of the lake was also found in a range between 1417.5 mg L^{-1}in

February and 1644.5 mg L^{-1}in July with the mean TDS of 1513.0 mg L^{-1}. In addition, the electrical conductivity (EC) of the water ranged from 1543.0 in July and 1889.0 µS cm^{-1} in February with the mean EC of 1782.1µS cm^{-1}. Finally, the mean chlorophyll-*a* content of the lake was 6.3 µg L^{-1} where low chlorophyll-*a* was recorded in February (6.0 µg L^{-1}), and high chlorophyll-*a* content was recorded in July (6.5 µg L^{-1}). The result showed a significant seasonal variation for all parameters (MANOVA, $p<0.05$) (Annex 2 in Table 2), but no significant variation was observed between the study sites (MANOVA, $p>0.09$) (Annex 2 in Table 1).

3.3.2 Diversity of fish species in Lake Langeno

A total of 4,207 fish specimens (1,950 males and 2,257 females) belonging to seven species categorized under three families (Cyprinidae*,* Cichlidae and Clariidae) were collected from the lake. Family Cyprinidae, which is composed of five species made 55.0% of the catch followed by family Cichlidae dominating the fish community. *Enteromius paludinosus* (40.7%) was the most abundant species in number followed by *O. niloticus* (39.4%). Nevertheless, *C. carassius* and *G. dembecha* were the least abundant in the catch (Table 3.4). The morphological identification methods and detailed descriptions of each fish species are explained in Annex 3.

Table 3.4: The fish species composition (%) in Lake Langeno, Ethiopia

Family	**Fish species**	**No. individuals**			**Percentage (%)**
		Male	**Female**	**Total**	
Cyprinidae	*E. paludinosus*	765	947	1712	40.7
	L. intermedius	127	129	256	6.1
	C. carpio	138	156	294	6.9
	G. dembecha	13	15	28	0.7
	C. carassius	17	10	27	0.6
Cichlidae	*O. niloticus*	778	880	1658	39.4
Clariidae	*C. gariepinus*	112	120	232	5.5

Total		1950	2257	4207	100.0

3.3.3 Diversity indices of fish species in Lake Langeno

Summarized values of Shannon-Weiner Diversity Index (SWDI) of fish species in Lake Langeno are shown in Table 3.5. The values of SWDI ranged from 1.00 to 1.35. Comparatively, the northern (Site Tufa) and southern part (Site Dole) of the lake had the highest SWDI among the sampling sites. However, the values of SWDI did not show significant heterogeneity among the sites (χ^2, p=0.984). This showed that there was no significant species distribution among the study sites.

Table 3.5: Shannon diversity index obtained from different sites of Lake Langeno, Ethiopia (H'= Diversity index, χ^2= Chi-square test was carried out at α=0.05).

Site	**Total**	**H'**	χ^2
Hora-Kelo	679	1.28	1.25
Hoitu	689	1.33	1.41
Tufa	969	1.35	1.32
Wabishebele	655	1.28	1.26
Middle	379	1.00	2.18
Dole	836	1.35	1.32
Total	**4207**	1.26	1.29

3.3.4 Distribution of fish species in relation to environmental variables

Gradient lengths of all axes were shorter than three in Detrended Correspondence Analysis (DCA), suggesting linear species response model (Table 3.6).

Table 3.6: Summary of the Detrended Correspondence Analysis (DCA) for fish community structure in Lake Langeno, Ethiopia.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.036	0.001	0	0
Lengths of gradient	0.465	0.171	0.171	0.171

Figure 3.1 represents a Principal Component Analysis (PCA) triplot of fish species, sampling sites and the environmental variables, and Table 3.7 summarizes output of the analysis. The first two axes (Axis-1 and Axis-2) represented 92.8% of variability in species composition with all of the environmental variables accounting for 93.1% of the total variability in the structure of fish community.

Table 3.7: Summary of the PCA for the species data and environmental variables in Lake Langeno, Ethiopia.

Axes	**1**	**2**	**3**	**4**	**Total variability**
Eigenvalues	**0.9**	**0.094**	**0.004**	**0.002**	**1**
Species-environment correlations	66.23	64.42	61.81	67.53	
Cumulative % variance of species data	**74.1**	18.7	4.2	2.7	
Cumulative % variance of species-environment relation	30	41.4	36.8	100	
Sum of all eigenvalues					1
Sum of all canonical eigenvalues					0.931

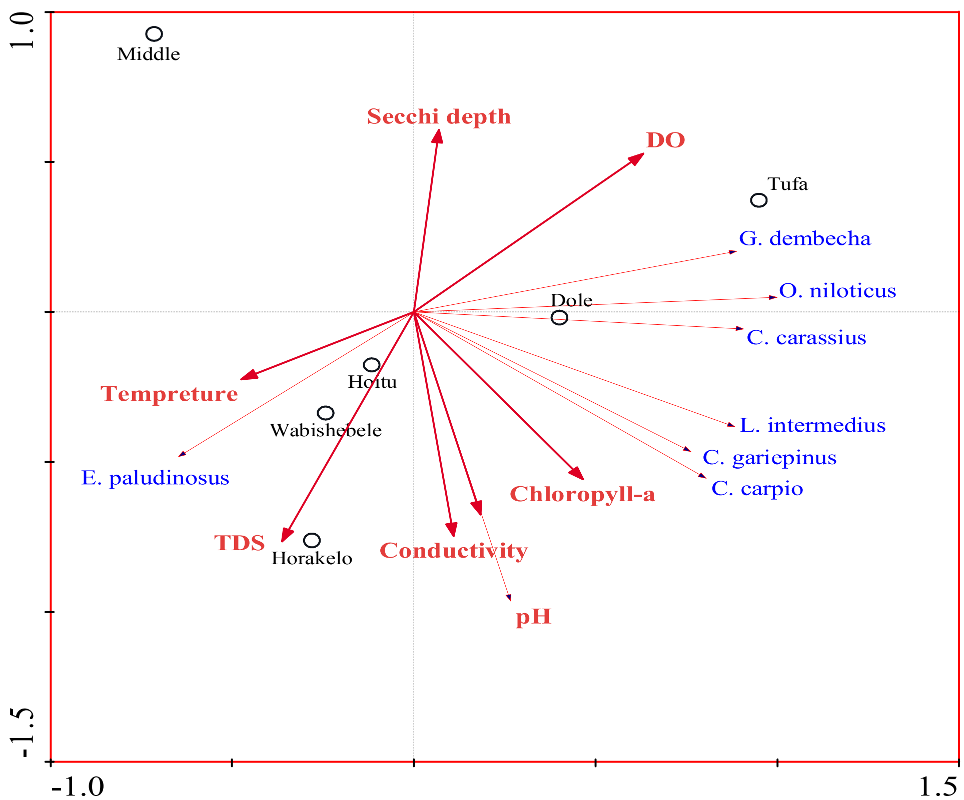


Figure 3.1: The species-environment-site PCA triplot of fish community in Lake Langeno, Ethiopia.

The PCA triplot of the species-environment-site association indicated that except for water temperature and TDS, all of the environmental variables were positively correlated with the first axis. Excluding of *E. paludinosus,* the distribution of all fish species had positively correlated with all of the environmental variables except for negative correlation observed with TDS and water temperature on this axis. On the other hand, environmental parameters like water temperature, pH, TDS and conductivity were negatively correlated with the second axis, which contributes for only 18.7% of species variance. All of the fish species except for *O. niloticus* and *G. dembecha* had negative correlation with the second axis, which also showed a direct relationship with all of the environmental variables except for a negative relationship with Secchi depth. The result indicated that all axes are reasonably less correlated (not strong) with the environmental variables except the strong correlation observed for Secchi depth (-0.50 to 0.68), suggesting that the species data is less governed by gradients on these axes (Table 3.8 and Fig. 3.1).

Table 3.8: The correlation matrix of RDA for the fish species abundances and environmental variables as well as the correlations between environmental variables and the axes in Lake Langeno, Ethiopia.

Environmental parameters	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4
Secchi depth	0.68	0.61	-0.46	0.59
DO	0.53	0.13	0.107	-0.43
Temperature	-0.48	-0.23	-0.04	0.18
pH	0.18	-0.48	0.46	0.01
TDS	-0.36	-0.46	0.34	0.32
Conductivity	0.11	-0.35	0.35	0.47
Chlorophyll-*a*	0.47	-0.56	0.41	0.05
O. niloticus	0.97	**0.15**	-0.01	-0.14
E. paludinosus	-0.08	-0.52	0.02	-0.31
C. gariepinus	0.10	-0.19	-0.85	0.37
L. intermedius	0.14	-0.19	0.33	0.82
C. carpio	0.11	-0.23	0.39	0.16
C. carassius	0.03	-0.01	0.09	0.04
G. dembecha	0.04	**0.03**	0.07	-0.21

Generally, Secchi depth explained 47.8% variance of fish species, and the effect was statistically significant ($p < 0.05$). Perhaps, the explanatory effects of other environmental variables were statistically not significant ($p > 0.05$) (Table 3.9).

Table 3.9: Summary of Monte Carlo permutation test for the strength of variability in fish assemblages explainable by the environmental variables in Lake Langeno, Ethiopia. The astrics indicated the statistical significant difference.

Parameters	% of variance	F-ratio	Monte Carlo p
Secchi depth	47.8	5.17	0.016*
DO	8	0.43	0.48
Temp	7	0.41	0.34
pH	3	0.23	0.73
TDS	6	0.39	0.56
Salinity	4	0.54	0.68
Conductivity	9	0.62	0.52

3.3.5 Spatial variation and relative abundance of fish community in Lake Langeno

The composition of fish species from all sampling sites were also ranked based on the index of their relative importance (Table 3.10). The catch from Site Tufa contributed the highest individual frequency (23.0%) followed by Site Dole (19.9%), but small number of fish catches were collected from the Site Middle (9.0%). The result showed that *E. paludinosus* was the most abundant fish species in all sampling sites of the lake. It was mainly the most abundant at Site Hora-Kelo (19.4%) followed by Site Wabishebele (17.7%). *Oreochromis niloticus* was the other most abundant fish species next to *E. paludinosus* at all sampling sites. The high abundance of *O. niloticus* was observed in Site Tufa (29.3%) followed by Site Dole (21.8%). *Clarias gariepinus* was the highest at Site Tufa (22.8%) followed by Site Wabishebele (22.4%). *Labeobarbus intermedius* was more abundant at Site Hoitu followed by Site Tufa than the other species. High abundance of *C. carpio* was observed at Site Hora-Kelo followed by Site Dole**.**

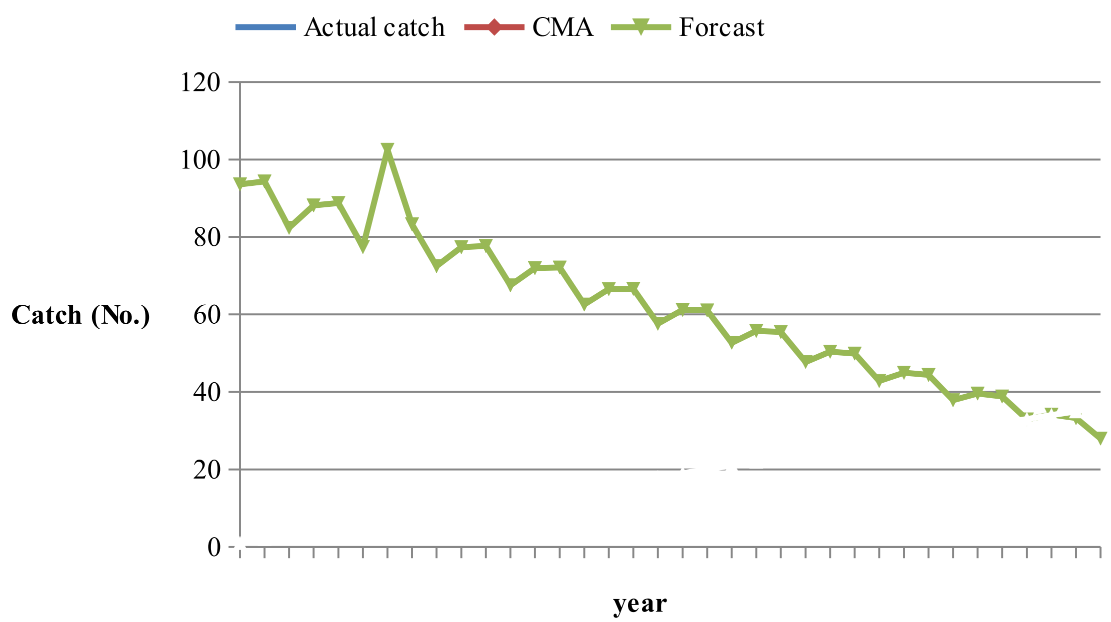
Table3-10: Percentage of IRI of different fish species in different sites of Lake Langeno, Ethiopia (N=total number, W=Total weight, F=Frequency of occurrence, IRI- Index of relative importance).

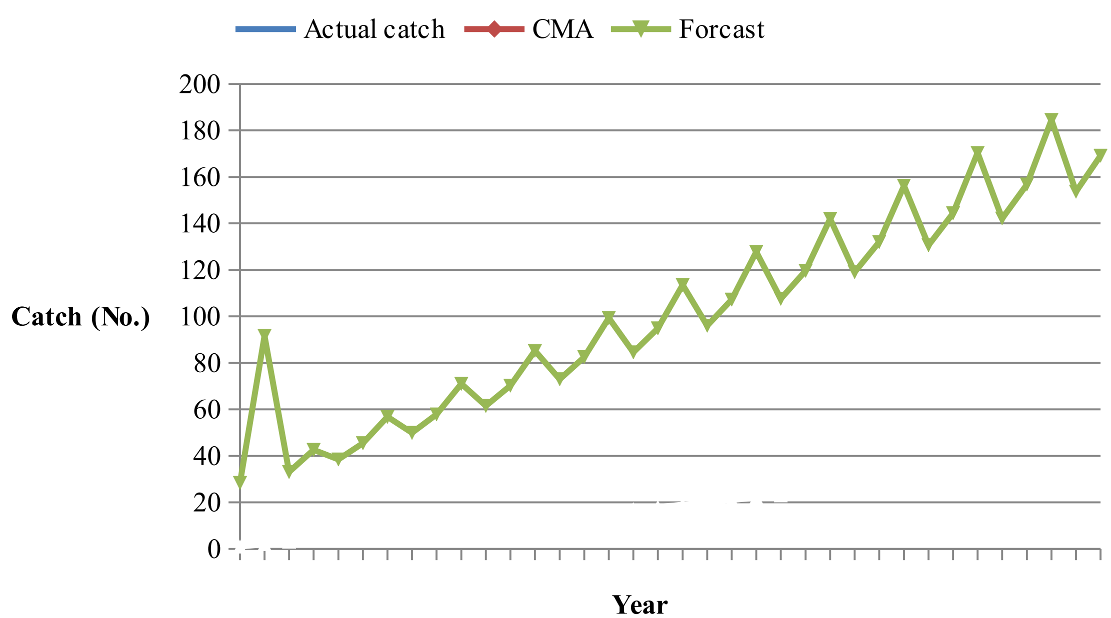
Site	Fish species	N	%N	W (kg)	%W	F	%F	IRI	%IRI
Hora-Kelo	*O. niloticus*	209	30.8	21.8	23.2	23	100.0	5402.5	27.8
	E. paludinosus	332	48.9	0.9	1.0	23	100.0	4989.9	25.7
	C. gariepinus	34	5.0	27.4	29.3	22	95.7	3277.3	16.9
	L. intermedius	42	6.2	12.7	13.5	22	95.7	1881.6	9.7
	C. carpio	58	8.5	29.8	31.7	22	95.7	3850.7	19.8
	C. carassius	3	0.4	1.2	1.3	3	13.0	22.5	0.1
	G. dembecha	1	0.2	0.01	0.01	1	4.4	0.7	0.01
	Total	**679**	**100.0**	**93.8**	**100.0**			**19425.2**	**100.0**
Hoitu	*O. niloticus*	249	36.1	25.7	27.9	23	100.0	6412.4	33.7
	E. paludinosus	294	42.8	0.8	0.9	23	100.0	4357.7	22.9
	C. gariepinus	35	5.1	21.5	23.4	21	91.3	2598.5	13.7
	L. intermedius	48	6.9	18.8	20.5	21	91.3	2507.9	13.2
	C. carpio	50	7.3	22.2	24.1	22	95.7	3000.1	15.8
	C. carassius	7	1.0	2.8	3.1	7	30.4	124.1	0.7
	G. dembecha	6	0.9	0.1	0.1	6	26.1	24.3	0.1
	Total	**689**	**100.0**	**91.9**	**100.0**		**0.0**	**19024.9**	**100.0**
Tufa	*O. niloticus*	485	50.1	40.3	30.1	23	100.0	8015.9	40.7
	E. paludinosus	280	28.9	0.8	0.6	23	100.0	2948.8	14.9
	C. gariepinus	53	5.5	34.2	25.5	23	100.0	3099.3	15.7
	L. intermedius	62	6.4	24.5	18.3	23	100.0	2472.4	12.6
	C. carpio	64	6.6	29.9	22.3	23	100.0	2894.8	14.7
	C. carassius	10	1.0	4.0	3.0	10	43.5	175.3	0.9
	G. dembecha	15	1.6	0.1	0.1	13	56.5	93.6	0.5
	Total	**969**	**100.0**	**133.9**	**100.0**		**0.0**	**19700.1**	**100.0**

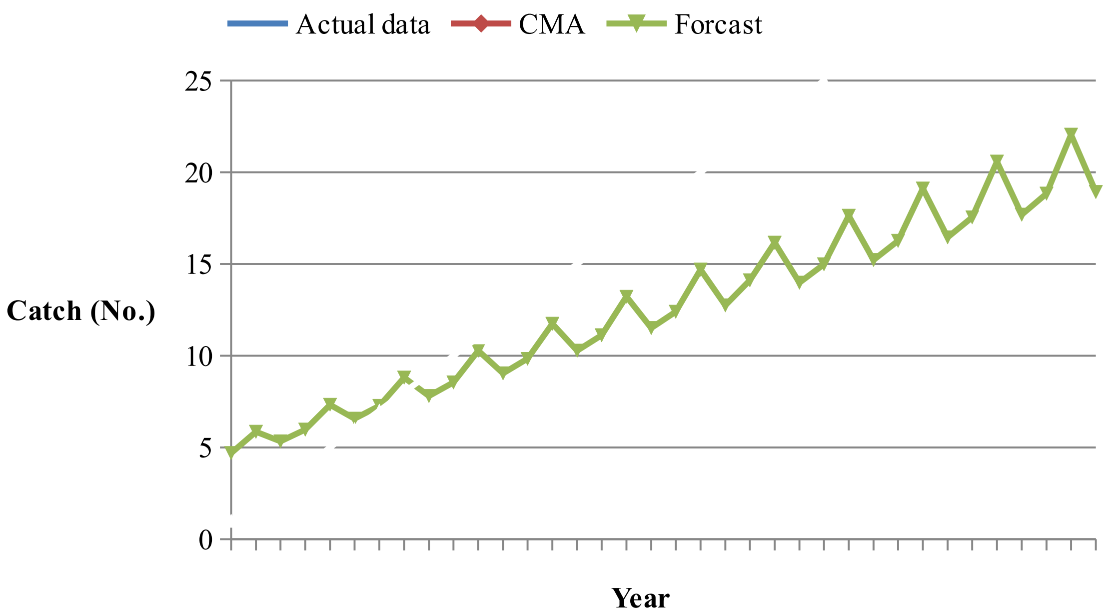
Site	Fish species	N	%N	W	%W	F	%F	IRI	%IRI
Wabishebele	*O. niloticus*	221	33.7	23.8	27.4	23	100.0	6112.2	31.1
	E. paludinosus	303	46.3	0.9	0.9	23	100.0	4724.9	24.0
	C. gariepinus	52	7.9	33.1	38.2	23	100.0	4613.1	23.4
	L. intermedius	34	5.2	9.5	10.9	22	95.7	1538.8	7.8
	C. carpio	42	6.4	18.7	21.6	22	95.7	2679.7	13.6
	C. carassius	2	0.3	0.8	0.9	2	8.7	10.7	0.05
	G. dembecha	1	0.2	0.01	0.01	1	4.4	0.7	0.01
	Total	**655**	**100.0**	**86.6**	**100.0**		**0.0**	**19680.2**	**100.0**
Middle	*O. niloticus*	133	35.1	15.4	43.2	23	100.0	7826.8	45.8
	E. paludinosus	212	55.9	0.6	1.7	23	100.0	5762.1	33.7
	C. gariepinus	18	4.8	9.9	27.9	17	73.9	2413.1	14.1
	L. intermedius	8	2.1	4.7	13.2	8	34.8	532.1	3.1
	C. carpio	8	2.1	5.0	14.1	8	34.8	562.3	3.3
	C. carassius	0	0.0	0.0	0.0	2	0.0	0.0	0
	G. dembecha	0	0.0	0.0	0.0	1	0.0	0.0	0
	Total	**379**	**100.0**	**35.7**	**100.0**		**0.0**	**17096.4**	**100.0**
Dole	*O. niloticus*	361	43.2	41.1	32.3	23	100.0	7548.5	38.2
	E. paludinosus	291	34.8	0.8	0.7	23	100.0	3545.6	17.9
	C. gariepinus	50	5.9	33.8	26.7	23	100.0	3253.6	16.5
	L. intermedius	62	7.4	18.9	14.8	23	100.0	2223.0	11.3
	C. carpio	62	7.4	30.2	23.8	23	100.0	3117.3	15.8
	C. carassius	6	0.7	2.4	1.9	6	26.1	68.1	0.3
	G. dembecha	4	0.5	0.04	0.03	4	17.4	8.9	0.05
	Total	**836**	**100.0**	**127.3**	**100.00**		**0.0**	**19764.9**	**100.0**

3.3.6 Seasonal variation of the fish community in Lake Langeno

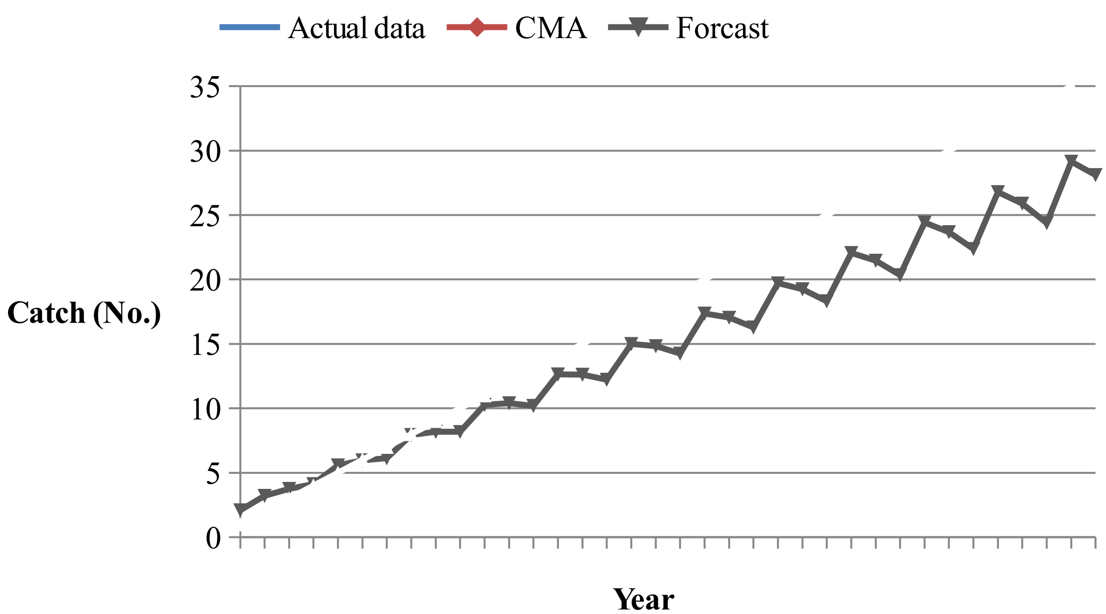
All of the fish species were collected in all of the sampling periods. However, the highest number of catch, which is dominated by *E. paludinosus*was collected from June to October, 2015. The result showed a significant catch variation of catch among the sampling periods (ANOVA, $p<0.05$). Large number of *O. niloticus* specimens was collected in March and July 2014. Similarly, more number of *E. paludinosus* was collected in August and September 2015. Generally, high number of fish specimens was collected in August and September 2015, whereas, it was very few in January and February 2014. The catch of *O. niloticus* has decreased from year one to year two; however, the catch of *C. gariepinus*, *C. carpio* and *L. intermedius* has increased, while that of *C. carassius* and *G. dembecha* did not show any variation. The result of ARIMA model confirmed that *O. niloticus* catch was highly decreased in the second year and the forecast of the model showed a decreasing trend of the fish catch by the following year based on the present finding. However, the forecast of other species indicated the increasing trend of fish catch composition if the current situation continues in similar manner (Fig. 3.2, a-e).


Actual catch
CMA
Forcast
120
100
80
60
40
20
0
Catch (No.)
year


Actual catch
CMA
Forcast
200
180
160
140
120
100
80
60
40
20
0
Catch (No.)
Year



Actual data
CMA
Forcast
Catch (No.)
Year



Actual data
CMA
Forcast
Catch (No.)
Year

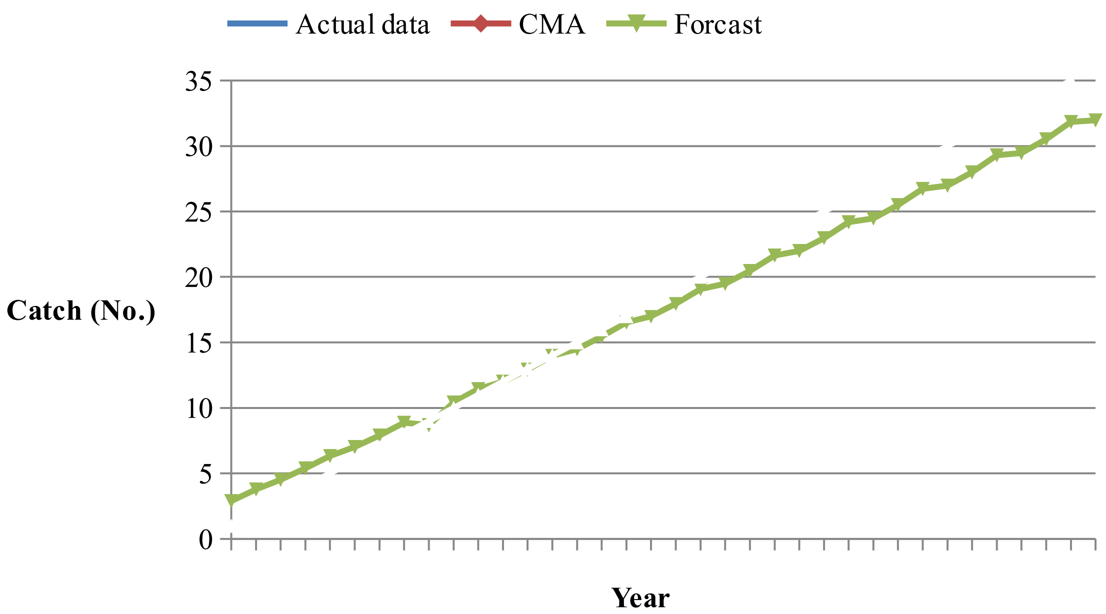


Figure 3.2: Seasonal variation and forecasting of one-year fishes catch composition (*O. Niloticus* (A), *E. paludinosus,* (B) *C. gariepinus* (C), *L. intermedius* (D) and *C. Carpio* (E)) in Lake Langeno, Ethiopia (Q1=Quarter 1, Q2=Quarter 2, Q3=Quarter 3, Q4=Quarter 4; number 1, 2 and 3 represents month 1, 2 and 3, CMA=central moving average).

3.4 Discussion

3.4.1 Physico-chemical parameters of Lake Langeno

Fish naturally tend to select the habitat that is most suitable for their physiological requirements. Particularly, physico-chemical properties of the water can affect the distribution of fish species in aquatic environment (Reash and Pigg, 1990). There are considerable variations between fish species in its tolerance range to variations of water parameters. In the present study, the result obtained for Secchi depth showed a seasonal fluctuation, which was strongly associated with the rainy season of the study area. This is highly consistent with what has been mentioned in Barroso *et al*. (2016) report. The Secchi depth of the lake (15.7 cm) (Table 3.3) is very low as compared to the report from Lake Zeway (Girma Tilahun and Ahlgren, 2010; Lemma Abera, 2016), Lake Hawassa (Admasu Woldesenbet, 2015), Lake Chamo (Adane Fenta and Almaz Kidanemariam, 2016), Lake Tana (Essayas Kabaa *et al.,* 2014), Lake Hashengie (Tsegay Teame *et al*., 2016a), Koka Reservoir (Elizabeth Kebede, 1996) and in some rivers of Abbay basin (Dereje Tewabe, 2014). This could be due to high silt and clay accumulation in the lake, which are known to form a stable colloidal suspension in Lake Langeno (Amha Belay and Wood, 1984). This shows that the lake is very turbid as compared to these other lakes.

Dissolved oxygen is vital for aquatic life. DO below 3 mg L^{-1} is stressful to most aquatic organisms and DO content 5 to 6 mg L^{-1} are usually required to perform the normal biological functions (Campbell and Wildberger, 1992). The mean DO content of Lake Langeno (5.2 mg L^{-1}) (Table 3.3) is within the recommended DO content for aquatic life and comparable with the reports from Lake Zeway (3.5 to 6.0 mg L^{-1}) (Lemma Abera, 2016) and Tana sub-basin (6.7 to 7.8 mg L^{-1}) (Shewit Gebremedhin *et al.,* 2014). However, it was less than that of Koka Reservoir (Elizabeth Kebede, 1996) (5-11.4 mg L^{-1}), Lake Haramaya (Brook Lemma, 2003) (6.0-10.0 mg L^{-1}), Lake Hawassa (Admasu Woldesenbet, 2015) (11.2-20.6 mg L^{-1}), Lake Chamo (Adane Fenta and Almaz Kidanemariam, 2016) (10.3-17.4 mg L^{-1}), and Tekeze and Abay basins (Dereje Tewabe *et al.,* 2010) (6.3-9.9 mg L^{-1}). The less DO content in this study might be attributed to the high water temperature during the study period and high depth of the water, which influences the distribution of aquatic plants in the lake. The studies indicated that variation in DO concentration of the water depends on temperature and depth of the water, because the solubility of oxygen decreases with the increasing of water temperature and depth (Ali *et al*., 2013; Langland and Cronin, 2003; Wetzel, 2001). The variation in DO may also depend on phytoplankton composition and other aquatic plants in the water, which produces DO as a waste product of photosynthesis (Jaeger *et al.,* 2017).

The mean water temperature of the lake (23.54°C) (Table 3.3) is comparable to the water temperature reported from Lake Zeway (Lemma Abera, 2016) and Lake Hawassa (Begashaw Abate *et al*., 2015), but it was less than the reports from Lake Chamo (Adane Fenta and Almaz Kidanemariam, 2016) and Tekeze Reservoir (Dereje Tewabe *et al*., 2010). This could be attributed to the difference in temperature of the area, for instance, Lake Chamo is located in the hottest humid area (Adane Fenta and Almaz Kidanemariam 2016). The variation in water temperature causes the changing of metabolic activities of fish, which results in the variation of fish growth, body condition and species distribution (Adane Fenta and Almaz Kidanemariam 2016; Langland and Cronin, 2003).

The mean pH recorded in Lake Langeno (9.45) (Table 3.3) showed slight variation from the report made by Zinabu Gebremariam *et al*. (2002) (8.91) in Lake Langeno. This might be associated with the water temperature and precipitation change observed during the study period (Wetzel, 2001). It is also greater than the pH reported from Lake Zeway (8.84-8.66) (Girma Tilahun and Ahlgren, 2010), Lake Hawassa (6.98-7.59) (Begashaw Abate *et al*., 2015), Lake Abaya (7.85-9.0) (Zinabu Gebremariam *et al*., 2002), Lake Chamo (8.45- 9.02) (Adane Fenta and Almaz Kidanemariam, 2016), Lake Tana (6.69-7.48) (Shewit Gebremedhin *et al.*, 2014) and Koka Reservoir (8.11-8.6) (Elizabeth Kebede, 1996). The high value of pH shows the high consumption of free CO_2 by algae, which results in decreasing H^+ concentration and influence the distribution of the aquatic organisms (Adane Fenta and Almaz Kidanemariam, 2016). According to Alebachew Tadie (2014), Lake Langeno is characterized by encompassing high algal composition, which could be a reason for the high pH value in this study. However, it was less than the report of Zinabu Gebremariam *et al.* (2002) from Lakes Abijata (9.5-10.3) and Shalla (9.4-10.2). The low pH value in this study could be attributed to the low salinity in this lake as compared to Lakes Abijata and Shalla (Zinabu Gebremariam *et al.*, 2002).

The result of TDS in our study (1512.9 mg L^{-1}) (Table 3.3) is greater than the findings of Berhanu Rabo (2008) from Lake Zeway (270.0 mg L^{-1}), Admasu Woldesenbet (2015) from Lake Hawassa (455.6 mg L^{-1}) and Adane Fenta and Almaz Kidanemariam (2016) from Lake Chamo (656.0 mg L^{-1}). According to Weber-Scannell and Duffy (2007), the difference in concentration of TDS in natural waters is determined by the geology of the drainage basin, atmospheric precipitation, anthropogenic activities and the water balance. Lake Langeno is characterized high silt load (Zinabu Gebremariam *et al.*, 2002) and anthropogenic activities (Mathewos Hailu *et al.,* 2010), which might have increased the high TDS in this study area.

The mean EC recorded in the present study (1782.1 µS cm^{-1}) (Table 3.3) also showed a slight increment as compared to the report madeby Zinabu Gebremariam *et al.* (2002) in Lake Langeno (1632.0 µS cm^{-1}). The increase of water temperature during this study period due to EL-Nino might have caused the high EC in this study. It was also higher than values reported from Lake Zeway (Lemma Abera, 2016), Hawassa (Admasu Woldesenbet, 2015) and Koka Reservoir (Zinabu Gebremariam *et al*., 2002), which indicates the high total solubility in Lake Langeno. The variation in EC of inland waters depends on many factors like concentration, charge and mobility of ions in the water, which is directly affected by water temperature, TDS and salinity (Miller *et al.,* 1988). According Miller *et al. (*1988), EC of water increases approximately 2-3% per 1°C increase of water temperature; though in pure water it will increase approximately 5% per 1°C. However, our result indicated the lowest EC measurement as compared to the reports from Lake Abijata (Tamiru Alemayehu, 2000) (19000 to 23000 µS/ cm), and Lake Arenguade, Lake Shalla and Lake Hora (6240, 23004 and 2166, µS/ cm, respectively) (Zinabu Gebremariam *et al.,* 2002). This might be due to the lower salinity, TDS and water temperature of Lake Langeno than these lakes (Zinabu Gebremariam *et al.,* 2002).

3.4.2 Diversity of fish species in Lake Langeno

Family Cyprinidae was the most dominant in terms of diversity and abundance (contributed 55% of the catch) (Table 3.4), which is similar to the findings from Lake Zeway (Lemma Abera, 2016) and in majority of the Ethiopian water bodies (Tadlo Awoke, 2015; Vijverberg *et al.,* 2012). Lemma Abera (2012a) and Vijverberg *et al.* (2012) reported three and five fish species, respectively, from the same lake. *Cyprinus carpio* and *Carassius carassius* were not mentioned in their reports, but *C. carpio* is now the third most abundant species in Lake Langeno. The difference could be due to the difference in the fishing gear types used, and the time in which the specimens were collected. *Enteromius paludinosus* was the most abundant fish species in this study, which contradicts with the previous reports of Lemma Abera (2012a) and Vijverberg *et al.* (2012), who reported *O. niloticus* as the dominant fish species. This shows that there have been changes (either natural or anthropogenic) that induced favorable conditions for the abundance of *E. paludinosus*.

The H' value of the present study (7 spp.; H'=1.0 to 1.35) (Table 3.5) is less than H' value reported in Lake Zeway (9 spp.; H'=1.51 to 1.67) (Lemma Abera, 2016) and Blue Nile River (*8* spp.; H'=1.23 to 1.64) (Tadlo Awoke *et al*., 2015). This indicated that Lake Langeno is comparatively poor in its ichthyofaunal diversity. The number of fish species recorded in the lake is also very small as compared to the reports made in Lake Tana (Dereje Tewabe, 2014), southern rift valley lakes (Vijverberg *et al*., 2012), Tekeze Reservoir (Tsegay Teame *et al.,* 2016b) and Baro basin (Golubtsov and Darkov, 2008), which confirms the low fish diversity in the lake (Golubtsov and Mina, 2003; Vijverberg *et al.,* 2012). The physical isolation of the lake from adjacent lakes might have caused the less diversity of fishes (Tadlo Awoke, 2015). However, the result is comparable with the diversity in Lake Naivasha (Aloo *et al.,* 2013) and greater than that of Gilgel Gibe I Reservoir (Mulugeta Wakjira, 2013).

3.4.3 Distribution in relation to environmental variables, spatial variation and relative abundance of fish species in Lake Langeno

The PCA analysis of the present study indicated that the association of physio-chemical parameters and abundance/and distribution of fish species were very weak except for Secchi depth (Table 3.7, 3.8, 3.9 and Fig. 3.1). The absence of significant environmental variation (Table 3.3) could a responsible factor for the weak association of fish species distribution/and abundance and water parameters. However, *E. paludinosus* showed a good correlation with the water temperature (Table 3.8). Similarly, Aloo *et al.* (2013) stated that *E. paludinosus,* which was initially only found at the north swamp and around the river mouth of Malewa, Kenya is increasingly becoming more abundant with the increasing of water temperature. Thisfish species were caught in all sampling sites except at Site Middle in which *G. dembecha* and *C. carassius* were absent (Table 3.).might be due to the high depth of this site, which extends up to 43.5m. The littoral zone is often considered as the most important habitat for fishes. This is because the structural complexities of the littoral zone provides a more diversified food resources, and serve as a breeding ground for many of the fish species (Benson and Magnuson, 1992). SWDI confirmed that there was no significant species segregation among the sampling sites, which showed that all fish species are adapted to live in all sampling sites (Table 3.5).The absence of significant heterogeneity of fish species among sites could be corroborated with the similarity in physico-chemical conditions (as discussed in Section 3.5.1, above).

Oreochromis niloticus and *E. paludinosus* were the most abundant fish species at all sampling sites (Table 3.).This showed a good correlation of these fish species with overall environmental factors of the lake. Mulugeta Wakjira (2013), Lemma Abera (2016) and Tsegay Teame *et al.* (2016a) also reported the dominance of *O. niloticus* at all landing sites of Gilgel Gibe I Reservoir, Lake Zeway and Tekeze Reservoir, respectively. It'sHigh abundance of *E. paludinosus* was also reported in Lake Zeway (Lemma Abera, 2016). The study indicated that *E. paludinosus*prefers quiet and well-vegetated waters or marginal areas of larger rivers and slow flowing streams (Skelton, 1993). However, it is unclear at this stage why the abundance of this fish species is highly increasing in the lake and this needs further study. *Garra dembecha* and *C. carassius* were the least abundant fish species at all sampling sites. The genus *Garra* is apparently highly tolerant and largely found in streams that hardly flow (Abebe Getahun and Stiassny, 1998). *Carrasius carassius* also prefer to live and reproduce in shallow ponds and lakes rich in vegetation, and slow moving rivers (Lorenzoni *et al*., 2007). Therefore, the absence of vegetation cover and high depth of the lake could be the responsible factors for the scarcity of fish species in the lake. In general, fish was higher in Northern site (Site Tufa) followed by Southern Site (Site Dole). This could be due to the shallowness and certain wetland coverage in these sites, which is very important for the reproduction of fishes (Graff and Middleton, 2001).

3.4.4 Seasonal variation of fish species in Lake Langeno

The results showed that almost similar fish species were collected during the entire sampling period with the highest number of catches in the wet season (June to October) (Fig. 3.2).According to Jackson and Harvey (1997), different fish species exhibit variation in the space they occupy over time. Moreover, biotic and abiotic factors, and seasonal changing of habitat may cause the seasonal variations in ichthyofaunal distribution. The seasonalof fishermen participation may also determine the seasonal changes of fish distribution (Lemma Abera, 2016). In this study area, most people in fishing as their primary work during dry season due to the absence of rainfall for other agricultural activities, and high demand of fish in the market as discussed in Unit 7, Section 7.4.10 (Assefa Mitike, 2014; Abdurahaman Kelil, 2002).

Our results indicated that the total number of fish caught showed a slight during the period of data collection. The catch of *O. niloticus* was highly reduced in the second year, whereas the catches of other species especially *E. paludinosus, C. carpio, C. gariepinus* and *L. intermedius,* increasedslightly. Similarly, the result of ARIMA model (Fig. 3.2, a-d) forcasted the decreasing trend of *O. niloticus* in the next year and increasing trend of other fish species. The changing trend of these fish speciescould be attributed to the increasing of water temperature and number of fishermen in the second year due to the reduction of other agricultural activities, which led them to focus on some commercially important fish species like *O. niloticus* (Mohammed and Uraguchi, 2013).Changes in water temperature restrict the survival, growth and distribution of fish species, because it causes depletion of dissolved oxygen. Therefore, fish species are believed to respond to environmental changes like a warming of water temperature by shifting their behavioral and ecological changes (Tacon and Metian, 2009; Mohammed and Uraguchi, 2013). This could be the case in the present study, which may have led the very tolerant and resilient fish species to be dominant in the lake.

In conclusion, our finding showed that Lake Langeno is poor in its ichthyofaunal diversity, and the species distribution does not show a spatial variation, but a significant seasonal variation was observed. Therefore, effective follow-up and appropriate managementthe resource is very important in order to minimize the seasonal base of fishing pressure on the lake, which is highly affecting the lake's resources and natural factors.

CHAPTER FOUR

4. LENGTH-WEIGHT RELATIONSHIP AND CONDITION FACTORS OF FISH SPECIES IN LAKE LANGENO, ETHIOPIA

4.1 Introduction

Length-weight relationship (LWR) is one of the most important biological tools in fishery management. It is used to estimate the average weight a fish can attain at a given length (Lawson *et al*., 2013). It also provides valuable information, such as the effect of environmental factors, habitat changes, species interaction and food availability in ecosystem, which used for aquatic ecosystem modeling (Dan-kishiya, 2013). Therefore, the length-weight relationship of fishes under various environmental conditions should be known.

The difference in LWR is based on the inherited body shape and condition of individual fish (Yousuf and Khurshid, 2008). Condition factor shows the degree of wellbeing of fishes in their habitat, which is expressed by coefficient of condition (Nehemia *et al.,* 2012). Fish attain a better body condition when the condition factor value is higher. Different factors, such as stress, sex, season, availability of food and other water quality parameters can affect the condition of fish (Ighwela *et al.,* 2011).

For most tropical and sub-tropical fish species, information on LWR is still very rare (Hossain, 2010). Lake Langeno is one of these lakes harboring different types of fish species. Yet, there is no sufficient information on LWR of fish species in Lake Langeno except some limited studies conducted on *O. niloticus* (Gashaw Tesfaye and Zenebe

Tadesse, 2008) and *C. gariepinus* (Leul Teka, 2001). Therefore, the present study aimed at assessing the size composition, length-weight relationship and condition factor of the most dominant fish species in Lake Langeno, Ethiopia.

4.2 Materials and methods

4.2.1 Fish sampling methods

The numbers of fish caught were recorded for each sampling occasion. Fork length (FL), standard length (SL), total length (TL) (mm) and total weight (g) of all fish samples were measured using measuring board to the nearest 0.1 cm, and OKI balance with sensitivity of 0.1g immediately after catch. All of the the fish samples were placed in plastic jars containing 10 % formalin, labeled, and transported to ZFRRC for further analysis. The catch data per species were grouped into size classes and analyzed separately for size-related distribution patterns.

4.2.2 Estimation of length-weight relationship

Length-weight relationship was calculated based on the Bagenal and Tesch (1978) method.

$$TW = a \times TL^{b}$$

Where: TW = Total weight in gram

TL = Total length in centimeter

a= intercept

b = slope

4.2.3 Estimation of condition factor

Fulton condition factor (FCF) was employed for each sex and species to body condition of individual fishes (Bagenal and Tesch, 1978). Fulton condition factor was calculated as:

$$FCF = \left(\frac{TW}{TL} 3 \right) x\, 100$$

Where, FCF = Fulton condition factor

TW = Total weight in gram

TL = Total length in centimeter

4.2.4 Data analysis

SPSS software version 21.0 and Microsoft Excel used to carry out the statistical and descriptive analysis. Descriptive statistics such as mean and standard deviation was used for morphometric description of the fishes. The relationship between length and weight of fishes were computed by linear regression method. Correlation analysis (r) was done in order to test statistical significance relationship between the total length and total weight of fishes. Independent t-test was used for comparison of the two slopes and body condition among the sexes at α=0.05. Under independent paired t-test, Monte Carlo permutation test at n=9999 was considered for the statistical test of the significance variation among the slopes and sexes. In addition, multivariate analysis (MANOVA) was used to test the significance difference of k values among the fish species. Chi square test was also used to assess the association of fish body condition and seasonal variation of the study area.

4.3 Results

4.3.1 Length distribution of fish species in Lake Langeno

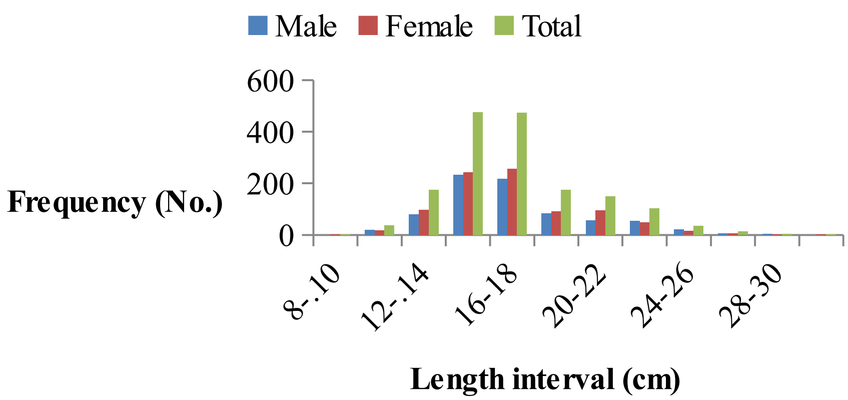
The study of length-weight relationship and condition factor was conducted for five fish species (1658 *O. niloticus,* 1712 *E. paludinosus,* 232 *C. gariepinus,* 256 *L. intermedius* and 294 *C. carpio*) collected using gillnets (6 cm, 8 cm, 10 cm and 12 cm) and long lines (hook size of No. 9 and 11) (Table 3.4). *Carassius carassius* and *G. dembecha* were not considered due to the small number of specimens collected for these species. For both sexes of *O. niloticus, E. paludinosus, C. gariepinus, L. intermedius* and *C. carpio,* the total length ranged between 9.0-30.5 cm, 3.3-12.1 cm, 18.0-68.5 cm, 15.5-53.5 cm and 14.5-51.0 cm, respectively. Their respective total weights ranged from17.5- 492.0 g, 0.3 - 13.1 g, 168.0 – 2692.0 g, 54.6 - 1303.8 g and 25.1 - 1604.3 g, respectively (Table 4.1).

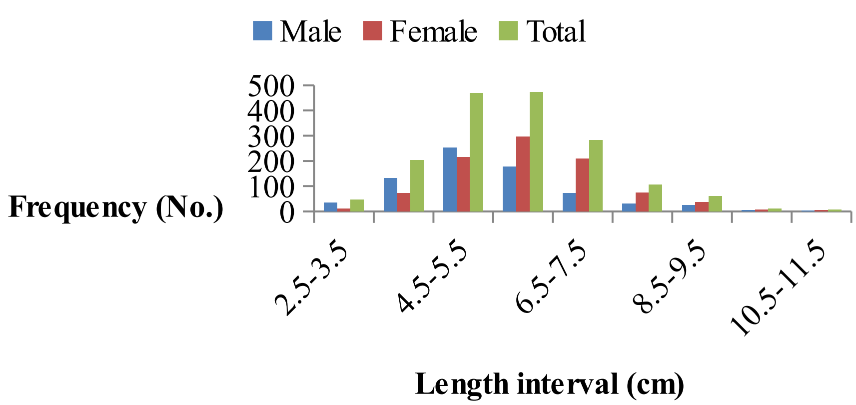
Table 4.1: Fish species sampled from Lake Langeno, Ethiopia from March 2014 to February 2016 (Min TL= Minimum total length, Max TL= Maximum total length, Min Wt= Minimum total weight, Max Wt= Maximum total weight, SD=Standard deviation).

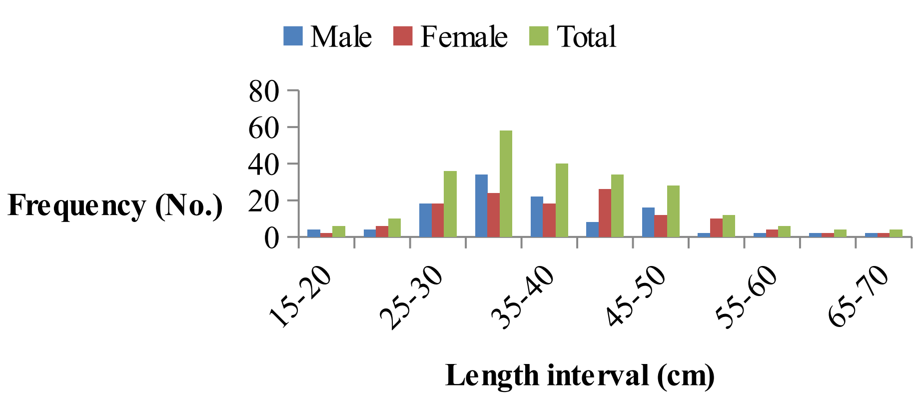
Species	**Sex**	**Total catch (no.)**	**Average catch month^{-1}**	**Min TL (cm)**	**Max TL (cm)**	**Mean TL±SD (cm)**	**Total weight (kg)**	**Min Wt (gm)**	**Max Wt (gm)**	**Mean (gm)**
O. niloticus	Male	778	32.4	10.3	29.0	17.3±3.3	77.9	17.5	428.5	100.6±6
	Female	880	36.7	9.0	30.5	17.3±3.2	88.6	18.5	492.0	101.2±6
	Total	**1658**	**69.1**	**9.0**	**30.5**	**17.3±3.2**	**166.5**	**17.5**	**492.0**	**101.6±6**
E. paludinosus	Male	765	30.6	3.5	11.5	6.3±1.2	2.1	0.4	20.3	2.7±1.5
	Female	947	37.9	3.3	12.1	6.1±1.2	2.7	0.3	13.1	2.6±1.6
	Total	**1712**	**68.5**	**3.3**	**12.1**	**6.2±1.2**	**4.9**	**0.3**	**13.1**	**2.6±1.5**
C. gariepinus	Male	112	4.5	18.0	65.5	37.5+10.3	70.7	168.9	1627.7	618.1±3
	Female	120	4.8	19.0	68.5	38.9±10.7	84.3	148.6	2692.0	708.0±4
	Total	**232**	**9.3**	**18.0**	**68.5**	**38.5±10.6**	**155.1**	**168.9**	**2692.0**	**663.8±4**
L. intermedius	Male	127	5.1	16.5	42.5	28.9±5.4	40.1	106.8	930.8	232.0±1
	Female	129	5.2	15.5	53.5	29.8±7.6	48.9	54.6	1303.8	376.3±2
	Total	**256**	**10.2**	**15.5**	**53.5**	**29.3±6.6**	**89.1**	**54.6**	**1303.8**	**349.5±2**
C. carpio	Male	138	5.5	15.5	51.0	31.9±7.6	62.6	26.5	1604.3	481.6±2
	Female	156	6.2	14.5	49.0	30.09±8.8	78.2	25.1	1396.0	476.6+3
	Total	**294**	**11.8**	**14.5**	**51.0**	**30.9±8.3**	**140.8**	**25.1**	**1604.3**	**478.8±2**
Total		**4152**	**173**				**558.0**			

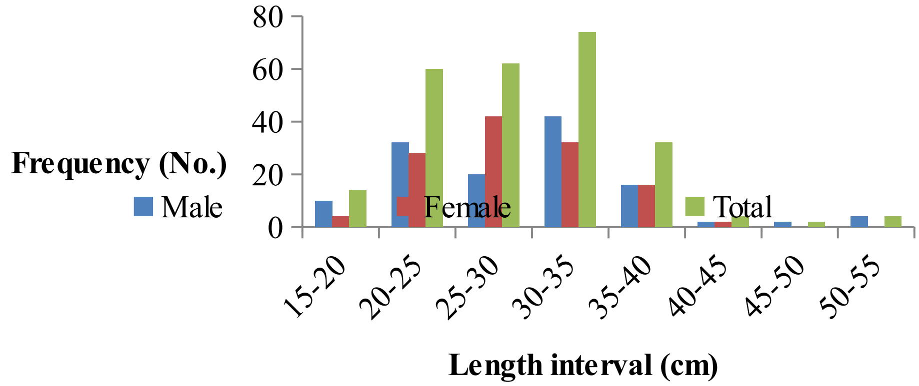
The greater proportion of sampled fishes were found between 14.0-18.0 cm TL, 4.5-6.5 cm FL, 30.0-35.0 cm TL, 20.0-35.0 cm FL and 25.0-40.0 cm FL for *O. niloticus*, *E. paludinosus, C. gariepinus, L. intermedius* and *C. carpio,* respectively (Fig. 4.1, a-e).

Generally, the result indicated that the populations of *O. niloticus* and *L. intermedius* were dominated by small size groups.









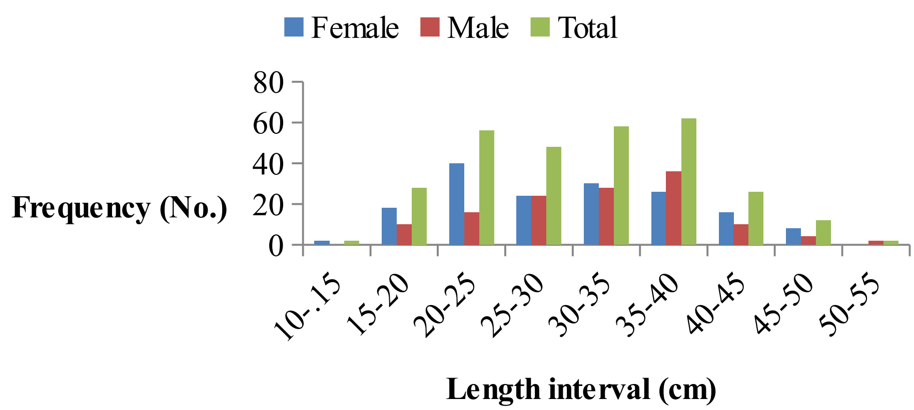
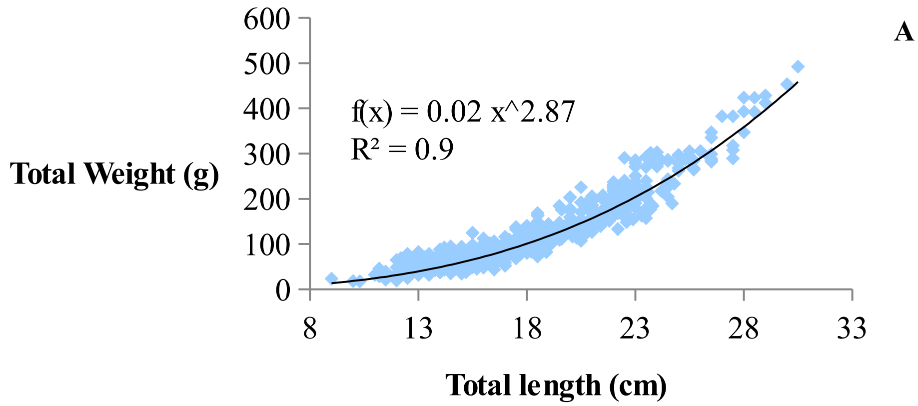
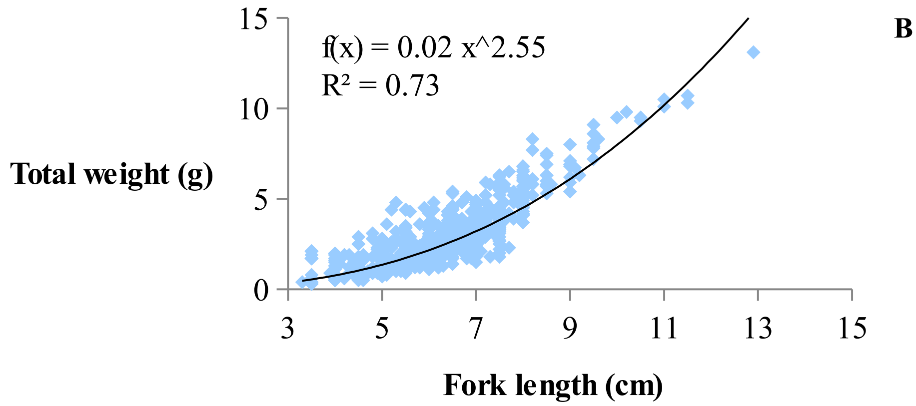


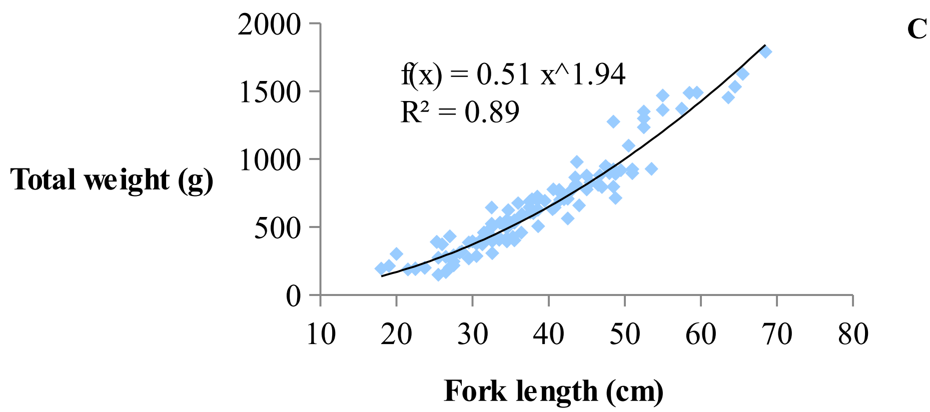
Figure 4.1: Length-frequency distribution of fish stocks in Lake Langeno, Ethiopia.

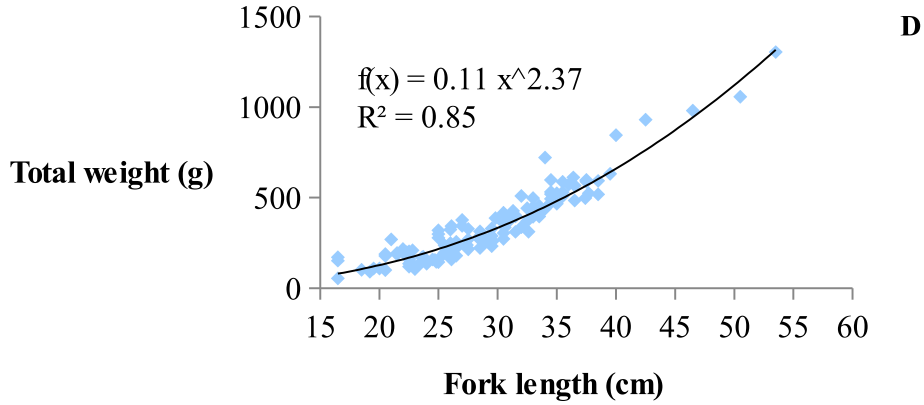
4.3.2 Length-weight relationship of fishes in Lake Langeno

The regressions analysis showed that the relationship between total length (TL) or Fork length (FL) and total weight (W) was curvilinear except for *C. carpio*, which showed linear relationship with a coefficient of determination (r^2) above 90% except for *E. paludinosus*. The relationship between the two was statistically significant for all fish species ($r>0.85$ and $p>0.05$) (Table 4.2). The mean value of length-weight coefficient b obtained for *O. niloticus* (b=2.88), *C. gariepinus* (b=2.82), *L. intermedius* (b=2.77) and *C. carpio* (b=2.92) showed nearly isometric growth, but *E. paludinosus* (b=2.55) had a negative allometric growth (Fig. 4.2, a-e). However, there was no significant difference observed in b values between the two sexes of all species (Monte Carlo , p>0.05).








D
f(x) = 0.11 x^2.37
R² = 0.85
Total weight (g)
1500
1000
500
0
15 20 25 30 35 40 45 50 55 60
Fork length (cm)

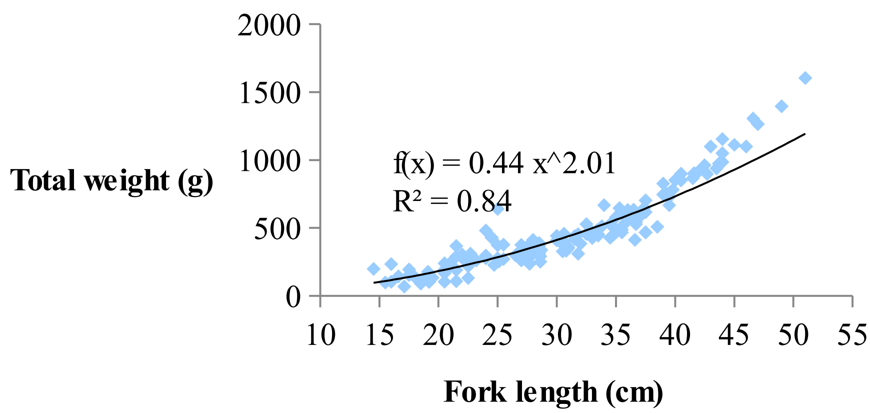

f(x) = 0.44 x^2.01
R² = 0.84
Total weight (g)
2000
1500
1000
500
0
10 15 20 25 30 35 40 45 50 55
Fork length (cm)

Figure 4.2: Length-weight relationship of (a) *O. niloticus* (b) *E. paludinosus* (c) *C. gariepinus* (d) *L. intermedius* (e) *C. carpio* in Lake Langeno, Ethiopia from March 2014 to February 2016.

Table 4.2: The summary of statistical analysis of the relationship between total length and total weight of fish species collected from Lake Langeno, Ethiopia. Astirics indicate the significance relationship.

Fish species	r value	p value
O. niloticus	0.94	0.001**
E. paludinosus	0.86	0.001**
C. gariepinus	0.96	0.001**
L. intermedius	0.95	0.001**
C. carpio	0.93	0.001**

4.3.3 Body condition factor of fishes in Lake Langeno

4.3.3.1 General condition factor of fishes

The fish species sampled in this study showed K value >1.0 except for *C. gariepinus* (Table 4.3). The result showed a highly significant difference in FCF value among the species (MANOVA, P<0.05). However, the result did not show a significant difference among the sexes for all fish species (Monte Carlo, p>0.05).

Table 4.3: Fulton condition factor obtained for five fish species sampled in Lake Langeno, Ethiopia (Mean TL= Mean total length, Mean Wt= Mean total weight, SD= Standard deviation; SE= Standard error). Astrics indicate the significant difference.

Species	Sex	Mean k±SE	t-value	p-value
O. niloticus	Female	1.76±0.4		
	Male	1.79±0.4	0.56	0.061*
	Total	**1.77±0.4**		

E. paludinosus	Female	1.05±0.5		
	Male	1.07±0.4	-1.79	0.074
	Total	**1.06±0.4**		
C. gariepinus	Female	0.59±0.5		
	Male	0.63±0.5	-0.58	0.56
	Total	**0.60±0.5**		
L. intermedius	Female	1.31±0.4		
	Male	1.34±0.5	0.33	0.74
	Total	**1.33±0.4**		
C. carpio	Female	1.46±0.7		
	Male	1.57±0.9	-1.86	0.068
	Total	**1.47±0.8**		

4.3.3.2 Seasonal variation in Fulton Condition Factor of important fish species

The mean monthly FCF value of *O. niloticus* ranged between 1.64 (in March) and1.89 (in July) with mean value of 1.74. On the other hand, the minimum and maximum FCF value of *C. gariepinus* was found in June (0.52) and October (0.64), respectively with the mean value of 0.58. The minimum and maximum condition factor for *L. intermedius* was recorded in July (1.26) and March (1.56), respectively with the mean value of 1.42. *Cyprinus carpio* showed a minimum FCF value in April (1.35) and maximum in November (1.64) with the mean FCF of 1.49. Generally, the result showed a significant association of fish condition factor and seasonal variation of the study area for all studied species (χ^2, $p<0.05$) (Table 4.4).

Table 4.4: The monthly variation of FCF of commercially important fish species sampled from Lake Langeno from March 2014 to February 2016 (K= Fulton condition factor value, SD= Standard deviation). Chi square test was calculated at α=0.05. Astrics indicates the significance association.

Months	*O. niloticus* K±SD	*C. gariepinus* K±SD	*L. intermedius* K±SD	*C. carpio* *K*±SD
March, 2014	1.88±0.03	0.61±0.14	1.59±0.12	1.36±0.21
April, 2014	1.91±0.05	0.60±0.17	1.64±0.11	1.36±0.25
May, 2014	1.88±0.04	0.54±0.16	1.46±0.22	1.39±0.26
June, 2014	1.73±0.03	0.55±0.06	1.40±0.07	1.47±0.21
July, 2014	1.71±0.02	0.53±0.07	1.32±0.16	1.47±0.20
August, 2014	1.68±0.03	0.56±0.17	1.29±0.05	1.58±0.11
October, 2014	1.76±0.03	0.66±0.08	1.40±0.03	1.64±0.19
November, 2014	1.76±0.02	0.64±0.15	1.46±0.11	1.65±0.14
December, 2014	1.85±0.06	0.59±0.08	1.45±0.06	1.59±0.21
January, 2015	1.86±0.02	0.56±0.07	1.52±0.09	1.46±0.15
February, 2015	1.85±0.02	0.58±0.08	1.54±0.07	1.43±0.11
March, 2015	1.74±0.02	0.58±0.12	1.56±0.11	1.37±0.07
April, 2015	1.81±0.03	0.56±0.14	1.57±0.13	1.34±0.11
May, 2015	1.77±0.03	0.53±0.11	1.41±0.10	1.36±0.13
June, 2015	1.66±0.02	0.53±0.12	1.38±0.10	1.44±0.12
July, 2015	1.51±0.02	0.55±0.12	1.27±0.12	1.49±0.11
August, 2015	1.57±0.02	0.58±0.12	1.28±0.11	1.59±0.07
September, 2015	1.53±0.02	0.59±0.13	1.30±0.10	1.57±0.10
October, 2015	1.65±0.02	0.63±0.12	1.38±0.12	1.61±0.13
November, 2015	1.69±0.02	0.60±0.13	1.41±0.13	1.63±0.12
December, 2015	1.74±0.02	0.56±0.12	1.40±0.13	1.54±0.14
January, 2016	1.76±0.01	0.52±0.13	1.48±0.12	1.43±0.

				13
February, 2016	1.71±0.02	0.54±0.13	1.50±0.13	1.40±0.12
Chi-square	14.27	10.65	8.92	8.39
p-value	0.031*	0.048*	0.046*	0.049*

4.4 Discussion

4.4.1 Length frequency distribution

The results indicated that small sized fishes have dominated the lake (Fig. 4.1, a-e). For instance, the maximum size recorded for *O. niloticus* in this study (30.5 cm) (Table 4.1) is very small as compared to the maximum size recorded for the same species in Lake Zeway (34 cm) (Lemma Abera, 2016), Amerti Reservoir (Mathewos Hailu, 2014) (35.5 cm), Koka Reservoir (35.2 cm) (Flipos Engdaw *et al*., 2013) and Fincha Reservoir (42.0 cm) (Fasil Degefu *et al.,* 2012). Catching the small sized fish is the characteristics of overfished and overstressed population. It is an adaptive mechanism by which fish cope-up with real or perceived stressors in order to maintain its normal or homeostatic state (Barton, 2002; Mous *et al.,* 2002). However, the size determined in this study were higher than those reported from Lake Beseka (25.0 cm) (Lemma Abera, 2013), Lake Babogaya (28.0 cm) (Lemma Abera, 2012b) and Lake Hayq (28.0 cm) (Workiye Worie and Abebe Getahun, 2014). This could be due the variation in gear size used, habitat and season of the fish sample collection (Amezcua and Amezcua-Linares, 2014; Portt *et al.,* 2006). Lake Beseka is highly saline lake than Lake Langeno (Eleni Ayalew, 2009), whereas Lakes Babogaya (Denbere Belay, 2007) and Hayq (Tadesse Fetahi*et al.,* 2011) are the highland lakes with a low water temperature, which influences the growth rate of fishes like *O. niloticus* directly or indirectly (Langland and Cronin, 2003).

On the other hand, the maximum size recorded for *C. gariepinus* sampled in this study (68.5 cm) (Table 4.1) is less than the previous report of Leul Teka (2001) in the same lake (104.0 cm). This indicates the decreasing trend of the fish size, which implies an overfishing of the lake or the changing of the water parameters. It is also less than the reports from other lakes, like Lake Zeway (96.0 cm) (Lemma Abera, 2016), Lake Babogaya (102. 0 cm) (Lemma Abera *et al*., 2014b), Lake Chamo (90.0 cm) (Elias Dadebo *et al.,* 2011) and Lake Wamala (Uganda) (90.0 cm) (Olokotum, 2015). The small size could be attributed to the low availablity of food or low quality of food in the water (Alebachew Tade, 2014) or the types of gears used for collection of the specimen (Portt *et al.,* 2006). However, the result is comparable with that of Keyombe *et al*. (2015) in Lake Naivasha (71.0 cm).

The maximum size recorded for *L. intermedius* in this study (53.5 cm FL) (Table 4.1) is comparable with the report made in Koka (49.0 cm) (Elias Dadebo *et al.,* 2013) and Gilgel Gibe I (54.0 cm) Reservoirs (Mulugeta Wakjira, 2013). However, it is greater than that of Lake Tana's gulf of Gorgora (43.8 cm) (Flipos Engdaw, 2014) and Lake Zeway (44.0 cm) (Lemma Abera, 2016). The seasonal variation of sample collection (Amezcuaand Amezcua-Linares, 2014) and the type of fishing gears used (Portt *et al.,* 2006) might be a reason for a variation of fish size. The maximum size recorded for *C. carpio* (51.0 cm FL) (Table 4.1) was comparable with the finding of Lemma Abera *et al*. (2015) from Lake Zeway (48.0 cm). However, it was less than the reports made by Fasil Degefu *et al*. (2012), Elias Dadebo *et al*. (2015) and Aera *et al.* (2014) from Fincha Reservoir (60.0 cm), Koka Reservoir (78.0 cm) and Lake Naivasha (60.0 cm), respectively. The variation in physico-chemical properties and elevation, which determine the availability of fish food in the water might be a responsible factor for small size of the fishin this study (Aera *et al*., 2014; Elias Dadebo *et al*., 2015; Lemma Abera *et al*., 2015). It was greater than the finding of Mathewos Hailu (2013) from Amerti Reservoir (45.0 cm) due the same problem.

4.4.2 Length-weight relationship (LWR)

The result obtained for LWR showed that most the fish species (*O. niloticus*, *C. gariepinus* and *C. carpio*) have obeyed the cube law of Bagenal and Tesch (1978), which assumes the regression slope (b) to be three or nearly three (2.8-3.2). This shows that the fishes are undergoing unchangeable body form in their growth (“b” is constant all over its life span, or some portion of life span). However, *L. intermedius* and *E. paludinosus* have shown negative allometric growth ($b<2.8$) (Fig. 4.2, a-e and Table 4.2), which indicates a decrease trend in body condition or an elongation in a body form with an increasing of the body length. Many authors indicated that isometric growth is the most appropriate for describing morphometric growth of fishes (Bagenal and Tesch, 1978; Lleonart *et al.*, 2002). Perhaps, it appears to be rare in nature, and the calculation is not optimally applicable to all metric comparisons, because the morphometric relationship reflects the effect of different factors, such as habitat type and feeding habits on the fish growth. The larger difference from 3.0 indicates the larger the change in condition or form of fish.

The coefficient of LWRs b recorded for *O. niloticus* in the present study ($b=2.872$) (Fig. 4.2, a) corroborates the isometric growth reported in different water bodies of Ethiopia (Dereje Tewabe, 2014; Fasil Degefu *et al*., 2012; Flipos Engdaw *et al.,* 2013; Gashaw Tesfaye and Zenebe Tadesse, 2008; Lemma Abera, 2016; Workiye Worie and Abebe Getahun, 2014) and in Lake Baringo, Kenya (Kembenya *et al.,* 2014). However, Lemma Abera (2013) reported a negative allometric growth for the same species in Lake Beseka. This could be attributed to the poor habitat (Eleni Ayalew, 2009), which could determine the growth rate of the fish.

The isometric growth obtained for *C. gariepinus* (Fig. 4.2, b) in our study is also in agreement with the former report of Leul Teka (2001) for Lake Langeno, and the reports of Lemma Abera *et al*. (2014b) and Lemma Abera (2016) in Lake Babogaya and Lake Zeway, respectively. Nevertheless, Dereje Tewabe (2014) reported negative allometric growth for the same species from the tributary river of Lake Tana, and Kembenya *et al.* (2014) and Keyombe *et al.* (2015)

reported positive allometric growth from Lakes Baringo and Naivasha, respectively. The variation of habitat and environmental parameters, which directly or indirectly influences the availability of food in the lake might have resulted the variation in growth of fish. For instance, the tributaries of Lake Tana are the highland running waters, whereas Lakes Baringo and Naivasha are shallower and highly vegetative than Lake Langeno.

Our finding also showed nearly isometric growth (b=2.77) (Fig. 4.2, c) for *L. intermedius,* which is in agreement with the growth of the same fish species reported from some tributaries of Lake Tana (Gizachew Teshome *et al.*, 2015), Lake Tana (Flipos Engdaw, 2014; Shewit Gebramedin *et al.*, 2014), Blue Nile River (Tadlo Awoke *et al.*, 2015), Gilgel Beles River (Zeleke Berie, 2007) and Lake Baringo, Kenya (Kembenya *et al*., 2014).

Cyprinus carpio showed isometric growth (b=2.91) (Fig. 4.2, d), which is in agreement with the finding of Lemma Abera (2016) and Mathewos Hailu (2013) in Lake Zeway and Amerti Reservoir, respectively. However, Aera *et al.* (2014) reported negative allometric growth for the same species in Lake Naivasha, Kenya, which is highly under the threat of anthropogenic activities (Becht *et al*., 2015). Generally, the differences in habitat types and food availability in the water bodies might have caused the growth variation for all fish species. According to Suquet *et al.* (2005), growth performance of fish (b value) can vary in different places and at certain time of the year depending on the variation of biological factors, such as availability of foods, quality and quantity of foods, feeding rate and spawning period of fish. In addition, environmental factors, such as water temperature, dissolved oxygen concentration, salinity and photoperiods influences the growth of many fish species (According to Dutta, 1994).

4.4.3 Condition factor

The measure of fish condition is determined by many various factors. Changes of food abundances, fluctuation of water level and water quality, and temperature of the water determine the body condition of fishes (Otieno *et al.,* 2014). The high body condition indicates the higher energy content, adequate food availability, reproductive potential and favorable environmental conditions (Pauker and Rogers, 2004).

The mean FCF obtained for *O. niloticus* in this study (1.74) (Table 4.3) was less than that of Gashaw Tesfaye and Zenebe Tadesse (2008) (1.84) in the same study lake, which showed a poor body condition of the fish as compared to the previous report. The result is also very small as compared to FCF of the same species reported in other Ethiopian lakes, such as Lake Hayq (1.81) (Workiye Worie and Abebe Getahun, 2014), Lake Zeway (1.82) (Lemma Abera, 2016), Lake Tana (1.89) (Zenebe Tadesse, 1997), Lake Babogaya (2.13) (Lemma Abera, 2012b) and Fincha Reservoir (1.83) (Fasil Degefu *et al*., 2012). The FCF was, however, greater than the reports made in Lake Victoria, Kenya (1.07) (Njiru *et al*., 2004a). This could be attributed to the poor food availability and environmental condition of the lake (Zenebe Tadesse, 1999). The poor body condition is usually associated with poor feeding and/or environmental conditions and vice versa (Dutil and Lambert, 2000; Pothoven *et al.,* 2001). According to Zenebe Tadesse (1999), the diet of *O. niloticus* in Lake Langeno is composed of a mixture of algal-based detritus, macrophytes scraps, phytoplankton and silt; which is very low in protein contents. The poor body condition observed in the wet season (Table 4.4) for *O. niloticus* coincides with the peak breeding time of the fish, which is in agreement with the findings in other parts of Ethiopia (Lemma Abera, 2012b; Workiye Worie and Abebe Getahun, 2014) and in other tropical countries (Dan-kishiya, 2013; Kembenya *et al*., 2014). This is because body condition of many fish species decreases during the low availability of foods and spawning period of fishes (Dutta, 1994; Froese, 2006). According to Froese (2006), fish at periods before reproductive time begin to show a marked departure from the law, and that changes may arise from the seasonal variation. The sudden loss of weight immediately after spawning period is also marked, although it appears to be rapidly regained.

The mean FCF recorded for *C. gariepinus* in this study (0.58) (Table 4.3) was less than the finding of Leul Teka (2001) for the same lake (0.61). The reduction of fish body condition is considered as adaptive responses to harsh environmental conditions and energetic stress (Huusko *et al.,* 2011). For instance, the study conducted by Wikelski and Thom (2000) indicated the shrinkage of fish body condition by 20% over the years of El-Nino events, which is very similar with our study period. It was also less than the reports made in Lake Babogaya (0.64) (Lemma Abera *et al.,* 2014b), Lake Zeway (0.76) (Lemma Abera, 2016), Lake Naivasha (0.89) (Keyombe *et al*., 2015) and Lake Wamala (1.08) (Olokutuma, 2015) for the same species. The poor body condition in this lake indicates the low availability of food for the fish or poor environmental condition as compared to the mentioned lakes above, because *C. gariepinus* are mainly relay on insects, snails and other invertebrates for food than phytoplankton (Omondi *et al*., 2013), which is very low in this study area (Alebachew Tade, 2014). A better body condition observed in months from August to December for *C. gariepinus* (Table 4.4) was strongly associated with the non-reproductive season of the fish (Imam *et al.*, 2010; Lemma Abera *et al.*, 2014b).

The mean FCF of *L. intermedius* in Lake Langeno (1.33) (Table 4.3) is comparable with that of same fish species in Lake Tana (1.29) (Shewit Gebramedin *et al*., 2014) and in some tributary rivers of Lake Tana (1.21) (Gizachew Teshome *et al.*, 2015). However, it showed slightly poor body condition as compared to the same species in Lake Zeway (1.73) (Lemma Abera, 2016).

This indicates the variation of food availability or water parameters in these two lakes, which is unclear at this stage and needs further study. A better body condition observed in dry season for *L. intermedius* (Table 4.4) is also associated with the non-reproductive season, which is in agreement with the findings of Shewit Gebremedhin *et al.* (2014), Flipos Engdaw (2014) and Tadlo Awoke *et al.* (2015) for the same species in different parts of Ethiopia.

Cyprus carpio in Lake Langeno had a poor body condition (1.47) (Table 4.3) than those in Lake Zeway (1.63) (Lemma Abera *et al*., 2015), but had a better body condition than those in Amerti Reservoir (1.22) (Mathewos Hailu, 2013) and Lake Naivasha (1.23) (Aera *et al.,* 2014). Carps are primarily selective benthic omnivores, specialized on invertebrates found in sediments (insects, crustaceans, crawfish and benthic worms) (Lammens and Hoogenboezem 1991). However, Alebachew Tadie (2014) reported that phytoplankton and detritus is highly dominant in Lake Langeno. Therefore, the poor body condition obtained in this study might be arising from the poor habitat and less availability of these food items in the lake. A better body condition recorded in wet season (Table 4.4) could also be associated with the availability these food items in this season, which is in agreement with that of Lemma Abera *et al.* (2015) in Lake Zeway and Singh *et al.* (2015) in West Bengal, India.

Our finding also indicated that females of all fish species relatively had poor body condition than males (Table 4.2). Condition factor shows variation that happens seasonally due to sex and gonad development (Flipos Engdaw, 2014**;** Froese, 2006; Morgan, 2008). This is because large part of energy is allocated for growth, ovary development and spawning of female fishes which results in the lower body condition of female fishes (Aera *et al.,* 2014; Froese, 2006).

In general, our result showed that most of the fish species had a poor body condition in Lake Langeno. This shows that either there is no sufficient food in the lake or the changing of environmental conditions caused the poor body condition of fishes. Females of all fish species had comparatively lower body condition than males, which may be attributed to the metabolic activities during maturation or spawning, and changes in feeding activity (Aera *et al*., 2014; Flipos Engdaw, 2014).

CHAPTER FIVE

5. REPRODUCTIVE BIOLOGY OF SOME FISH SPECIES IN LAKE LANGENO, ETHIOPIA

5.1 Introduction

In fish biology, knowledge of fish reproductive biology is very important for the rational utilization of fish stocks and their sustainable production (Cochrane, 2002). Understanding the reproductive aspects of fish is also very important for providing sound scientific advice in fishery management (Domínguez-Petit *et al*., 2015). Availability of fish reproductive data is important for a better understanding of the observed fluctuations in a population (Shalloof and Salama, 2008). Studies on breeding season, fecundity and their associated factors are usually used to protect the new recruits and predict recruitment variability (Domínguez-Petit *et al*., 2015; Gómez-Márquez *et al*., 2003). Life history parameters, such as size or age at sexual maturity, sex ratio and spawning time considerably vary between fish species (Fitzhugh *et al*., 2012). This variation involves balancing of energy allocation between fish growth, reproduction and interactions with mortality (Morgan, 2008). Observation of changes in seasonal gonad development is the most suitable method for determining the reproductive biology of fishes (Gómez-Márquez *et al*., 2003). Study of seasonal gonad development is usually conducted through an observation of morphological changes that gonad undergo to attain full growth and ripeness (Sivakumaran *et al*., 2003).

Lake Langeno is known for its high contribution of fish catch to the local and national markets (Gashaw Tesfaye and Wolff, 2014). However, very limited studies have been conducted on the reproductive biology of the fish species, except on the size at sexual maturity of *O. niloticus*

(Gashaw Tesfaye and Zenebe Tadesse, 2008) and *C. gariepinus* (Leul Teka, 2001) in the lake. This study thus focused on assessing the reproductive biology (sex ratio, breeding season, length at sexual maturity and fecundity) of the most important fish species in Lake Langeno, in order to provide the robust and updated information for both studied and non studied fish species.

5.2 Materials and methods

5.2.1 Estimation of sex-ratio, breeding season and gonado-somatic index

Sexes of the individual fish specimens were differentiated visually by dissecting all of the collected fishes. Maturity stage of fishes were assessed based on size, appearance, shape, texture and color of the gonads following fish maturity indexes (Armstrong *et al.,* 2004; Demeke Admassu, 1996; Hörstgen-Schwark and Langhölz, 1998) as described in Annex 4**.** Ovary of the matured fishes were removed and preserved in 10% formalin immediately. The preserved ovaries were transported to ZFRRC for further analysis. The proportion of fishes representing the five-point maturity scales by sex was estimated (Demeke Admassu, 1996). The percentage of fishes in different stages of maturity was calculated as:

$$MS_i\% = \frac{MSi}{\sum_{i=1}^{5} MSi} 100^4$$

Where: MSi% = the percent fish of maturity stage i

MSi = number of fish in maturity stage i

∑ MSi = total number of fish of all maturity stages (1 to 5)

Sex ratio (Female: Male) was also calculated for each species and the total samples. The breeding season of all sampled fishes was determined from the percentage of fishes with ripe gonad sampled in each month. The Gonado Somatic Index (GSI) was also computed for each fish species to determine the breeding season of fishes in the lake (Armstrong *et al*., 2004).

GSI = (GW/ TW) X 100

Where, GSI = Gonado somatic index

GW = Gonad weight in g

TW = Total weight in g where mass of the gonad is the mass of the fresh gonad, blotted on absorbing paper

5.2.2 Estimation of length at 50% sexual maturity (L_{50})

First, the total/ fork length and total weight of each fish specimen with mature gonads were measured for the purpose of reproductive biology assessment using measuring board to the nearest 0.1 cm, and sensitive balance with a sensitivity of 0.1 g. An investigation of length at sexual maturity (L_{50}) was done based on the length of fishes with mature gonads (Owiti and Dadzie, 1989).

5.2.3 Estimation of fecundity

Estimation of fish fecundity was carried out for female fishes with mature gonads (maturity stage of V ovaries). The ripe gonads of mature female fishes were removed and preserved in Gilson's fluid (Simpson, 1959). In the laboratory, after vigorous shaking, gonads (eggs) of each ripe female fish were weighed to the nearest 0.01 g using a sensitive balance. The preserved ovaries were washed with tap water, and ovarian membranes were removed mechanically. For estimation of fecundity of *O. niloticus*, the total eggs were directly counted. However, for *C. gariepinus, L. intermedius* and *C. carpio*, three sub-samples of 1 g eggs per ovary were counted, and the total number of eggs per ovary was estimated by proportion.

The total number of eggs was computed using the following formula:

N/n = W/ w, from which N= (nW)/ w

Where, N - Total number of eggs

n - Number of eggs in sub sample (=1000)

W - Weight of all eggs (g)

w - Mean weight of the sub sample (g)

Finally, the mean fecundity was determined for each of fish species at their total/ fork length and total weight (Wt).

5.2.4 Data analysis

Data were analyzed using SPSS statistical software version 20.0, and presented using various descriptive statistics. Non parametric Chi square test was performed for a single variable in order to see the heterogeneity of sex ratio and maturity stages between the two sexes. Linear regression was used to obtain the coefficient of determination of fecundity-total length, fecundity-total weigh and fecundity-gonad weight relationship of the fishes followed by correlation analysis in order to see the statistical test of significant relationship between fecundity and the total/ fork length, fecundity and total weight and fecundity and gonad weight of the fishes. In addition, permutation test was considered in order to see the significance relationship between fecundity and the total/ fork length, fecundity and total weight.

5.3 Results

The reproductive biology was assessed for 4,152 of fish specimens representing five fish species (*O. niloticus, E. paludinosus, C. gariepinus, L. intermedius* and *C. carpio*). Because of the small number of specimens collected for *C. carassius* and *G. dembecha*, the reproductive aspect was not considered in this study

5.3.1 Sex ratio of the collected fish species

From the 4,152 fish specimens collected, 46.24% (n=1,920) were males and 53.76% (n=2,232) were females. The sex ratio of *O. niloticus* and *E. paludinosus* were significantly different from the hypothetical ratio of 1:1 with the Chi square greater than two ($p<0.05$) (Table 5.1).

Table 5.1: Number and the corresponding sex ratios of fish species collected from Lake Langeno, Ethiopia from March 2014 through February 2016. Chi-square test was performed at $\alpha=0.05$ (Astrict was used for the significant values).

Fish species	**No. individuals**					
	Total	**Female**	**Male**	**Sex ratio**	**Chi square**	**p-value**
O. niloticus	1658	880	778	1.13:1	2.72	0.014*
E. paludinosus	1712	947	765	1.24:1	6.35	0.000*
C. gariepinus	232	120	112	1.07:1	1.29	0.456
L. intermedius	256	129	127	1.02:1	0.71	0.790
C. carpio	294	156	138	1.13:1	1.84	0.161
Total	**4152**	**2257**	**1950**	**1:16:1**	**5.14**	**0.001**

5.3.2 Maturity and breeding season of fish species in Lake Langeno

Totally, 2440 fish specimens (47.34% (n=1,155) males and 52.67% (n=1,285) females) were examined for this study, because the study of reproductive biology focused only on large fish stocks, which are commercially important (*O. niloticus, C. gariepinus, L. intermedius* and *C.*

carpio). The result showed that fishes with the maturity stage two (II) were dominant in both sexes of all fish species followed by maturity stage three (III). The proportion of males and females with sexually mature gonads (IV) were 8.9 and 10.3% for *O. niloticus*, 28.3 and 19.4% for *C. gariepinus*, 17.7 and 18.5% for *L. intermedius* and 11 and 23.1% for *C. carpio,* respectively (Fig. 5.1, a-d). The proportion of maturity stages between the two sexes were very homogenous for all fish species (χ^2, $p>0.05$).

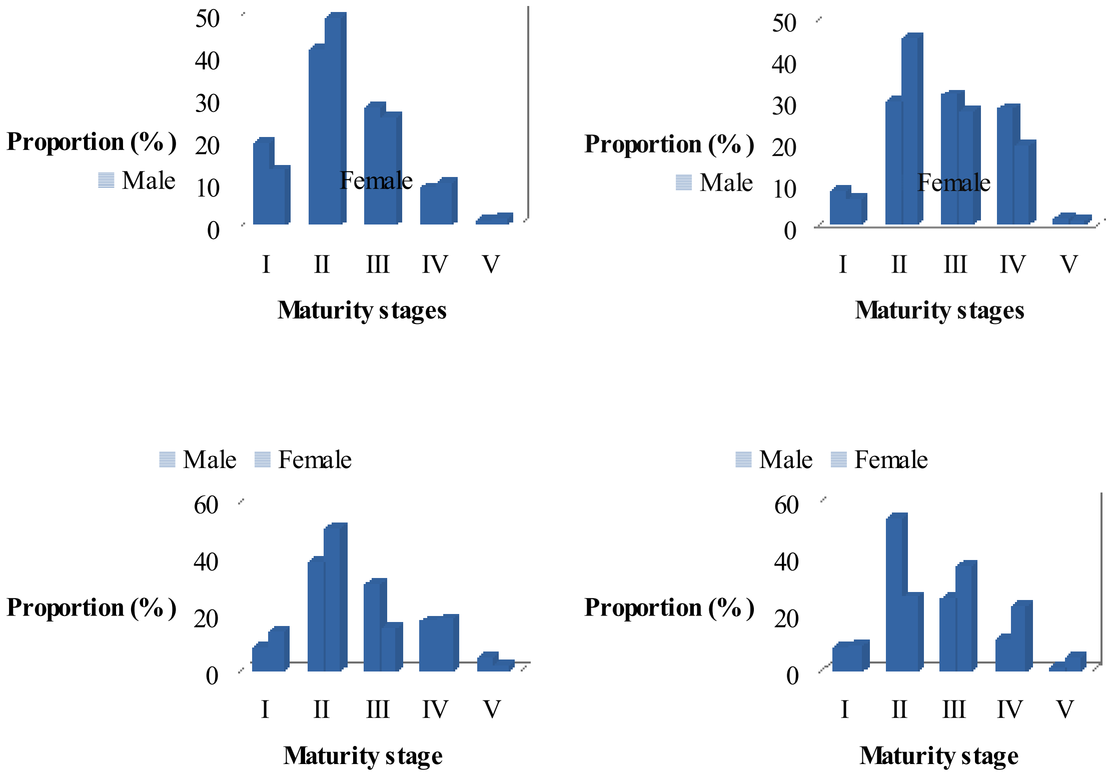


Figure.5.1: Proportion of gonad maturity stages of *O. niloticus* (a), *C. gariepinus* (b), *L. intermedius* (c) and *C. carpio* (d) in Lake Langeno, Ethiopia from March 2014 to February 2016 (I= maturity stage one, II, maturity stage two, III= maturity stage three, IV= maturity stage four, V=maturity stage five).

On the other hand, the proportion of fishes with the fully mature gonads showed a significant seasonal association for all species (χ^2, $p<0.05$). For instance, high number of fish with fully mature gonads (IV) was collected between April to June, June to July, June to August and March to May for *O. niloticus, C. gariepinus, L. intermedius* and *C. carpio,* respectively, whereas the least number of fish species with mature gonads was collected in October to November, October to December, October to December and September to November, respectively (Fig. 5.2, a-d).

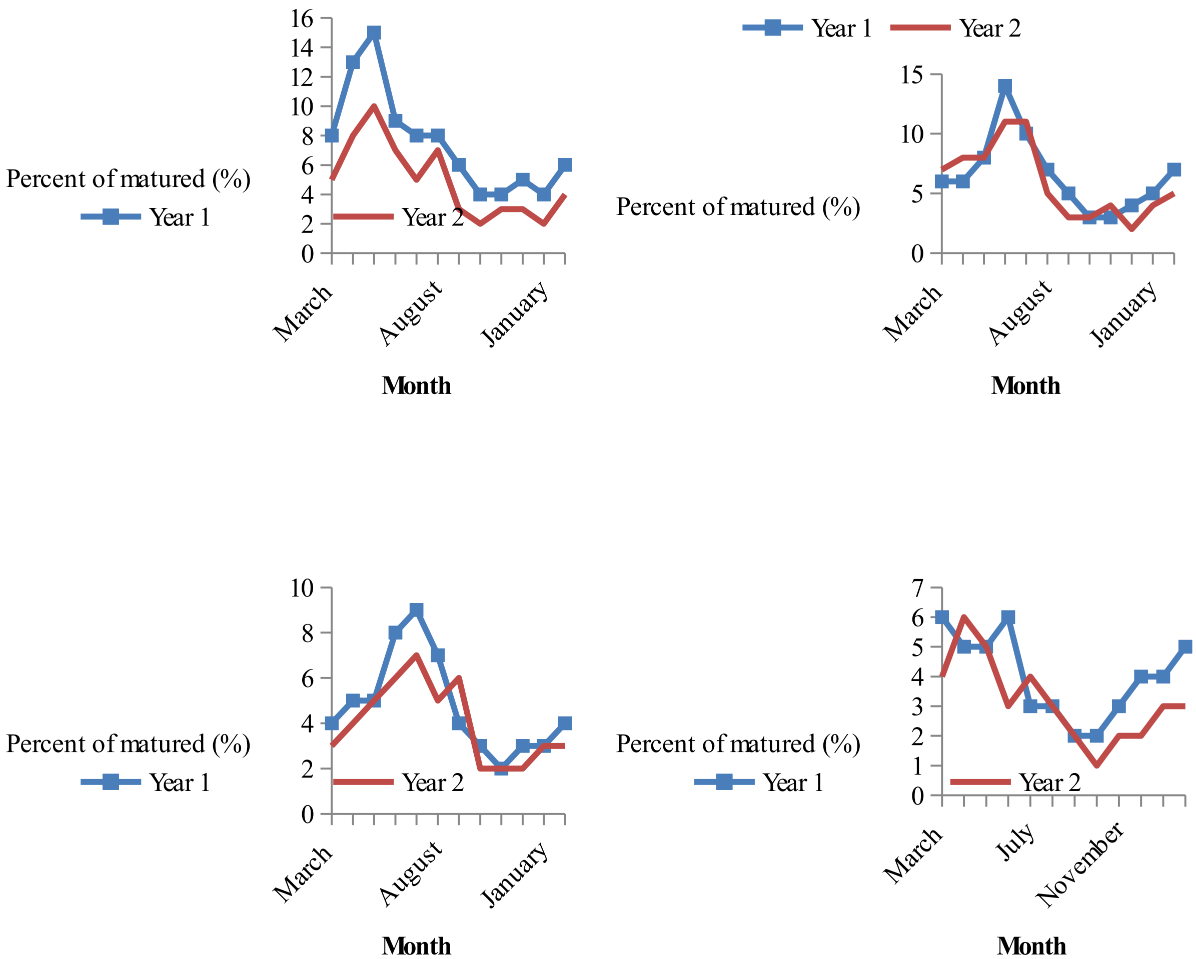
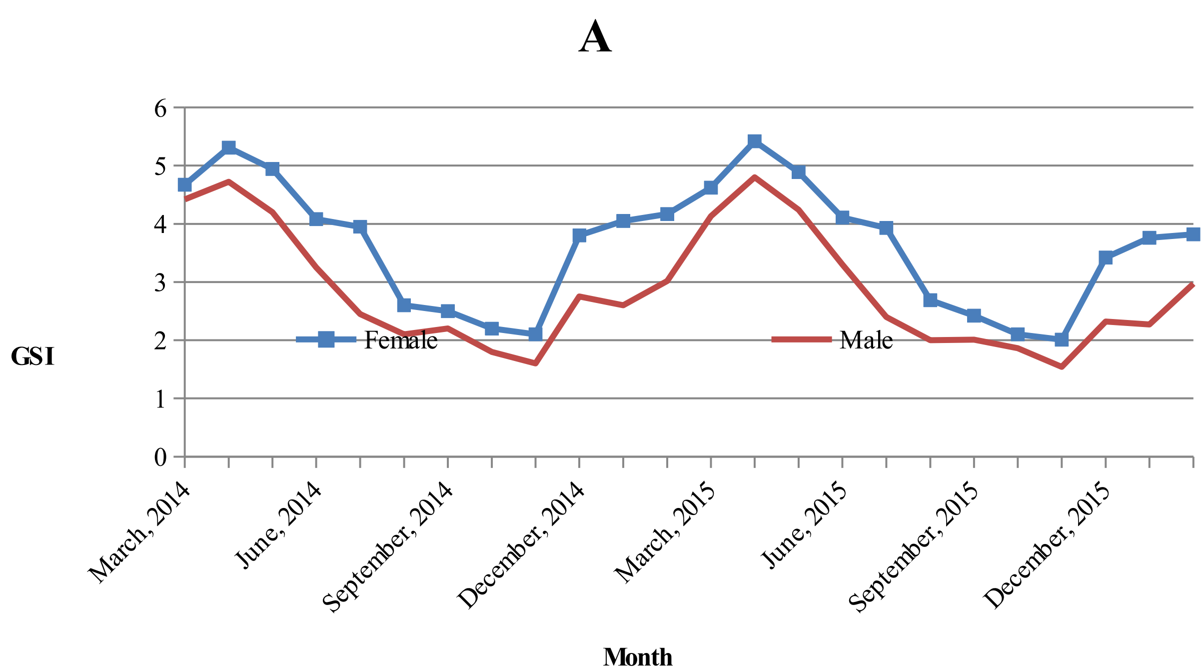


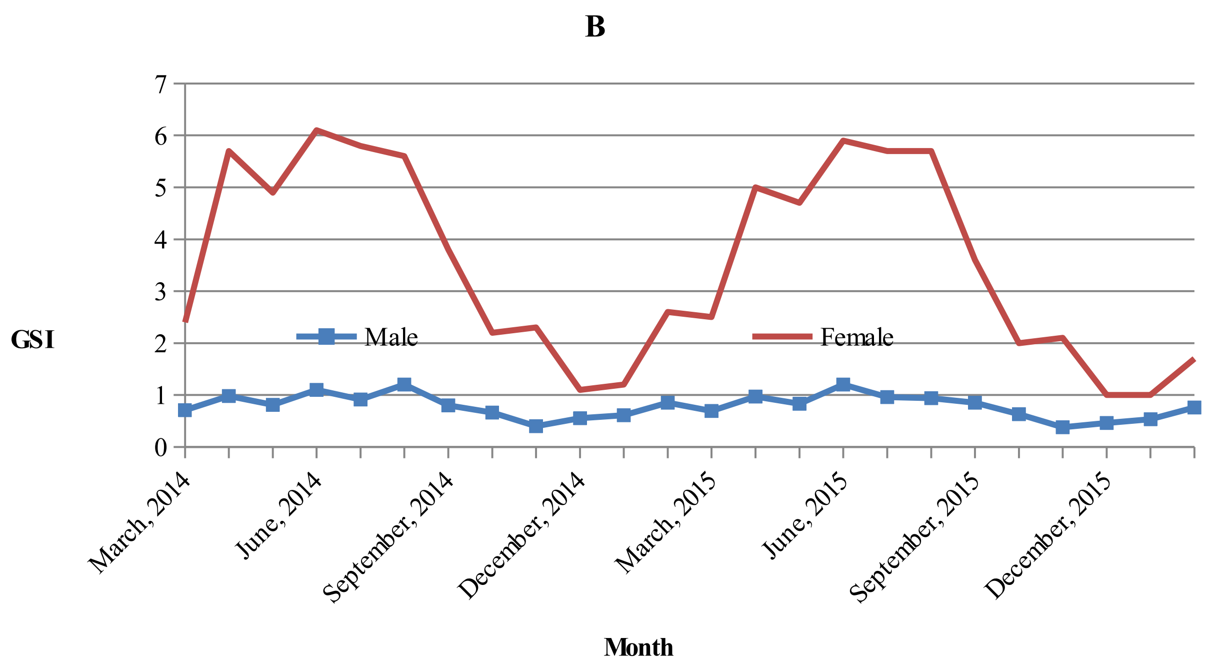
Figure 5.2: Monthly distribution of *O. niloticus* (a), *C. gariepinus* (b), *L. intermedius* (c) and *C. carpio* (d) with ripe gonads collected from Lake Langeno, Ethiopia from March 2014 to February 2016.

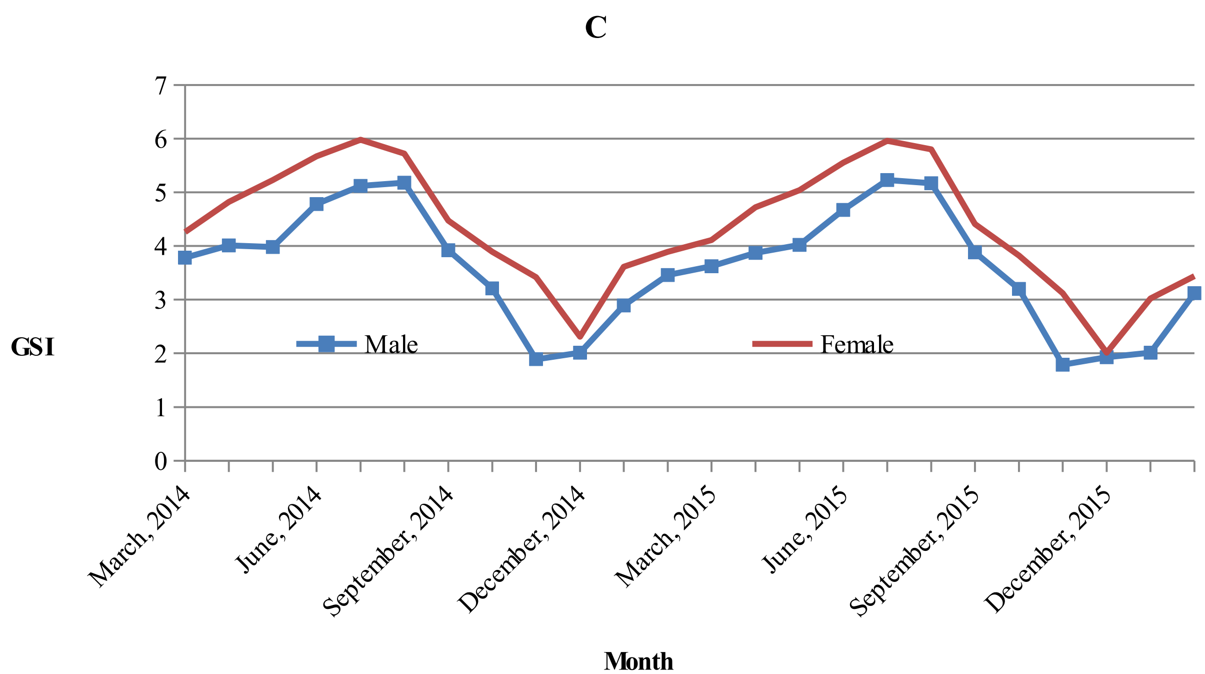
5.3.3 Gonadosomatic Index (GSI) of fish species

The monthly variation of GSI for *O. niloticus* ranged from 2.1 to 5.3 (mean 3.8±1.1) for females and 1.6 to 4.7 (mean 2.9±1.1) for males. The highest GSI was observed in April, and the least was observed in November (Fig. 5.3A). Similarly, the GSI value of *C. gariepinus* ranged from

1.1 to 6.1 (mean 3.6±1.9) for females and 0.4 to 1.2 (mean 0.8±0.2) for males with the highest and least GSI value recorded in June and December, respectively (Fig. 5.3B).In other words, *L. intermedius* had GSI values ranging from 2.31 to 5.98 (mean 3.4±1.1) for females, and 1.89 to 5.18 (mean 3.7±1.1) for males with the highest GSI value scored in July and the least value scored in December (Fig. 5.3C). The minimum and maximum GSI value recorded for *C. carpio* was 7.3 and 12.2 (mean 9.7±1.4) for females, and 2.1 and 4.8 (mean 3.6±0.9) for males. The highest GSI value was observed in May, and the least value was in November (Fig. 5.3D). The result showed a significant association of GSI and seasonal variation for all fish species (χ^2, $p< 0.05$). However, there was no significant variation observed between the two sexes for all of fish species (Permutation t-test, $p> 0.05$).




B
GSI
Male
Female
Month
March, 2014
June, 2014
September, 2014
December, 2014
March, 2015
June, 2015
September, 2015
December, 2015
0
1
2
3
4
5
6
7


C
GSI
Male
Female
Month
March, 2014
June, 2014
September, 2014
December, 2014
March, 2015
June, 2015
September, 2015
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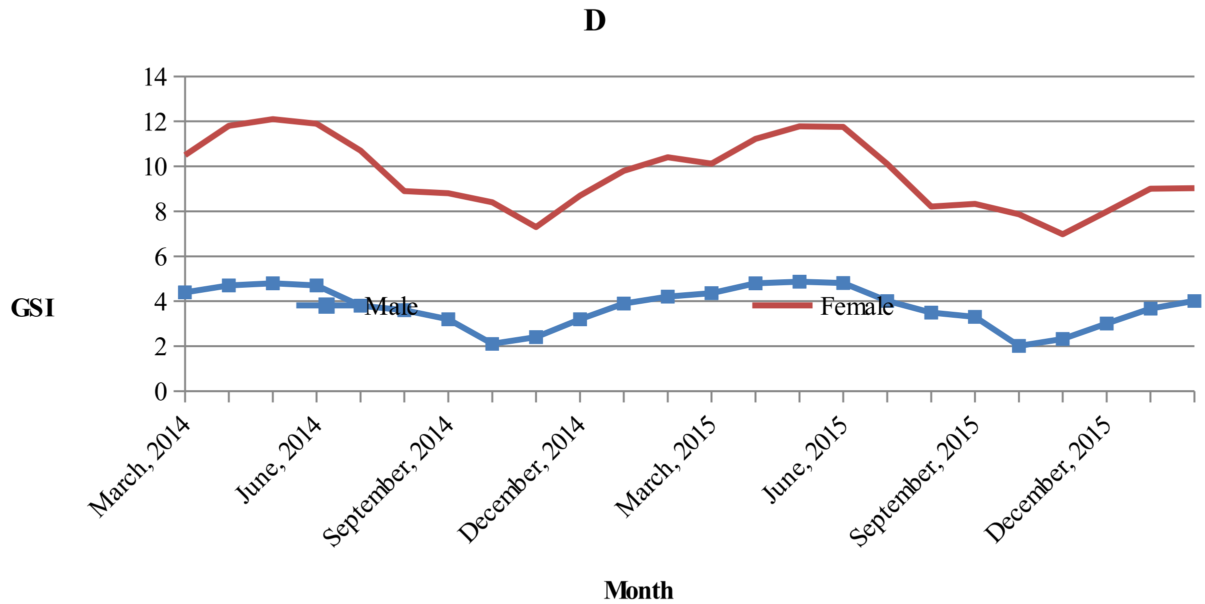


Figure 5.3: Mean monthly variation of GSI of fish species (A. *O. niloticus*, B. *C. gariepinus*, C. *L. intermedius*, D. *C. carpio*) in Lake Langeno, Ethiopia from March 2014 to February 2016.

5.3.4 Length at sexual maturity (L_{50})

The smallest sexually mature female and male caught in this study was 12.8 cm and 13.5 cm TL for *O. niloticus*, 24.5 cm and 25.5 cm TL for *C. gariepinus,* 17.5 cm and 18.3 FL for *L. intermedius,* and 19.3 cm and 20.5 cm FL for *C. carpio.* Their respective total weights were 52.0 g and 63.2 g, 318.0 g and 271.0 g, 149.6 g and 162.0 g, and 147.2 g and 165.0 g, respectively. The length at 50% sexual maturity (L_{50}) obtained was 17.4 cm and 17.2 cm TL, 32.5 cm and 33.1 cm TL, 29.5 cm and 30.5 cm FL, and 30.4 cm and 29.6 cm FL for both females and males of *O. niloticus*, *C. gariepinus, L. intermedius* and *C. carpio,* respectively (Fig. 5.4 to 5.7).

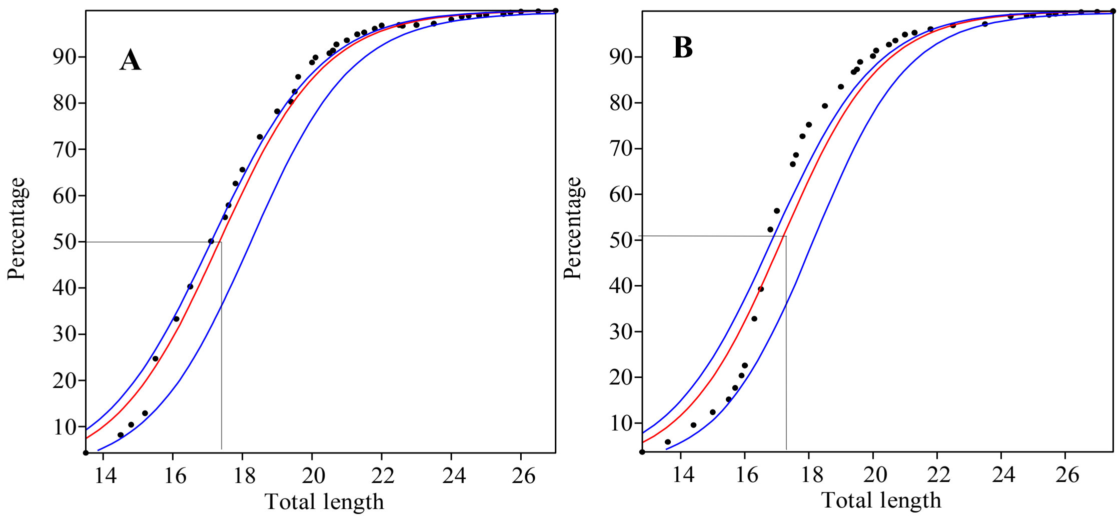


Figure 5.4: Length at first sexual maturity (L_{50}) of *O. niloticus* (male (a) and female (b)) in Lake Langeno, Ethiopia. The dot line represents the observed value, the red line represents the logistic curve and the blue line represents the 95% CL.

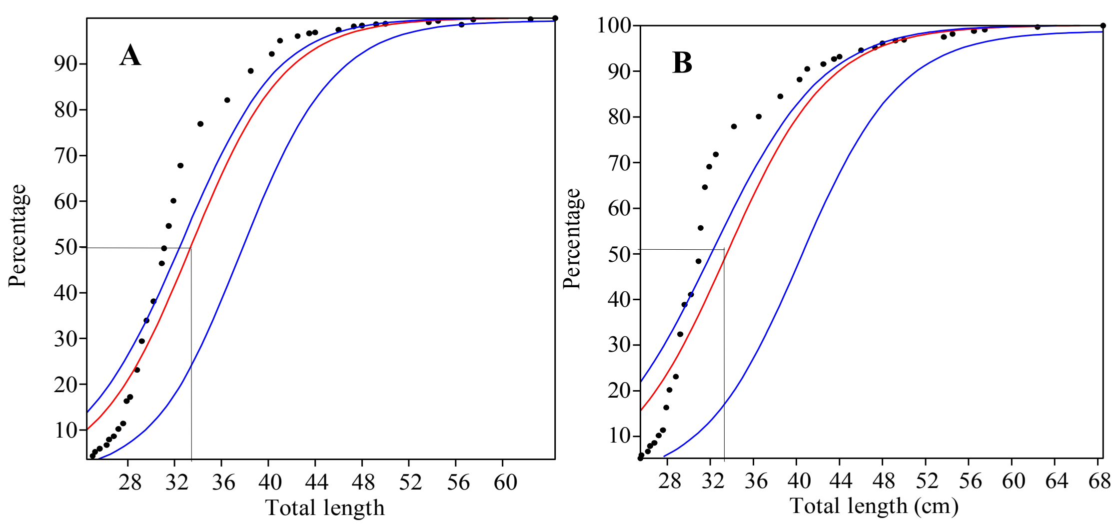


Figure 5.5: Length at first sexual maturity (L_{50}) of *C. gariepinus* (male (a) and female (b)) in Lake Langeno, Ethiopia. The dot line represents the observed value, the red line represents the logistic curve and the blue line represents the 95% CL.

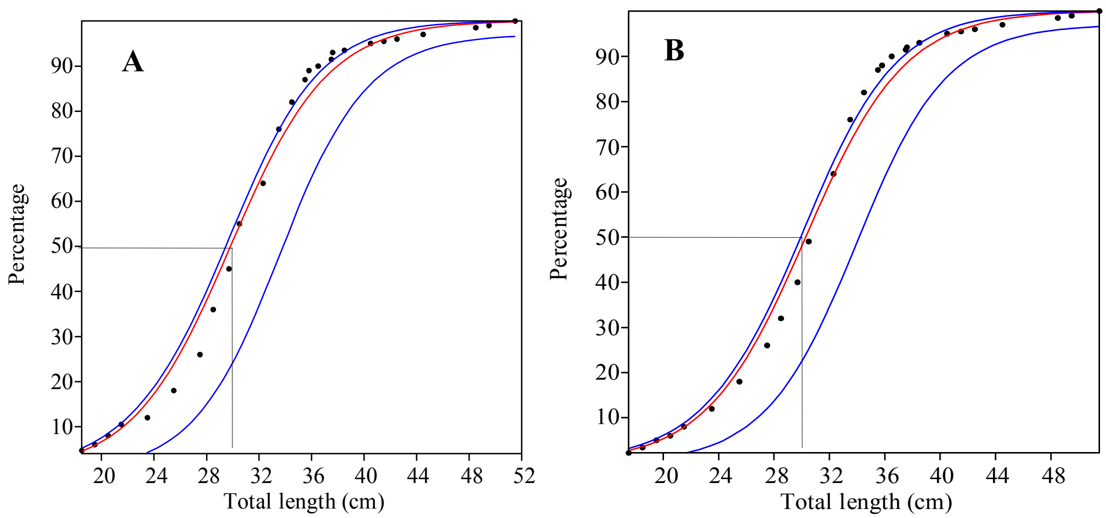


Figure 5.6: Length at first sexual maturity (L_{50}) of *L. intermedius* (male (a) and female (b)) in Lake Langeno, Ethiopia. The dot line represents the observed value, the red line of the logistic curve and the blue line represents the 95% CL.

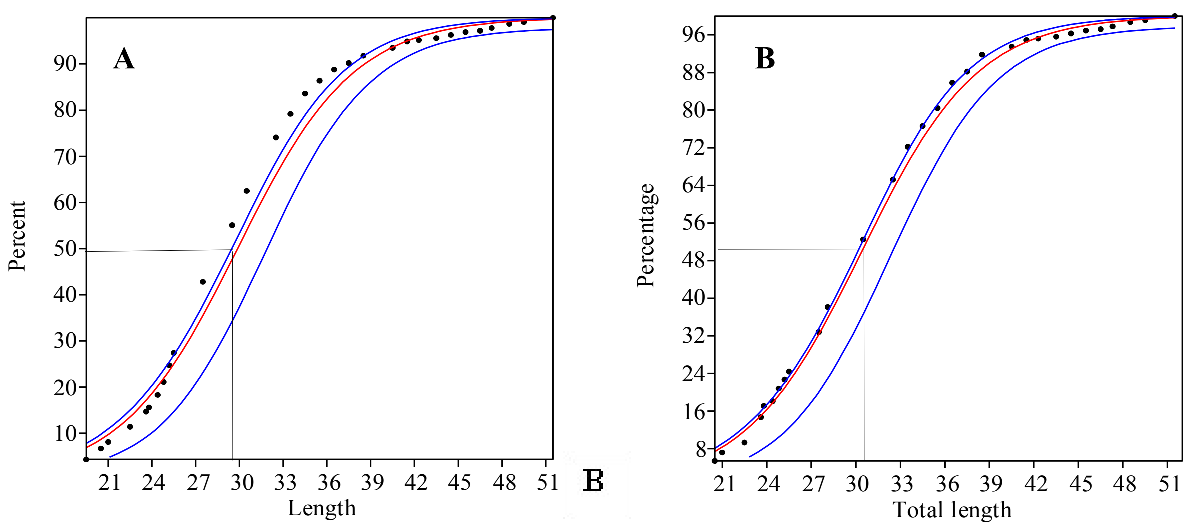
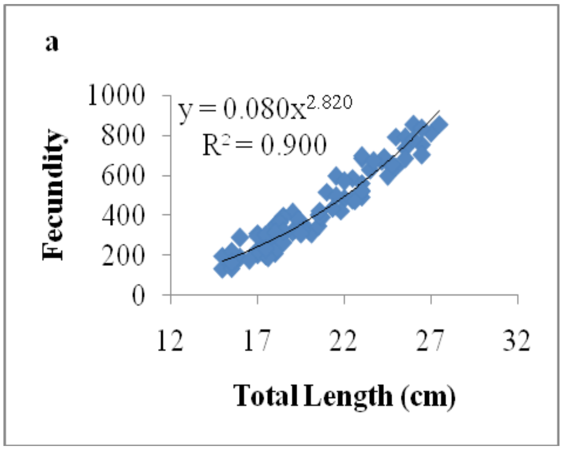


Figure 5.7: Length at first sexual maturity (L_{50}) of *C. carpio* (male (a) and female (b)) in Lake Langeno, Ethiopia. The dot line represents the observed value, the red line represents the logistic curve and the blue line represents the 95% CL.

5.3.5 Fecundity

Fecundity was determined for 126 ripe females of *O. niloticus*, for 32 females of *C. gariepinus*, for 33 females of *L. intermedius* and for 36 ripe females of C. *carpio*. The total/ fork length of the examined fish species ranged between 12.8 cm to 27.5 cm TL, 25.5 cm to 68.5 cm TL, 18.5 cm to 51.5 cm FL and 19.3 cm to 51.5 cm FL for *O. niloticus*, *C. gariepinus*, *L. intermedius* and *C. carpio,* respectively. Their respective total weights were also found in between ranges of 52.4 to 347.0 g, 318.0 to 2,189.0 g, 162.5 to 1,156.0 g and 147.2 to 1,604.3 g, respectively. The total fecundity also ranged between 187 to 978 eggs for *O. niloticus*, 427 to 1,132 eggs/ gram with absolute fecundity of 22,600 to 211,442 eggs for *C. gariepinus*, 1,078 to 6,532 eggs for *L. intermedius* and 681 to 1,922 eggs/ gram with absolute fecundity of 32,749 to 392,487 eggs for *C. carpio.* The mean fecundity scored for these fish species were 463.83±114, 141,466±40,982, 3,055±2,234 and 105,631±46,680 eggs, respectively.

The relationship between fecundity and total/ fork length were curvilinear for all fish species, while the relationship between fecundity and total weight were linear for all species except for *C. gariepinus,* which showed curvilinear relationship. The relationship indicated that the amount of variation in fecundity that can be accounted by length is >90% for all species except for fecundity-weight relationship of *C. gariepinus* (Fig. 5.8 to Fig. 5.11). The relationship of fecundity with TL and TW were very strong for all fish species (r=0.94 and 0.97 for *O. niloticus*, r=0.95 and 0.93 for *C. gariepinus*, r=0.95 and 97 for *L. intermedius* and r=0.96 and 0.98 for *C. carpio,* respectively). The relationship between fecundity and total length and/or total weight was statistically very strong (Permutation test, $p<0.05$).



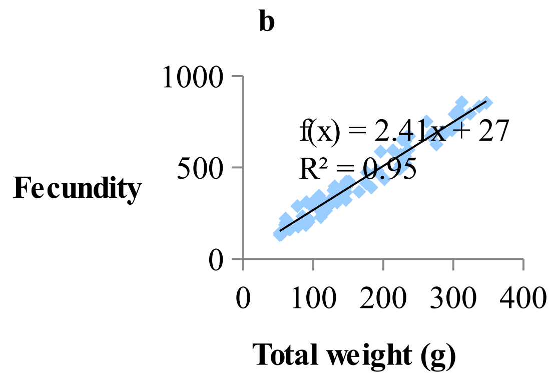
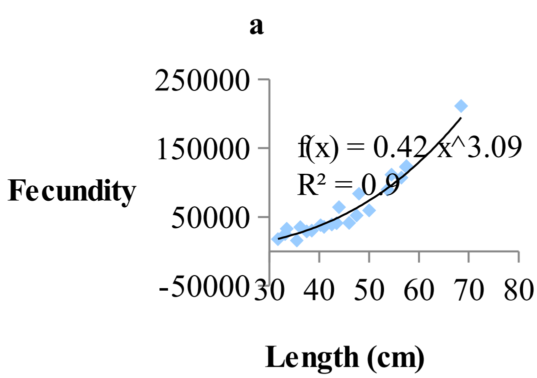


Figure 5.8: The relationship between fecundity and fish total length (a) and total weight (b) of *O. niloticus* in Lake Langeno, Ethiopia (n=126).



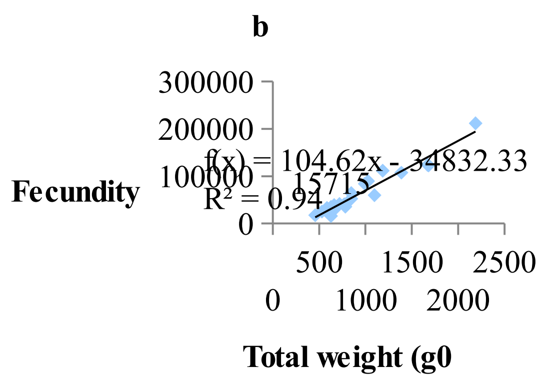


Figure 5.9: The relationship between fecundity and fish total length (a) and total weight (b) of *C. gariepinus* (n=32) in Lake Langeno, Ethiopia.

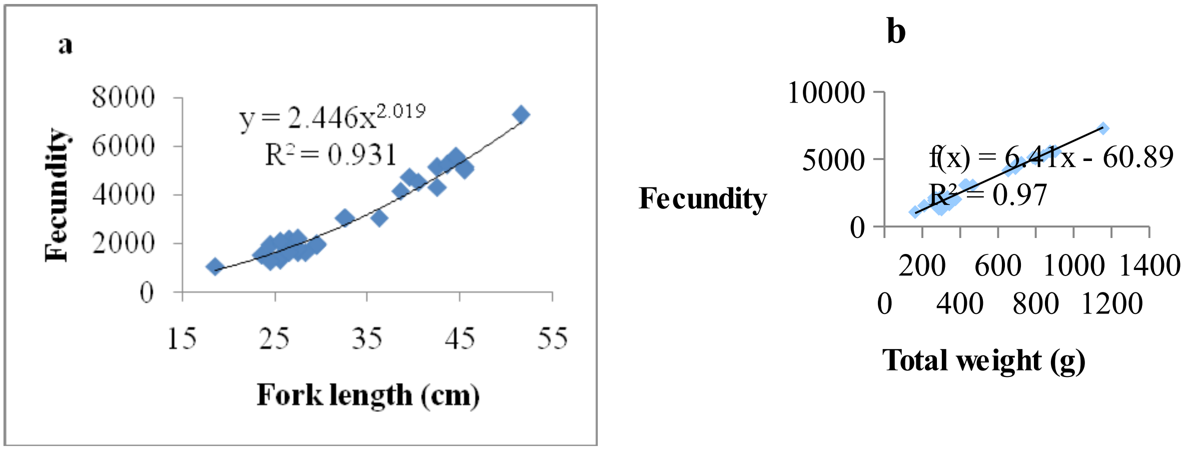


Figure 5.10: The relationship between fecundity and fish total length (a) and total weight (b) of *L. intermedius* (n=33) in Lake Langeno, Ethiopia

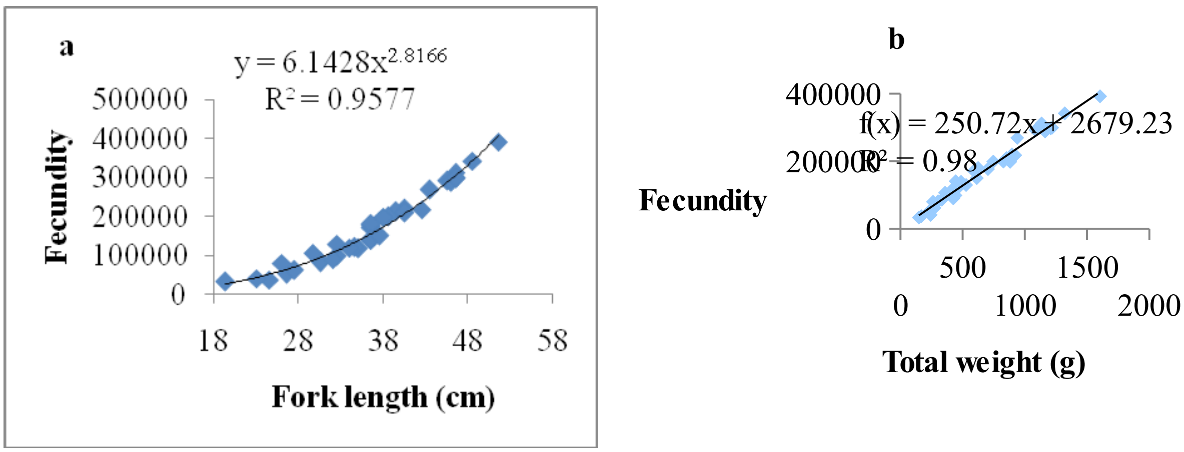


Figure 5.11: The relationship between fecundity and fish total length (a) and total weight (b) of *C. carpio* (n=36) in Lake Langeno, Ethiopia.

The relationship between fecundity and ovary weight of fish stocks were also described in Figures 5.12. The regression model of ovary weight and fecundity relationship in this study was best fitted (r^2>0.85). The resulted showed a linear relationship of ovary weight and fish fecundity, and the relationship was statistically significant (r=0.93 for *O. niloticus*; r=0.97 for *C. gariepinus*; r=0.99 for *L. intermedius* and r=0.97 for *C. carpio*) (Permutation test, $p<0.05$).

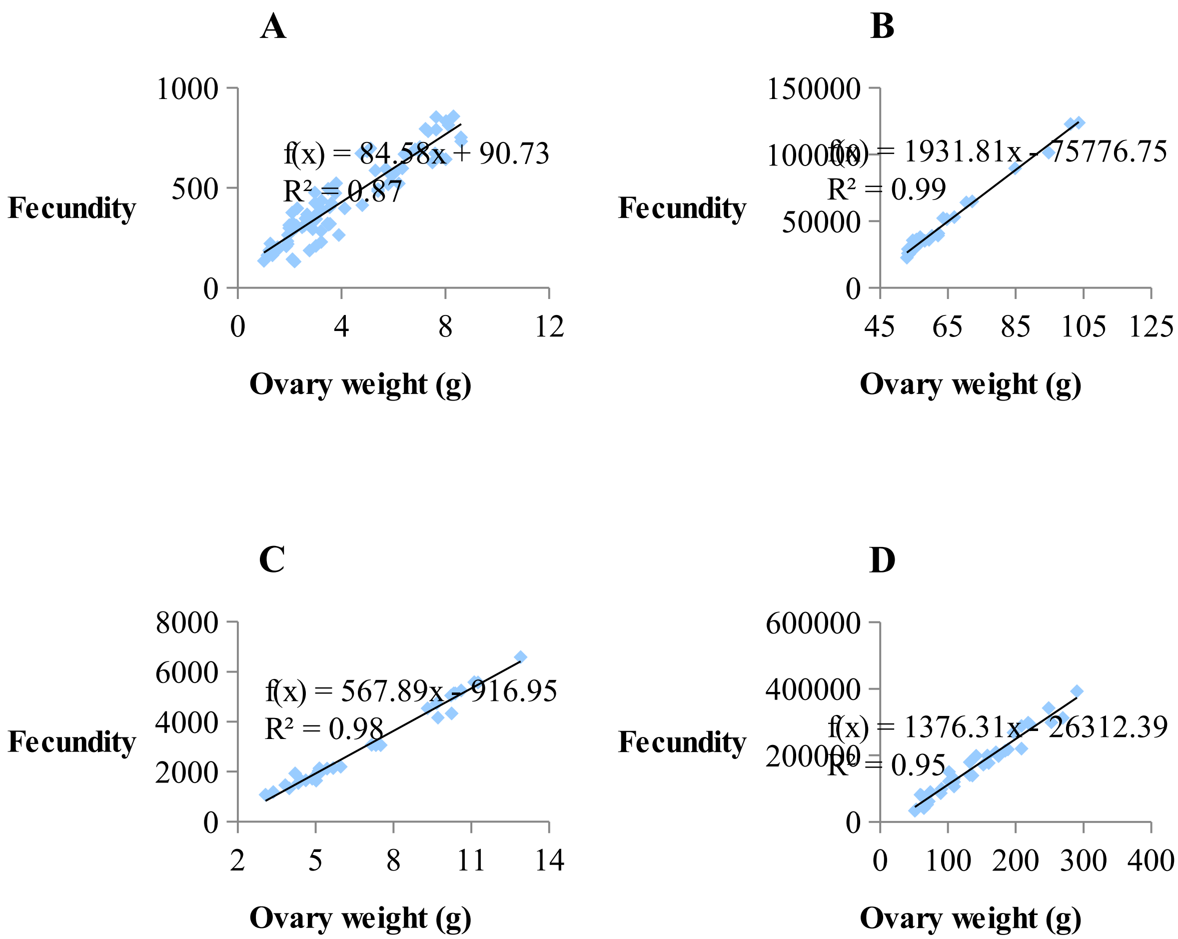


Figure 5.12: The relationship between fecundity and ovary weight of *O. niloticus* (A), *C. gariepinus* (B), *L. intermedius* (C) and *C. carpio* (D) and *C. carpio* in Lake Langeno, Ethiopia.

5.4 Discussion

5.4.1 Sex ratio

The overall sex ratios of all fish species were significantly different from 1:1 ratio, where females dominated the samples (Table 5.1). Similar findings were reported for *O. niloticus* from Lake Babogaya (Lemma Abera, 2012b), Beseka (Lemma Abera, 2013), Hayq (Workiye Worie and Abebe Getahun, 2014), Hawassa (Demeke Admassu, 1996) and Albert Nile, Uganda (Nyakuni, 2009). However, it is in contrary to the reports from Lake Tana (Zenebe Tadesse, 1997) and Lake Victoria (Njiru *et al.*, 2004a). On the other hand, the sex ratio of *C. gariepinus* in this study is also in contrary to the findings of Elias Dadebo *et al.* (2011) and Lemma Abera *et al*. (2014b), who reported the dominance of males from Lake Babogaya and Lake Chamo, but it is in agreement with the finding of Lemma Abera *et al.* (2014a) from Lake Zeway. Similarly, Dereje Tewabe (2014), Gizachew Teshome *et al.* (2015), Tadlo Awoke *et al*. (2015) and Wassie Anteneh *et al.* (2007) reported the dominance of female *L. intermedius* in Lake Tana, in its tributary rivers, in Blue Nile River, and in Dirma and Megech tributary rivers, respectively. The dominance of female *C. carpio* in this study is also in agreement with that of Lemma Abera (2016) in Lake Zeway. In general, the unbalanced ratio between males and females could be due to the behavioral difference between sexes, which renders one sex to be more vulnerable to the fishing gear than the others or the difference in refuge preference due to deviation in sexual maturity stages during the spawning season (Demeke Admassu, 1994).

5.4.2 Sexual maturity, GSI and breeding season of fish species in Lake Langeno

The result of GSI showed that all of the fish species studied breed throughout the year (Fig. 5.1 to Fig. 5.3). According to Lowe-McCconnell (1975), the seasonal fluctuations in water temperature and photoperiod are generally very low in tropics, and this is more favorable for many species to spawn at any time of the year. However, all fish species have different intensity of breeding time in the year, which mainly depends on the availability of food and water temperature (Pawiroredjo, 2001). Temperature is the most important factor that influences the spawning time, survival of larvae and growth of juvenile fishes (Hontela and Stacey, 1995). Most of the tropical freshwater fishes, especially family Cyprinidae, spawn seasonally with the peak breeding time in rainy season (Lowe-McConnell, 1975). The beginning of rainy season and subtle change in water temperature mainly triggers the spawning period of many tropical fishes (Elias Dadebo, 2000).

In this study, for instance, *O. niloticus* had a unimodial peak breeding time from March to May for both sexes (Fig. 5.2a and Fig. 5.3a). Several environmental factors such as the beginning of rainy season, subtle change in water temperature and changing of water level could be responsible for the high breeding activity in this time (Elias Dadebo, 2000; Mathewos Hailu, 2013). Similar peak breeding time for the same fish species was reported as from April to August, April to June, March to June, January to July and March to September from Lake Babogaya (Lemma Abera, 2012b), Lake Tana (Dereje Tewabe, 2014), Lake Chamo (Yirgaw Tefei *et al.,* 2001), Fincha Reservoir (Fasil Degefu *et al.*, 2012) and Abu-Zabal Lake, Egypt (Shalloof and Salama, 2008), respectively. Lemma Abera (2013) and Njiru *et al. (*2004a) also reported that *O. niloticus* in Lake Beseka and Lake Victoria can breed throughout the year with the peak breeding time from September to August, and January to April, respectively. The difference could be attributed to the variation in water temperature, water level and food availability in these water bodies (Lemma Abera *et al.,* 2015; Mathewos Hailu, 2013).

Similarly, the intensive breeding time of *C. gariepinus* obtained in this study (April to August) coincided with the rainy season (Fig. 5.2b and Fig. 5.3b), which is in agreement with the reports from Lake Hawassa (Elias Dadebo, 2000), Lake Tana (Dereje Tewabe, 2014), Lake Babogaya (Demeke Admassu *et al.*, 2015), Lake Chamo (Elias Dadebo *et al*., 2011) and Tanoe-Ehy Swamp forest, South-Eastern Côte d'Ivoire (Konan *et al.*, 2015).

The peak breeding time of *L. intermedius* observed in our study (June to August) (Fig. 5.2c and Fig. 5.3c) is also associated with the rainy season of the study area, which is very similar to the findings of Dagnew Mequanent *et al*. (2014) (August to September), Dereje Tewabe (2014) (May to August) and Wassie Anteneh *et al.* (2007) (July to October) in Blue Nile River, Lake Tana, and in Derma and Megech tributary rivers, respectively. It has been shown that *Labeobarbus* spp. migrates to river mouth for reproduction during the rainy season (Gizachew Teshome *et al.,* 2015; Shewit Gebremedhin *et al*., 2012; Wassie Anteneh *et al*., 2007). Migration to breeding grounds is always triggered by the onset of rainfall patterns and water level fluctuation (Nagelkerke and Sibbing, 1996; Shewit Gebremedhin *et al*., 2012).

The mean monthly variation of GSI is also an evidence that *C. carpio* can breed throughout the year with the peak breeding time between April and June (Fig. 5.2d and Fig. 5.3d). The studies showed that when water temperature reaches its critical point in the spring, the final maturational stages of oocyte development is completed, and *C. carpio* starts spawning this time (Hontela and Stacey, 1995). Davies *et al.* (1986) reported that 20-25ºC is a favourable temperature range for spawning of *C. carpio* under experimental conditions, which is similar with the water temperature of our study area (Chapter 3, section 3.4.1). The peak breeding time of *C. carpio* is also reported as February to April from Amerti Reservoir (Mathewos Hailu, 2013), February to

May from Lake Zeway (Lemma Abera *et al*., 2015) and March to July from Fincha Reservoir (Fasil Degefu *et al.*, 2012).

5.4.3 Length at first sexual maturity (L_{50})

Fish length at a sexual maturity (L_{50}) is the minimum size attained at maturity or the size at which 50% of the fish attain maturity for the first time (Roa *et al.,* 1998; Stamps *et al*., 1998). According to Jonsson and Jonsson (2014), fish living in stressful environments often exhibit an earlier sexual maturity, because it is a strategy to maintain the maximum reproduction in response to high level of stress. The L_{50}% obtained for *O. niloticus* in this study was 17.4 cm TL for females and 17.2 cm TL for males (Fig. 5.4a and b), which is smaller than the previous report of Gashaw Tesfaye and Zenebe Tadesse (2008) in the same species in Lake Langeno (19.5 cm TL for both sexes). It was also less than the reports from Lake Chamo (42.0 cm TL) (Yirgaw Teferi *et al*., 2000), Lake Hawassa (18.8 cm and 19.8 cm TL) (Demeke Admassu, 1994), Fincha Reservoir (21.2 cm and 23.4 cm TL) (Fasil Degefu *et al.*, 2012), Lake Victoria (30.8 cm and 34.6 cm TL) (Njiru *et al.*, 2004a) and Lake Albert Nile (22.4 cm and 23.0 cm TL) (Nyakuni, 2009) for females and males of the same species, respectively. This showed that *O. niloticus* in Lake Langeno matured at early age, which implies that the fish are either living in stressful environment or under the pressure of overfishing. Perhaps, it was higher than the L_{50}% value reported for the same species in Lake Beseka (14.0 cm and 16.0 cm TL for female and male) (Lemma Abera, 2013) and Lake Hayq (Workiye Worie and Abebe Getahun, 2014) (14.5 cm and 15.5 cm TL for females and males). This could be attributed to the habitat variation that could lead to the variation in food availability (Stamps *et al*., 1998).

The L_{50}% exhibited by *C. gariepinus* in this study (31.5 cm and 32.5 cm TL for females and males, respectively) (Fig. 5.5a and b) is comparable with the report of Lemma Abera (2016) from Lake Zeway (28.7 cm and 27.0 cm TL for females and males). However, L_{50}% is attained very early as compared to the same species in Lake Tana (57.7 cm and 43.2 cm TL for females and males) (Dereje Tewabe, 2014), Lake Babogaya (50.0 cm and 56.0 cm TL for females and males) (Lemma Abera *et al.*, 2014a) and Lake Chamo (52.0 cm and 58.0 cm TL for females and males) (Elias Dadebo *et al.*, 2011). Similar to the findings obtained in other parts of Ethiopia (Dereje Tewabe, 2014; Elias Dadebo *et al.*, 2011), fishing pressure on *C. gariepinus* is very low because of its low demand on the market (Chapter 7, Fig. 7). Thus, fishing pressure cannot be the responsible factor for having the smallest L_{50}% of this fish. Rather, other environmental factors such as food availability and environmental parameters could be a reason for smaller size at the first sexual maturity of the fish.

The result of L_{50}% recorded for *L. intermedius* in the present study (30.5 cm and 29.5 cm FL for females and males) (Fig. 5.6a and b) is also comparable with L_{50}% recorded for the same species in Lake Tana (32.7 cm and 25.9 cm FL for females and males) (Dereje Tewabe, 2014). However, it reaches L_{50}% later than the same species in Dirma and Megech tributary rivers (22.6 cm FL for both sexes) (Wassie Anteneh *et al*., 2007), and in Lake Tana (26.0 cm FL for both sexes) (Dereje Tewabe *et al.,* 2010). Similarly, the length at L_{50}% obtained for *C. carpio* (30.4 cm and 29.6 cm FL for females and males) (Fig. 5.7a and b) is very close to the findings of Lemma Abera *et al*. (2015) (28.7 cm and 27.2 cm FL for females and males) and Mathewos Hailu (2013) (28.3 cm and 27.2 cm FL for females and males) from Lake Zeway and Amerti Reservoir, respectively. However, the higher $L_{50\%}$ were reported from Fincha Reservoir (37.5 cm and 24.5 cm FL for female and male) (Fasil Degefu *et al*., 2012) and Lake Naivasha (42.0 cm and 34.0 cm FL for females and males) (Britton *et al*., 2007) for of the same fish species. The abundances, availability and quality of foods in combination with the other environmental factors might be a factor for L_{50}% variation of fishes (Grammer *et al.,* 2012), which is unclear at this stage and needs further study for the feeding biology of the fish in the lake.

5.4.4 Fecundity, length-fecundity and weight-fecundity relationship of fishes

Fecundity obtained for *O. niloticus* in this study (187 to 978 eggs fish^{-1} with the mean fecundity of 463.8 eggs ovary^{-1}) is very comparable with the findings from Lake Hawassa (304 to 967 eggs ovary^{-1}) (Demeke Admassu, 1994), Lake Tana (495 to 1,243 eggs ovary^{-1}) (Zenebe Tadesse, 1997), Lake Hayq (290 to 1,287 eggs ovary^{-1}) (Workiye Worie and Abebe Getahun, 2014) and Abu-zabal Lake, Egypt (289 to 1,456 eggs ovary^{-1}) (Shallof and Salama, 2008). However, it was much less than the fecundity of same species in Lake Chamo (1,047 to 4,590 eggs ovary^{-1}) (Yirgaw Teferi *et al.*, 2001), Lake Victoria (905 to 7,619 eggs ovary^{-1}) (Njiru *et al.*, 2004a) and Lake Albert Nile, Uganda (412 to 2,380 eggs ovary^{-1}) (Nyakuni, 2009). The lower fecundity in this study indicates the less availability or quality of food in the lake (Zenebe Tadesse, 1999), which is determined by many factors, such as water depth, water temperature and environmental variability (Lambert *et al.*, 2003; Lambert, 2008; Njiru *et al.*, 2004a;). According to Lambert (2008), the variability of environmental conditions influences the growth and nutritional status of fish directly or indirectly, which results in a wide range of potential fecundity variations.

Fecundity of *O. niloticus* scored in the present study increased in proportion to 2.82 power of fish total length (r^2=0.90) and 0.93 power of the weight (r^2=0.94) (Fig. 5.8a and b). In many tropical freshwater fish species, fecundity increased in proportion to 2.81-3.96 power of total length (Lowe- McConnell, 1975). Bagenal and Tesch (1978) also reported that the value of “b” is about 3 when fecundity is related to length, and about one when it is related to weight. Therefore, fecundity of *O. niloticus* in this study depends on both their total weight and total length, which agrees with this biological principle. Similarly, Yirgaw Teferi (2001) reported that fecundity of *O. niloticus* depends on both total length and total weight, which is mainly determined by the environmental conditions and availability of the foods in the environment.

Our finding also revealed that the fecundity of *C. gariepinus* in this lake (22,600 to 211,442 eggsg^{-1} with the mean absolute fecundity of 141,466 eggs ovary^{-1}) is very low as compared to the reports of Demeke Admasu *et al. (*2015) from Lake Babogaya (11,000 to 580,571 eggs ovary^{-1}), Elias Dadebo *et al.* (2011) from Lake Chamo (5,000 to 1,240,000 eggs ovary^{-1}) and Lemma Abera (2014a) from Lake Zeway (10,000 to 560,000 eggs ovary^{-1}). The low fecundity indicates the poor nutritional status and poor body condition of the fish (Lambert, 2008). The result indicated that fecundity of *C. gariepinus* had a positive relationship with the total length, total weight and gonad weight of the fish. However, comparatively the fecundity was highly correlated with the increasing of its length than its weights (3.088 power of the length (r=0.90) and 1.58 power of the weight (r=0.89)) (Fig 5.9 a and b) based on the Bagenal and Tesch (1978) principle. This is in contrast with the finding of Yalçin *et al.,* (2001), who reported that fecundity of the fish is highly associated to the total weight of the fish than its length in the River Asi, Turkey. This could be due to the habitat variation which encompasses different food items for the fish. According to Lambert (2008), variation in potential fecundity-size/weight relationships is seen as the response of individual females to varying combination of biological and environmental factors.

The result of fecundity obtained for *L. intermedius* in this study (1078 to 6,532 eggs ovary^{-1} with the mean fecundity of 3055 eggs ovary^{-1}) is comparable with the results of Tadlo Awoke *et al.* (2015) from Blue Nile River (1345 to 7235 eggs ovary^{-1}) and Wassie Anteneh *et al*. (2007) from tributaries of Lake Tana (1761 to 8367 eggs ovary^{-1}). However, it was lower than the fecundity reported for the same species from Lake Tana (1935 to 11224 eggs ovary^{-1}) (Shewit Gebremedhin *et al.,* 2014), Gilgel Beles River (1535 to 13864 eggs ovary^{-1}) (Zeleke Berie, 2007), and in Gelda and Gumara Rivers (1265 to 13289 eggs ovary^{-1}) (Gizachew Teshome *et al.*, 2015). The habitat variations might have caused the fecundity differences since Lake Langeno is the stagnant water and those waters mentioned above are running waters, which is comfortable for its reproduction. The studies show that highly oxygenated water and gravel beds are the general requirements for *Labeobarbus* reproduction due to its critical importance in the development of eggs and larvae (de Graaf, 2005).

Fecundity of *L. intermedius* in the present study showed strong relationship with the fish total length, total weight and ovary weight (Fig. 5.10 and b, Fig. 5.12c). The fecundity of the fish was increased in proportion to 2.019 power of the length (r^2=0.93) and 1.01 power of the weight (r^2=0.91) (Fig. 5.10 and b). This indicated that thought there is a relationship of the fish fecundity with all of these morphological factors; the fecundity was highly dependent on the weight than their length. This is in agreement with the finding of Tadlo Awoke *et al.* (2015) in Blue Nile River and Shewit Gebremedhin *et al.* (2014) in Lake Tana sub-basin Ethiopia.

The absolute fecundity recorded for *C. carpio* in this study (32,749 to 392,487 eggs ovary^{-1}with the mean fecundity of 105,631 eggs ovary^{-1}) was very close to the results obtained for the same fish species in Amerti Reservoir (36,955 to 318,584 eggs ovary^{-1}) (Mathewos Hailu, 2013). However, it was close to the fecundity of same species reported from Lake Zeway (75,645 to 356,743 eggs ovary^{-1}) (Lemma Abera *et al.,* 2015), Southeastern Caspian Sea (33,695 to 123,4567eggs ovary^{-1}) (Vazirzadeh and Yelghi, 2015), Lake Victoria, Australia (75,000 to 262,000 eggs ovary^{-1}) (Sivakumaran *et al.,* 2003) and New Zealand (29,800 to 771,000 eggs ovary^{-1}) (Tempero *et al*., 2006). Bajer and Sorensen (2010) stated that female *C. carpio* can carry >1,000,000 eggs ovary^{-1} for length groups >60 cm FL. Therefore, *C. carpio* in Lake Langeno is very poor in its fecundity as compared to this estimation and the results reported by other researchers. The reproductive cycle and pattern of gonad development of *C. carpio* in natural ecosystems greatly depends on water temperature and food availability (Tempero *et al.,* 2006). Fecundity of *C. carpio* in this study is strongly associated with its total weight, total length and ovary weight (increased in proportion to 2.82 power of length (r^2=0.96) and 1.04 power of the weight (r^2=0.97)) (Fig. 5.11 and b), which is in agreement with the report of Lemma Abera *et al.* (2015) in Lake Zeway.

Generally, fishes in Lake Langeno exhibited low $L_{50\%}$ and poor fecundity as compared to many of the similar fishes found in Ethiopian rift valley lakes and the previous reports from the same study area. This might be due to the combination of many factors (i.e. both natural and human factors), which needs further monitoring and effective follow-up. Sexual maturity, breeding time and fecundity of all fish species also showed a considerable variation with seasonal fluctuation and morphometric variation of fish species.

CHAPTER SIX

6. FOOD AND FEEDING BIOLOGY OF *Oreochromis niloticus* (NILE TILAPIA) IN LAKE LANGENO, ETHIOPIA

6.1 Introduction

Fish require quality nutrients for growth, reproduction and other normal physiological functions. In an inland ecosystem, phytoplankton, zooplankton, plant materials, insects, insects' larvae, worms and smaller fish are the major food types of fish (Wakil *et al*., 2014). The availability of food in any aquatic environment determines the well-being and reproductive potential of fish (Keyombe *et al*., 2015). Weight and size of fish is a reflection of food availability in the aquatic ecosystem (Bolarinwa and Popoola, 2015). Fish tend to show preference for particular food items within their environment. Many environmental factors, such as water temperature, food availability, stocking density and environmental conditions influence the food selection behavior of fish (Houlihan *et al.,* 2001). Size of food items, size of fish and age of fish can also determine the food selection behavior (Otieno *et al.,* 2014). According to Otieno *et al.* (2014), fish mainly feed on food items that can fit into their mouth, and what their stomach can digest. As fish grow, the stomach becomes longer, and their digestive system becomes more developed. However, the feeding rate relative to body weight decreases, whereas the absolute rate of food consumed increases (Wakil *et al*., 2014).

The study of food and feeding habits of freshwater fish species is a subject of continuous research. This is because studies on natural feeding of fishes enable the identification of their trophic relationships and status in aquatic ecosystems, identifying food composition, structure and stability of food webs (Adeyemi *et al.,* 2009; Otieno *et al*., 2014; Shalloof and Khalifa, 2009).

Nile tilapia (*O. niloticus*) is one of the most important fish species in tropical and subtropical freshwaters (Amal and Zamri-Saad, 2011), often forming a basis of commercial fisheries in many African countries (Mohammed and Uraguchi, 2013). Its high tolerance to environmental conditions and its ability to accept formulated and natural feeds makes it economically viable (Adeyemi *et al*., 2009). It has a versatile feeding behavior, characterized by herbivorous generalist and opportunistic omnivorous feeding behavior (Canonico *et al*., 2005). Its diet composition may vary with seasonal and spatial variation of environmental conditions (Houlihan *et al*., 2001). Therefore, understanding of its food and feeding behavior is a key factor to its successful culture in a controlled environment (Shalloof and Khalifa, 2009).

A number of researchers have studied the food and feeding habits of *O. niloticus* in different water bodies of Ethiopia (Flipos Engdaw *et al*., 2013; Workiyie Worie and Abebe Getahun, 2015; Zenebe Tadesse, 1999). However, there is no enough information on the food and feeding biology of this fish species in Lake Langeno, Ethiopia. Therefore, the present study had the aim to document the natural feeding behavior of Nile tilapia (diet composition, seasonal variation of diet composition and the relationship between feeding behavior and size of the fish) in Lake Langeno, Ethiopia.

6.2 Materials and methods

6.2.1 Stomach collection method

The stomachs of *O. niloticus* specimens collected were classified as distended, full, 3/4 full, 1/2 full and 1/4 full by visual observation. The stomachs extracted from the live fish were preserved immediately in 5% formaldehyde solution for later analysis. All samples were transported to Ghent University, Laboratory of Animal Nutrition in Belgium for further analysis.

6.2.2 Stomach content analysis

In laboratory, the stomach contents were kept for five minutes to remove excess formalin. The stomachs were dissected; and the stomach contents were taken and added to the graduated test tube filled with distilled water. After vigorous shaking, the volumes of the content were computed and the samples were transferred to the agar plate. The larger food items were identified visually, whereas, the small sized food items were differentiated by dissecting (LEICA MS5, magnification 40X) and compound microscope (LEICA DME, magnification 400X). The food items were identified to lowest possible taxonomic level by using description, illustrations and keys in the literature (Baker and Fabbro, 2002; Botes, 2003; Carling *et al.,* 2004; Shiel, 1995; Vuuren *et al*., 2006; Witty, 2004). Fish diet composition was computed by frequency of occurrence and volumetric methods (point method) (Hyslop, 1980).

Frequency of occurrence, $\%O_i = \frac{Ji}{P} \times 100$

Where Ji, is number of fish containing food item and

P is number of fish with food in their stomach.

Volumetric method ($\%V_i$) was also computed as:-

$$\%V\,i = \frac{\text{Number of points allocated}}{\text{Total points allocated}} \,¿\, component\, i \frac{¿}{¿} subsample \,¿\, x\,100$$

Where $\%V_i$ is the percentage volume of the prey component *i*

An index of preponderance (IP) was also used to evaluate the relative abundance of different organisms in the fish diet based on Natarajan and Jhingran (1961) as:

$IPi = (\%V_i)\ (\%O_i)$

Where, $\%V_i$ = percentage volume of a particular diet in the total volume of food items

$\%O_i$ = percentage observation of a particular food item in the total number of stomachs examined.

In order to evaluate the relative importance of food items and species-level dietary variations, Geometric Index of Importance (GII_i) was computed (Assis, 1996).

$GII_i = (\%N_i + \%V_i)\ \%O_i$

Where$\%N_i$, $\%V_i$and $\%O_i$and represents percentages of number, volume and frequency of occurrence prey i,respectively. The standardized index of GII ranges from 0–1(1-100%), with values close to 0 indicating feeding specialization and values close to 1.0 representing generalization (Hurlbert, 1978).

6.2.3 Statistical analysis

The Log-ratio principal component analysis (PCA) was used to test the diet compositions variation of the prey volumes (Chipps and Garvey, 2007). In order to assess the seasonal variation of prey items in the food composition multivariate analysis (MANOVA) test was done with randomization of prey volumes. Randomization was required to counterbalance the non-normal distributional nature of the food composition data. A Wilk‘s lambda (Λ) test was considered for the randomization procedure. When MANOVA test was significant, Mann-Whitney U test was performed to identify specific prey categories that caused seasonal variations in fish food composition. For size based composition of food analysis, the fish was categorized into five size classes based on the frequency distribution of total length (SL) of the sample specimens. Regression analysis was used to determine the coefficient of determination (r^2) in order to check whether the model is fitted or not for the analysis and compute the correlation analysis (r). Linear correlation analysis (r) was done to test the relationship between preys composition and total length of fish and/or seasonal variation. In addition, permutation test was performed in order to see the statistical significance of the seasonal and length based variation of prey. The statistical analyses were carried out by CANOCO software version 4.5 and PAST software version 3.08.

6.3 Results

6.3.1 The status of collected stomach samples

A total of 1658 *O. niloticus* fish (46.9% (n=778) males and 53.08% (n=880) females) were collected. The number and relative stomach volume of O. niloticus examined are indicated in Table 6.1.

Table 6.1: Proportion of stomach contents of *O. niloticus* (%) in Lake Langeno

Stomach volume	No. of fish	Percent (%)
Distended	149	8.9
Full	363	21.9
3/4 full	345	20.8
1/2 full	247	14.9
1/4 full	298	17.9
Empty	256	15.4
Total	1658	100

6.3.2 Diet Composition

Generally, a total of 512 (30.9%) fish (only fishes with distended and full stomachs) were examined for their stomach contents. The size of sampled fish ranged between 9 cm and 30.5cm TL. Phytoplankton, zooplankton, insects, detritus, macrophytes, fish parts, ostracods and nematodes were the identified food items in the stomachs of *O. niloticus*. In total, 43 different taxa of phytoplankton, 6 taxa of zooplankton, and 13 insect types were identified in the stomachs of the studied fish (Annex 5). Phytoplankton and detritus were the most dominant food items identified, whereas zooplankton and macrophytes were the intermediately consumed prey types. Fish parts, insects, ostracods and nematodes were rarely consumed items identified, which were observed only in 15.9%, 8.6%, 10.1%, and 7.8% of the studied stomachs (Table 6.2).

Table 6.2: Volumetric contribution and frequency of occurrence of different food items (%) in the diet of *O. niloticus* (n=512) in Lake Langeno, Ethiopia.

Food type	%O_i	%V_i	**IP**	**%IP**
Phytoplankton	100.0	64.3	6825.0	74.5
Zooplankton	87.1	12.8	576.7	6.3
Insects	8.6	1.6	13.8	0.2
Detritus	99.5	14.6	1462.0	15.9
Macrophytes	65.8	4.7	222.7	2.4
Fish parts	15.9	1.4	22.5	0.3
Nematodes	7.8	0.3	2.2	0.02
Ostracods	10.1	0.6	6.5	0.1
Unidentified	6.04	1.3	35.4	0.4

The different food items of phytoplankton, zooplankton and insect groups identified in the diet of *O. niloticus*is presented in Table 6.3 and annex 5. Of the phytoplankton groups, Cyanophyta (blue green algae) (mainly *Microcystis* spp. and *Chroococcus* spp.) were most abundant in the diet composition of *O. niloticus*. *Microcystis* spp. and *Chroococcus* spp. were observed in 100% and 92% of stomachs with the volumetric contribution of 24.9% and 9.1%, respectively. From the Bacillariophyta (diatom) groups, *Cyclotella* spp. were the most abundant followed by *Surirella* spp., *Cymbella* spp., *Navicula* spp. and *Pinnularia* spp. (observed in 99.5%, 98.0%, 92.0%, 90.0% and 76.0% of the studied stomachs, respectively), while, *Oocystis* and *Chlorella* spp. were the dominant Chlorophyta groups both in frequency of occurrence and volumetric contribution (observed in 78.0% and 76.0% of the stomachs).

The food items of animal origin comprised zooplankton (*Bosminas, Daphnias, Sididaes, Calanoids, Cyclopoids* and *rotifers*), insects (Dipteran, Plecopteran, Trichopteran, Chilopoda, Coleoptera, Odonata, Hemiptera, Ephemeroptera and Hymenoptera), fish parts (eggs and larvae), nematodes and ostracods. *Rotifers* were the dominant zooplankton group observed in 76.9% of stomachs followed by copepods and cladoceran (mainly *Daphnia* spp.) (Observed in 48.3 and 33.6% of stomachs, respectively).

Table 6.3: Frequency, volumetric contribution and Index of preponderance of different food items in the diet of *O. niloticus* (n=512) in Lake Langeno, Ethiopia.

Food type	**Specific items**	%O_i	**%V_i**	**IP**	**%IP**
Phytoplankton	Cyanophyta (Blue Green algae)	100.0	4.8	477.0	10.1
	Bacillariophyta (Diatom)	99.5	16.9	1684.5	35.6
	Chlorophyta (Green algae)	78.0	9.9	778.4	16.5
	Chrysophyta	32.4	2.6	84.6	1.8
	Cryptophyta	47.6	6.9	330.8	7.0
	Dinophyta	72.6	6.1	440.7	9.3
	Rhodophyta	16.8	3.0	51.1	1.1
	Euglenophyta	74.8	11.3	843.7	17.9
	Heterokontophyta	14.4	2.6	37.3	0.8
Zooplankton	Anomopoda	6.0	0.4	2.6	0.5
	Cladocera	33.6	3.7	123.5	21.4
	Ctenopoda	12.3	1.0	12.5	2.2
	Copepoda	48.3	3.8	183.1	31.8
	Rotifera	76.9	3.2	247.9	43.0
	Ostracoda	10.1	0.6	6.5	1.1
Insects	Diptera	4.7	10.3	49.5	10.4
	Plecoptera	4.2	12.7	52.9	11.1
	Trichoptera	3.7	11.8	43.3	9.1
	Chilopoda	4.8	14.5	70.1	14.7
	Coleoptera	3.8	6.96	26.1	5.5
	Odonata	8.4	13.7	114.3	23.9
	Hemiptera	5.0	8.2	41.0	8.6
	Ephemeroptera	4.6	11.5	52.8	11.1
	Hymenoptera	2.7	10.4	27.8	5.8

In terms of index of preponderance, *Microcystis* spp. (24.9% IP), detritus (15.9% IP), *Chroococcus* spp. (9.1% IP), *Rotifer* spp. (3.4% IP**)** and *Cyclotella* spp. **(**3.6% IP) were the most important food items identified, respectively. The percentage of geometric importance index value (% GII) also showed that phytoplankton is the primary consumed food item, whereas detritus, zooplankton and macrophytes were the secondary consumed types by *O. niloticus* in this study area (Fig. 6.1).

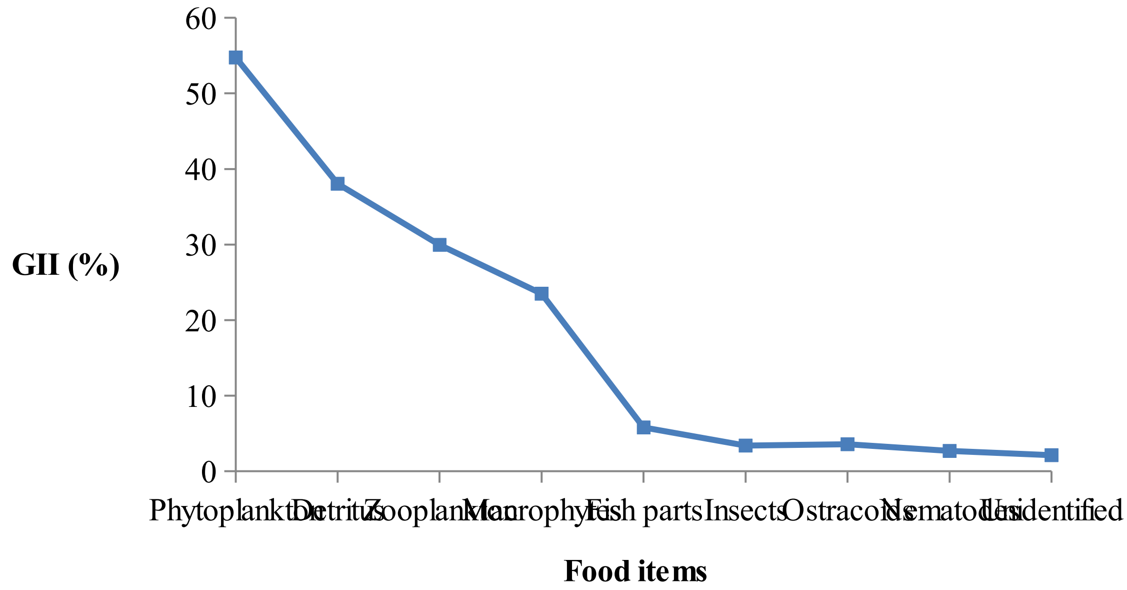


Figure 6.1: The percentage of geometric importance index value (% GII) of different food items in the diet of *O. niloticus* in Lake Langeno, Ethiopia. Vertical lines separate the different degrees of preference of the food items.

6.3.3 Seasonal variation in the diet composition of *O. niloticus* in Lake Langeno

Log-ratio principal component analysis (PCA) for the seasonal prey's composition in the food of Nile tilapia is given in Figure 6.2. Preys composition in gut content of the fish varied largely on Axis 1 and Axis 2, which together accounted for 88.42% of total variance (Table 6.4).Except for phytoplankton, all of the prey items were positively correlated with the first axis, where the correlation of Zooplankton, detritus, aquatic insect larvae and macrophytes with the months on the axis was very strong ($r>0.80$) and statistically significant (Permutation test, $P<0.05$).August, June and July months were highly associated with the all prey items on this axis, which contributed 80.45% of the total variance. However, phytoplankton was negatively correlated with the axis, which also showed negative correlation with these months (r=-0.90; Permutation test, $p<0.05$). Similarly, all of the prey items except for fish parts were positively correlated with the second axis, which contributed 7.97% of total variance on this axis. February, March and January months had high positive correlation with a heavy load on phytoplankton prey composition on this axis (r=0.79) Permutation test, $p<0.05$). Generally, the log-ratio of PCA clearly depicted a seasonal variation as most of them tended to feed on the highly abundant foods in the lake (Permutation test, $p<0.05$).

Table 6.4: Summary of the percentage variance (%) and correlation matrices (r) accounted by the first two principal components (PCA) of fish food composition and the study months

Prey	**Canonical coefficient**	
	Axis 1	**Axis 2**
Eigenvalue	**18.36**	**1.82**
% of variance	**80.45**	**7.97**
Phytoplankton	-0.90	**0.79**
Zooplankton	0.89	0.35
Detritus	0.95	**0.30**
Insects	0.87	**0.21**
Macrophytes	0.83	**0.08**
Fish parts	0.11	-0.37
Nematode	0.64	0.18
Unidentified	0.28	0.02

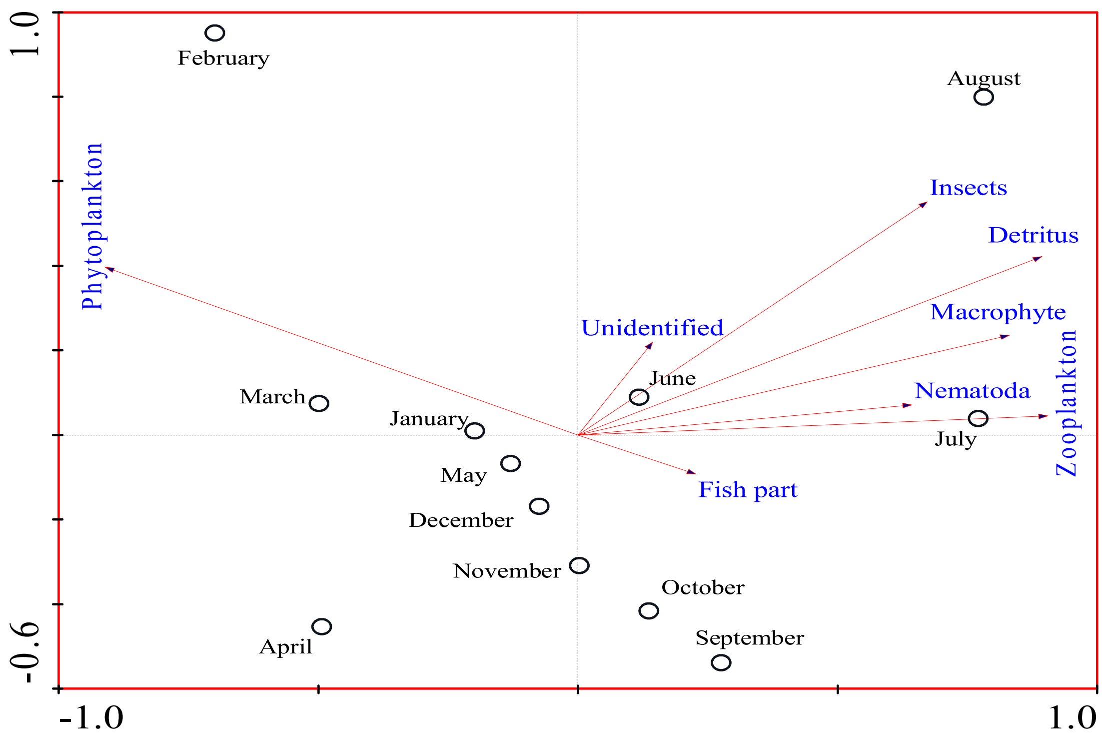


Figure 6.2: Preys-months PCA biplot of stomach content analysis for *O. niloticus* collected from Lake Langeno, Ethiopia.

The abundance and volumetric contribution of phytoplankton were highest in dry season. The result indicated a significant seasonal variation of phytoplankton composition in the stomachs of the fish (Wilk's Λ=0.4, $F_{(1, 10)}$ =14.86, $p<0.05$). Phytoplankton mainly blue green algae (*Microcystis* spp. and *Chroococcus* spp.) and diatoms (Bacillariophyta (*Cyclotella ocellata* spp.)) dominated the stomach content of the fish in dry season (November to May), whereas Chlorophyta (Green algae) (mainly *Oocystis* spp.) and Euglenophyta (mainly *Trachelomonas* spp.) had taken the largest stomach volume in wet season (June to October) (Fig. 6.3 a and b).

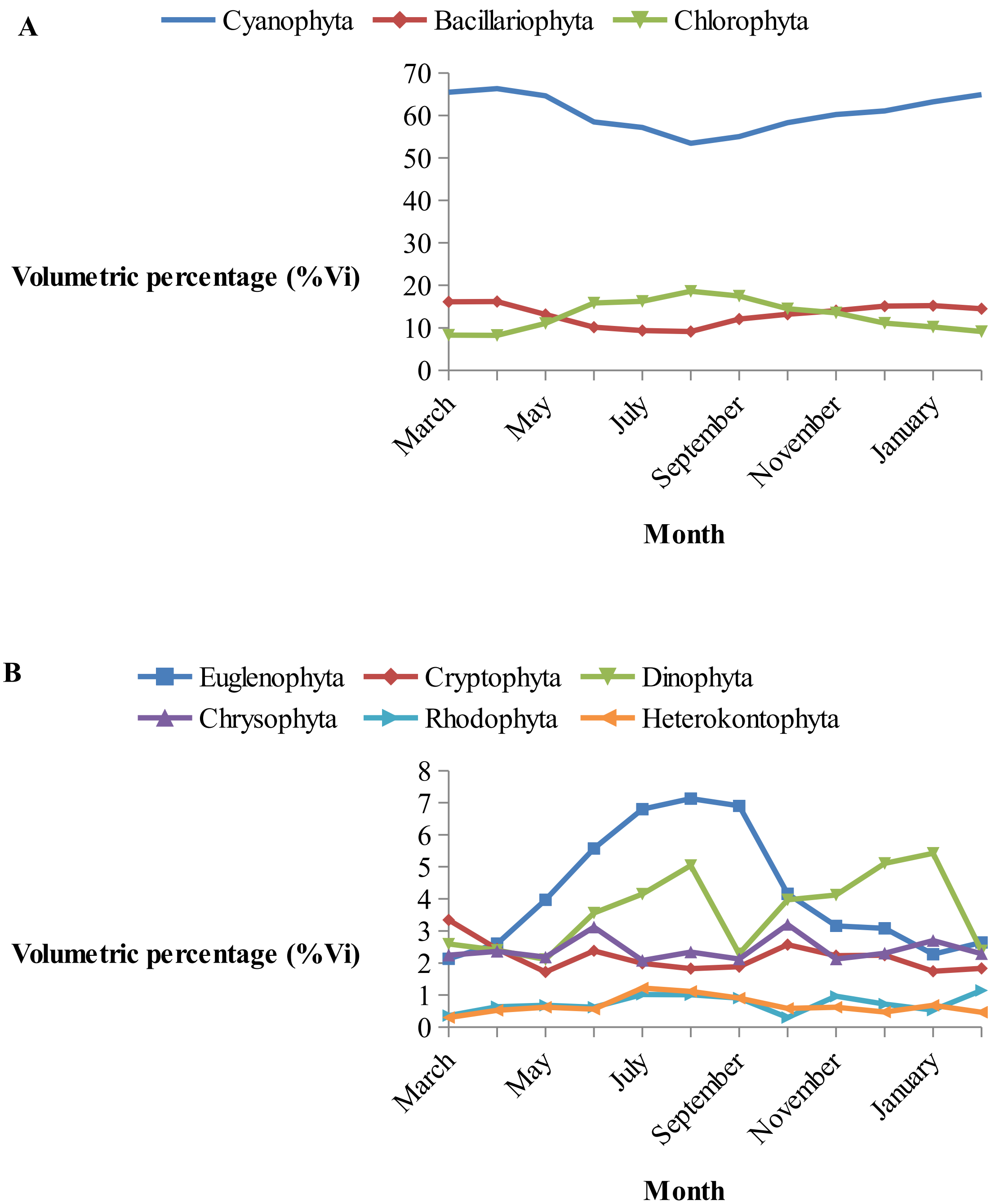


Figure 6.3: The monthly variation in volumetric contribution of phytoplankton composition (%) in the food of *O. niloticus* from Lake Langeno, Ethiopia.

Similarly, the contribution of zooplankton in the food composition of *O. niloticus* was highest in wet season and low in dry season, which showed a significant seasonal variation ($p<0.05$) (Fig. 6.4).

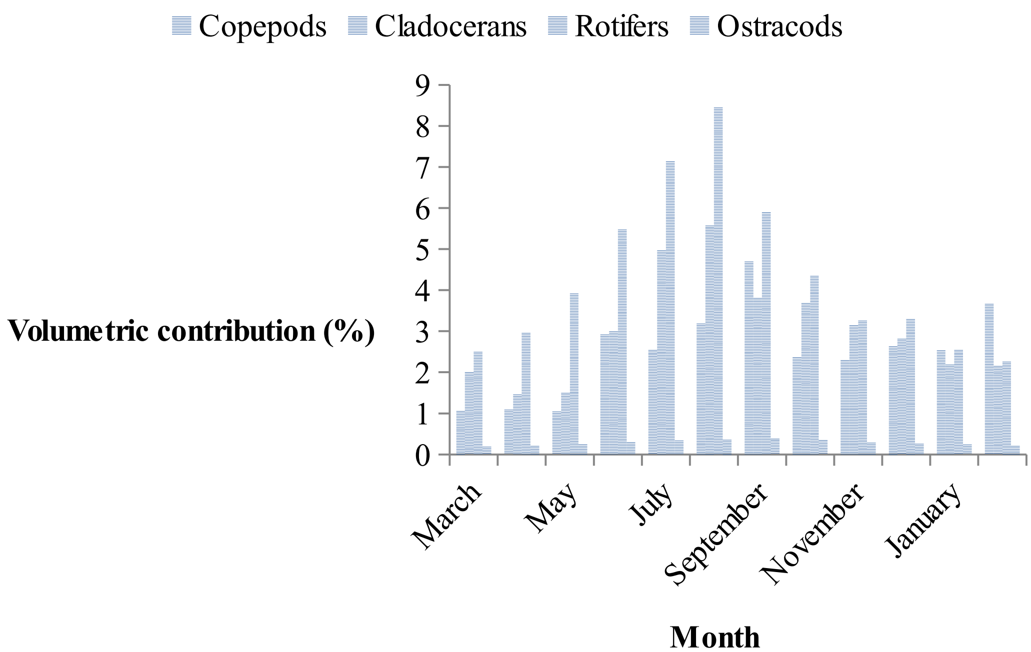


Figure 6.4: The monthly variation in volumetric contribution of zooplankton preys (%) in the food composition of *O. niloticus,* in Lake Langeno, Ethiopia.

The results of seasonal variation of detritus and macrophytes composition identified from the guts of *O. niloticus* are presented in Fig. 6.5. Though the contribution of detritus in food of *O. niloticus* was year round, relatively the highest contribution was observed in months with the high rainfall (May to July), which was statistically significant (Wilk's $\Lambda=0.42$; $F_{(1, 10)}=10.06$, $p<0.05$). Similarly, the composition of macrophytes in gut of the fish was highest in months from

July to September. Similarly, the composition of macrophytes showed a significant seasonal variation (Wilk's Λ= 0.47; $F_{(1, 10)}$ =12.26; $p<0.05$).

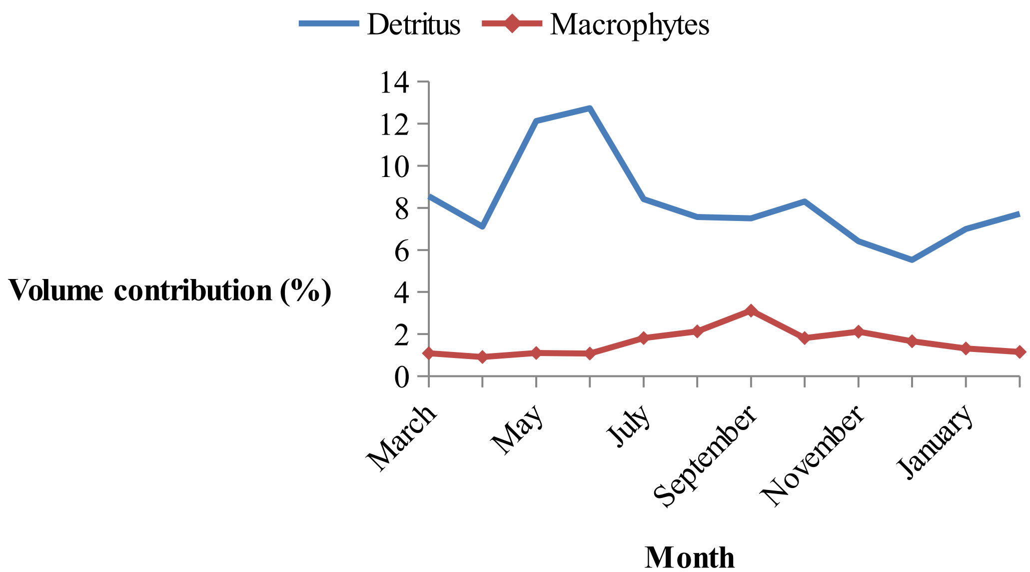


Figure 6.5: The monthly variation in volumetric contribution of zooplankton preys (%) in the food composition of *O. niloticus,* in Lake Langeno, Ethiopia from March 2014 to February 2016.

The results of seasonal variation of insects, nematodes and fish parts identified from the guts of *O. niloticus* are presented in Fig. 6.6. They were relatively observed in a few numbers of guts and their volumetric contribution was as well very low. Relatively, their volumetric contribution in food composition was highest in the wet season. However, the result did not show a significant seasonal variation (Wilk's Λ=0.997, $F_{(1,110)}$ = 0.23, $p>0.05$ for insects preys; Wilk's Λ= 0.80, $F_{(1, 10)}$ = 2.373, $p>0.05$ for nematodes and Wilk's Λ =0.81; $F_{(1, 10)}$ = 2.47, $p>0.16$ for fish parts composition in the studied guts).

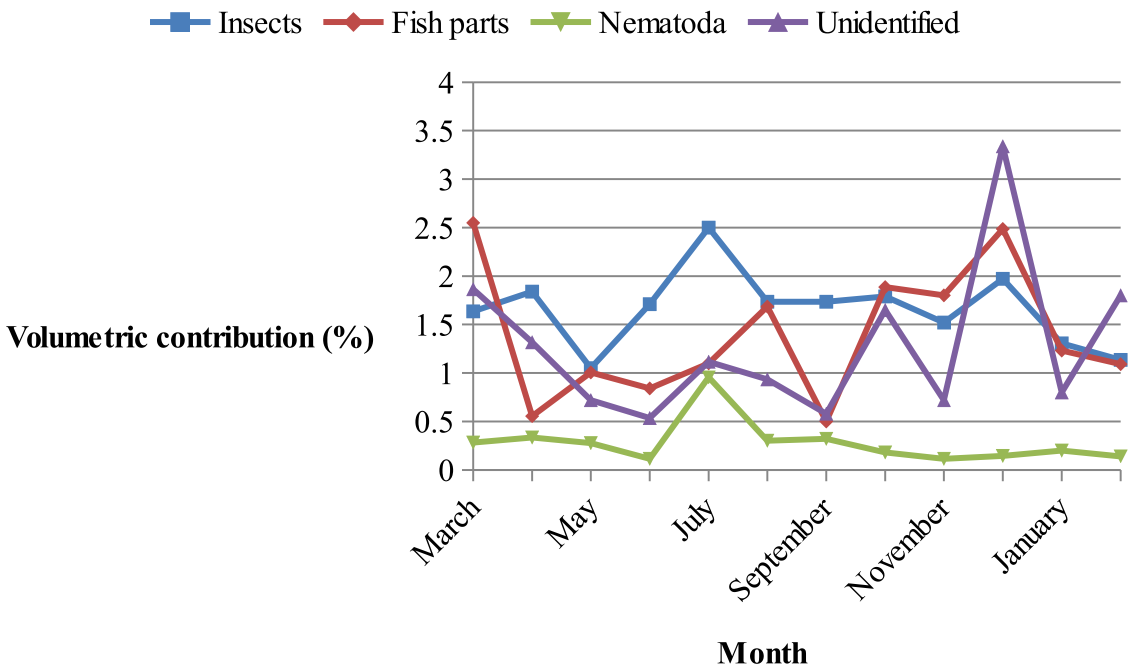
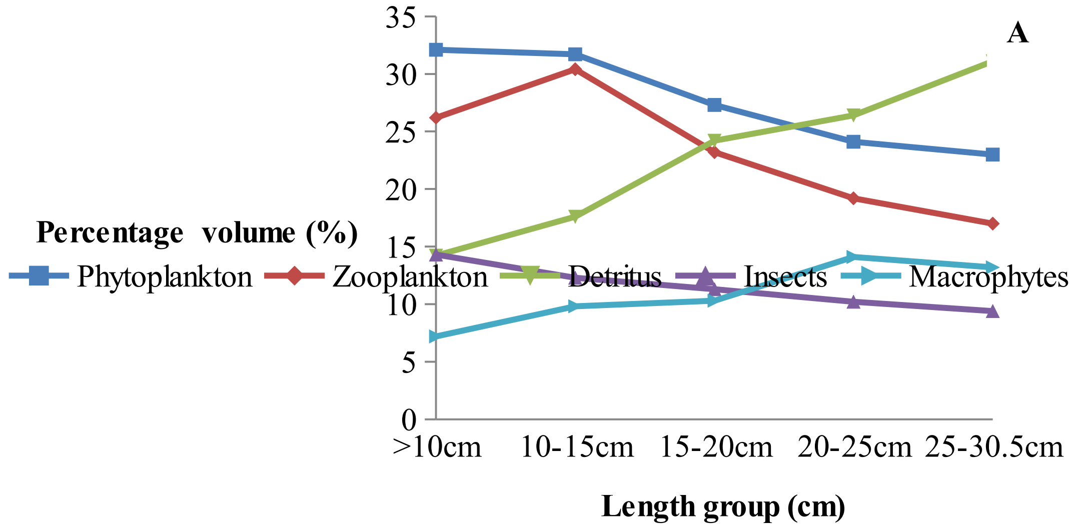


Figure 6.6: The monthly variation in volumetric contribution of detritus, macrophytes, aquatic insects, fish parts and nematode preys (%) in the food composition of *O. niloticus* from Lake Langeno, Ethiopia from March 2014 to February 2016.

6.3.4 Variation of food composition with fish size

Of the 512 assessed fish, about 5.8% (n=30) of them had <10 cm TL, 25.7% (n=131) had 10-15 cm TL, 22.2 % (n=114) had 15-20 cm TL, 30.1% (n=154) had 20-25 cm TL and 16.1 % (n=82) had above 25 cm TL. For the length group <10 cm, the contribution of phytoplankton (32.1%), zooplankton (26.2%) and insects (14.3%) were highest. However, the contribution of these prey items decreased by 23%, 17% and 9.4% as the total length increased to 30.5 cm TL. For the length group 20-25 cm TL and above, the composition of detritus (31.1%), macrophytes (13.2%) and fish parts (3.4%) were very high in the stomachs (Fig. 6.7 a and b).



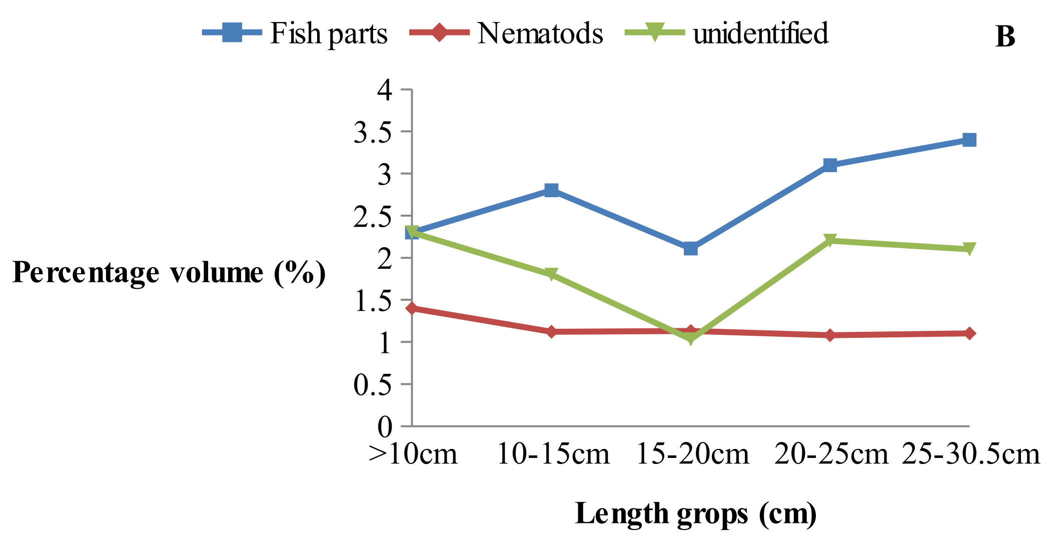


Figure 6.7: Volumetric contributions of different food items (%) in the stomachs of different length groups of *O. niloticus* in Lake Langeno, Ethiopia.

The relationship between food composition and length variation of the fish was linear and the regression model was best fitted for phytoplankton (r^2=0.94), zooplankton (r^2=0.76), detritus (r^2=0.98), insect food items (r^2=0.96) and macrophytes (r^2=0.86). The result showed a significant correlation of phytoplankton (r=-0.97; $t_{(1,4)}$=-7.76; $p<0.05$), zooplankton (r=-0.87; $t_{(1,4)}$=3.02, $p<0.059$), detritus (r=0.99, $t_{(1,4)}$=12.86, $p<0.05$), aquatic insect preys (r=-0.98, $t_{(1,4)}$=-9.62, $p<0.05$) and macrophytes (r=0.92, $t_{(1,4)}$=4.34, $p<0.05$) composition with the different length groups, but the relationship was not very significant for fish parts (r=0.51, $t_{(1,4)}$=1.01, $p>0.05$) and nematodes (r=0.50; $t_{(1,4)}$=-1.03, $p>0.05$) composition in the gut contents.

6.4 Discussion

6.4.1 Diet composition

The stomach contents analysis indicated that *O. niloticus* is feeding on a variety of food categories in Lake Langeno, including food from plant origin, such as phytoplankton, macrophytes and detritus, as well as food from animal origin, such as zooplankton, insects, nematodes, fish parts (eggs and larvae) and ostracods (Table 6.2). The ingestion of insects, ostracods, nematodes, some fish parts and most genera of the algae groups identified in the present study were not reported by Zenebe Tadesse (1999).Basically, the variation in diet composition is affected by many factors, such as season, spatial variation and ontogenetic dietary shift of fishes (Bozza and Hahn, 2010). Availability, composition and abundance of the prey items also determine the dietary composition of fishes (Meurer and Zaniboni-Filho, 2012).

The high abundance of phytoplankton in this study (Table 6.2, 6.3 and Annex 3) is in agreement with that of Zenebe Tadesse (1999) from the same lake, and similar findings have been reported in Gilgel Gibe I Reservoir (Mulugeta Wakjira, 2013), Koka Reservoir (Flipos Engdaw *et al.*, 2013), Lake Hayq (Workiyie Worie and Abebe Getahun, 2015) and Omo-Turkana Basin (Mulugeta Wakjira, 2016). A logical explanation for their high abundance in stomach contents of this fish is the high availability of these food items in tropical lakes (Bwanika *et al.*, 2007). Similarly, several authors have reported the high abundance of detritus in the diet of *O. niloticus* in different parts of Ethiopia next to phytoplankton (Flipos Engdaw *et al.*, 2013; Workiyie Worie and Abebe Getahun, 2015). The variation could, however, emphasize the opportunistic feeding behavior of *O. niloticus,* which depends on the availability of prey, seasonal and spatial differences of food distribution (Canonico *et al.,* 2005).

The high prevalence of *Microcystis* spp. in the diet of *O. niloticus* in our study (Annex 3) agrees with findings from Koka Reservior (Flipos Engdaw *et al.*, 2013) and Lake Hayq (Workiyie Worie and Abebe Getahun, 2015). Yet, the dominance of *Botryococcus* (green algae) and Oscillatoria (blue green algae) were reported in the food composition of the same fish in Lake Hawassa (Tudorancea *et al*., 1988), Lyngbya (blue green algae) in Lake Zeway (Zenebe Tadesse, 1988) and Melosira (diatoms) in Lake Chamo (Getachew Tefera, 1993). The dominance of one food item over the other could be the result of selective feeding behavior of fish to increase their nutritional benefits (Kohl *et al*., 2015). It would also results from differences in availability of foods between lakes (Flipos Engdaw *et al.*, 2013). Availability of food items in the lake depends on the variation of water conditions of the lake (Workiyie Worie and Abebe Getahun, 2015). For instance, the mean Secchi depth recorded in this study (15.7 cm) (Table 3.3) was very low as compared to the report from Lake Zeway (Lemma Abera, 2016), Hawassa (Admasu Woldesenbet, 2015) and Chamo (Adane Fenta and Almaz Kidanemariam, 2016), which indicates the high turbidity of the lake. The mean water pH of the lake (9.5) (Table 3.3) is also higher than the findings from Lake Zeway (Girma Tilahun and Ahlgren 2010), Lake Hawassa (Begashaw Abate *et al*., 2015) and Lake Chamo (Adane Fenta and Almaz Kidanemariam, 2016). Similarly, the mean TSD in Lake Langeno (1513 mgL^{-1}) (Table 3.3) was greater than the reports from Lake Zeway (270 mg L^{-1}) (Girma Tilahun and Ahlgren, 2010), Hawassa (455.6 mg L^{-1}) (Admasu Woldesenbet, 2015) and Chamo (656 mg L^{-1}) (Adane Fenta and Almaz Kidanemariam, 2016), which might have caused the variation in the availability of different food items in these lakes.

In addition, rotifers, cladoceran and copepods contributed an appreciable amount in the food composition of *O. niloticus* in Lake Langeno (Table 6.3). Zenebe Tadesse (1999) also reported the presence of rotifers and copepods in the food of *O. niloticus* in the same lake. However, cladocerans were absent in their report. According to Battarbee (2000), cladocerans are zooplankton that shows the seasonal variation in aquatic environments. Therefore, the emergence of cladocerans in this study could be attributed to the collection of samples in all seasons. Similarly, the studies carried out in some rift valley lakes, such as Lake Chamo (Yirgaw Teferi *et al.,* 2000), Lake Hawassa (Tudorancea *et al.,* 1988), LakeZeway (Zenebe Tadesse, 1998) and elsewhere (Shalloof and Khalifa, 2009) confirmed the high proportion of rotifers, cladocerans and copepods in the food of *O. niloticus*.

6.4.2 Seasonal variation in the diet of *O. niloticus* in Lake Langeno

Results of the present study showed a substantial seasonal variation in the food compositions of *O. niloticus* (Table 6.4, Fig. 6.2). For instance, the contribution of phytoplankton was highest in stomachs of *O. niloticus* in the dry season (January to May) (Fig 6.3 a and b). The proportion of phytoplankton in the water is relatively low in the wet season due to high flooding from the catchment area, which can causes the fluctuation in water level and increase turbidity (Njiru *et al.,* 2004b). Turbidity decreases the penetration of sunlight and affects the growth and abundance of phytoplankton (Paaijmans *et al*., 2008). Some authors also confirmed the seasonal variation of phytoplankton in the food composition of *O. niloticus* in some rift valley lakes (Flipos Engdaw *et al.,* 2013; Yirgaw Teferi *et al*., 2000).

The proportion of zooplankton in the diet of *O. niloticus* was highest in wet season (June to July) (Fig. 6.4), which might have attributed to the low water temperature of the season. According to Mergeay *et al.* (2006), low water temperature is a prerequisite condition to the hatching of zooplanktons. The seasonal flooding could also contribute to the high abundance of zooplankton population in wet season. The influent water is likely to bring in nutrients from the river and drained agricultural land, and help in mixing of autochthonous nutrients amongst the different strata of lake, which trigger off phytoplankton production and consequently zooplankton productivity (Okogwu, 2010). This corroborates with the reports of Workiyie Worie and Abebe Getahun (2015) in Lake Hayq and Flipos Engdaw *et al*. (2013) in Koka Reservoir.

The high dietary proportion of detritus in the wet season (April to July) (Fig. 6.5) might have emerged from plant materials flooding in during the rainy season (Workiyie Worie and Abebe Getahun, 2015). The dominance of detritus in the diet during the rainy season agrees with observation made in Lake Zeway (Zenebe Tadesse, 1988). Simialrly, the increase of ingested macrophytes in the wet season (July to October) (Fig. 6.5) could be explained by fish movements to shallow parts of the lake for reproduction. They stay there for a long period of time and feed on macrophytes and vegetation in wet season (Getachew Tefera, 1993). Spatial and seasonal changes in the lake induce variation in the food composition of *O. niloticus* (Ayoade *et al.,* 2008). This seems logical, but it shows that Nile tilapia is capable of switching to food that is more abundant or diverse radiation in its feeding habit and can utilize a wide spectrum of food items in the environment (Workiyie Worie and Abebe Getahun, 2015).

6.4.3 Variation of food compositions with fish sizes

The proportions of phytoplankton**,** zooplankton and insect larvae were very high in the stomach of fish with <10 cm sizes (Fig. 6.7a). The study indicated that juveniles of *O. niloticus* are generally omnivorous, but mainly feed on zooplankton and insect larvae and phytoplankton of which diatoms are the major food component (Benavides *et al.,* 1994; Flipos Engdaw *et al.,* 2013). This is because juvenile fish need high protein intake to support high growth rate and metabolism (Benavides *et al.,* 1994). Additionally, the variation in habitat preference between different size groups of fish can result the difference in their food composition (Benavides *et al.,* 1994).

Larger fish (>15 cm) rather relied on food from plant origin, such as macrophytes and detritus. Fish change their feeding behavior from primarily omnivorous to herbivorous with the high-energy demands as they grow in size (Benavides *et al.,* 1994; Flipos Engdaw *et al*., 2013; Workiyie Worie and Abebe Getahun, 2015). The growing demand of energy cannot be met by feeding only on zooplankton and benthic invertebrates. This enables them to shift their feeding behavior from eating only zooplankton and benthic invertebrates to the generalist behavior. In addition, the bigger fish are more capable of digesting cell wall material, and therefore can be less selective in their feeding pattern (German, 2009). The shift in feeding behavior shows a low degree of intraspecific competition for particular food among different length groups (Ayoade *et al.,* 2008). Many investigators also reported similar feeding variation in different size groups of *O. niloticus* in different water bodies (Njiru*et al.*, 2004b; Workiyie Worie and Abebe Getahun, 2015; Yirgaw Teferi *et al*., 2000).

In conclusion, the *O. niloticus* in Lake Langeno are characterized by omnivorous feeding habit that showed seasonal and length based variation of food composition. The size-related shifts in food item preferences of *O. niloticus* in the lake seem to depend upon physiological requirements, whereas the seasonal changes in dietary pattern might rather reflect the opportunistic feeding behavior of the species. It is unclear at this stage what these changes mean for the fish's physiology, but warrant further investigation in view of their meaning for aquaculture applications as well as for consequences of climate change.

CHAPTER SEVEN

7. PRODUCTION, SOCIO-ECONOMIC CHARACTERISTICS AND MANAGEMENT SYSTEM OF FISHERIES IN LAKE LANGENO, ETHIOPIA

7.1 Introduction

Fish is an important source of protein and serves as a source of income for many people engaged in fishing and related activities (Mohamed and Uranguchi, 2013; Vadacchino *et al*., 2011). It is the most accessible and affordable source of animal protein mainly for poor households in rural or semi-rural areas (Bene and Heck, 2005). Studies show that the contribution of fish to people in Sub-Sahara African countries is significant with a mean annual per capita consumption of 9.4 kg (Bene and Heck, 2005; Vadacchino *et al*., 2011).

It is also the main source of protein supply for many Ethiopians, particularly, for those who are living in the vicinity of the major water bodies (Gashaw Tesfaye and Wolff, 2014; Hussien Abegaz *et al.,* 2010a). The activity is closely linked with the other agricultural activities, such as farming and rearing of livestock (Aytegeb Anteneh, 2013). However, fishing practices in the country are still at its infancy (Abebe Ejigu *et al.* 2015). The sector is still traditional, and the resources are being exploited without enough knowledge of fishes (Gashaw Tesfaye and Wolff, 2014). Hence, the existing role of fishery is insignificant in the country's overall economy and food security (less than 0.05%) (Abduraman Kelil, 2002; Aytegeb Anteneh, 2013). Therefore, in addition to increasing the food production from the other agriculture sectors, it is also necessary to exploit aquatic resources sustainably to increase the contribution of fish to food security by virtue of the high potential productivity (FAO, 2011).

Several factors are affecting the fish production and community welfare in Ethiopia. Not integration of fish into the diet of most Ethiopian people, influence of the religious beliefs on fish consumption and high increase of price are the major challenges being observed (Abdurhman Kelil, 2002; Assefa Mitike, 2014). Old fishing practices, poor preservation methods and market constraints are also affecting the sector (Assefa Mitike, 2014; Mathewos Temesgen and Abebe Getahun, 2016). Poor implementation of the fishery proclamation, use of inappropriate fishing gears and open access nature of the fishery resources are also other factors for under development of the sector (Abdurhman Kelil, 2002, Felegeselam Yohannis, 2003; Mathewos Temesgen and Abebe Getahun, 2016). In addition, unemployment in other sectors is causing an increase in the number of fishermen, and overexploitation of the resources in some lakes nearer to the large cities (Asefa Mitike, 2014; Abdurhman Kelil, 2002).

Lake Langeno is one of the Ethiopian central rift valley lakes facing such types of challenges (Dawit Garoma *et al.,* 2013). Very limited studies were conducted on biological aspects of fishes in the lake (Gashaw Tesfaye and Zenebe Tadesse, 2008; Lemma Abera, 2012a; Leul Teka, 2001; Vijverberg *et al.,* 2012; Zenebe Tadese, 1999) and assessment of the determinant factors in gross margin income generated through fishing activity to rural households of the fishermen (Dawit Garoma *et al.,* 2013). However, yet nothing is known about the total annual catch, socio-economic contribution and management system of fisheries in the lake. Therefore, this chapter was aimed at investigating of fish production, socio-economic contribution, management system and the major constraints in fisheries production of Lake Langeno, Ethiopia.

7.2 Materials and methods

7.2.1 Site selection, study design and sample size determination

There are 6 fishery cooperatives with more than 47 landing sites around the lake, hosting 12 peasant associations (Kebeles). Of all the landing sites, 14sites (one from each of 10 Kebeles and two sites from each of Hurufa lole and Hora-kelo kebeles due their high number of landing sites) were selected randomly for the primary data collection (Fig. 7.1). From each of the landing site, a total of 180 fishermen were selected by systematic random sampling technique for an interview. Eighty one (81) of them were selected from members of the fishery cooperatives, and 99 of them were selected from those who are not members of any fishery cooperatives. Sample size was determined by Arsham's (2005) mathematical formula, which was computed as:

$N = 0.25/SE^2$

Where N = Sample size

SE = Standard error; which was calculated by using confidence interval of 10% and confidence level of 95%,

$SE = 0.1/1.95=0.05$

Based on this formula, 100 people were planned to be interviewed from each district. However, since the contribution of the lake for fishermen of Adami Tullu Jiddo Kombolcha District were few and only 80 fishermen were selected from that district. In addition, five hotels and five retailer shops each from Batu and Arsi Negelle towns were selected purposely to get the mean fish prices at hotels and shops in order to compare it with the prices at landing sites.

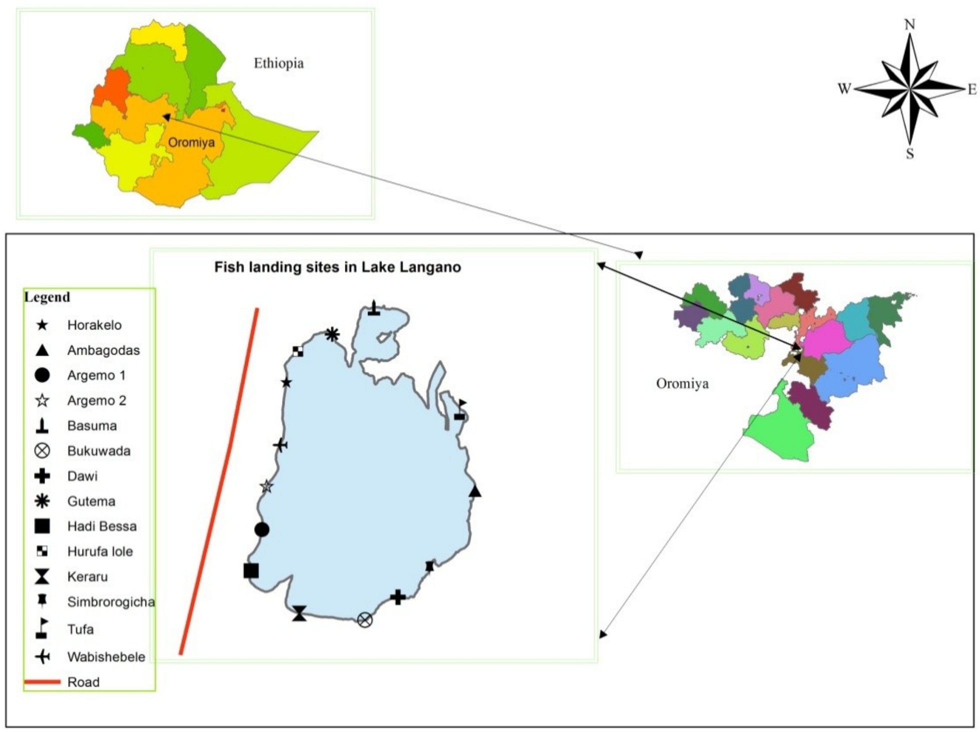


Figure 7.1: Location of the selected commercial landing sites for data collection

7.2.2 Method of data collection

The study was conducted from March 2015 through February 2016. Before the start of data collection, preliminary survey was conducted from December 2013 through February 2014. This helped to identify boundary of the lake, and to have a general understanding of the overall situations of the lake's fishery. Questionnaires were developed and translated to the local language (Afan Oromo), and pre-tested among some groups of the population, which were not included in the main sampling population.

Qualitative and quantitative data were collected through administration of open and close-ended questionnaires (Freund and Wilson, 2003) (Annex 6).To get appropriate data, respondents with age of 17 to 59 years were involved in the interview. Questionnaires were designed to investigate the socio-economic characteristics, status of fishes in the lake, livelihood background of the fishermen, the average annual total catch, socio-economic contribution of the fishery, the average annual consumption, fishing facilities used, the prices of fish and fish markets, factors affecting the fish catch, perception of the fishermen towards the resources and management systems being carried out.

In addition, discussion with different focus groups and key informants was made in order to get a comprehensive and robust data. The focus group discussion was held at each sampling site and at peasant association level. The member of focus group discussants involved in the discussion was 3 to 5 people. In general, the executive committees of the fishery cooperatives, members of the fishery cooperatives and peasant association executive committees were included in focus group discussion. In addition, key informants involved in the focal discussion were staff of fishery corporation Zeway branch, staff of ZFRRC and the two district's livestock and fishery officers.

Secondary data was also collected from the nearby districts, fishery corporation enterprise Zeway branch and from ZFRRC. In addition, the data on mean annual catch and the mean annual gross income were collected from fishery cooperative business executive committees based on their daily landing and buying data, and from the landed data. This was because the fishermen cooperatives associations are engaged both on catching and trading of fish, by collecting the fish directly from both licensed and non-licensed fishermen. The total annual production from the lake was estimated for the whole body (not filleted) of fishes, because the information obtained was by quintals of the whole body from the fishery cooperative associations. The average annual total catch of fish from the lake was also calculated as:

$$AnProd = \sum DFPr \times FDays$$

AnPr= Annual production at all landing sites

DFPr= Fish production day^{-1}

FDays= Fishing days

The filleted fish was considered to estimate the seasonal and spatial variation of fish prices, because fish trade in this area is being done in filleted form exclusively focusing on *O. niloticus*. The annual gross income earned/ fisherman was also computed as:

$$IncFr = FProdInc \times FDays \times FMkPr$$

Where IncFr = Gross annual income earned from fisheries in Ethiopian Birr (ETB $year^{-1}$)

FProdInc = Portion of fishes sold for income by fisher (kg day^{-1}, Fish day^{-1})

FDays = Number of days at fishing per year (days $year^{-1}$)

FMkPr = Market price of fish (ETB kg^{-1}, ETB $Fish^{-1}$)

Fish consumption was estimated based on estimation of quantity and frequency of daily eating fish/ household or family level. The amount of annual fish consumption per fisherman household was also computed as:

$$FCons = FProdCons \times FDays$$

Where, FCons = Annual fish consumption (kg $year^{-1}$, Fish $year^{-1}$)

FProdCons = Portion of fish consumed per fisher household (kg day^{-1}, Fish day^{-1})

FDays = Number of fishing days per year (days $year^{-1}$)

7.2.3 Data analysis

Descriptive statistics such as percentage, mean, mode and standard deviation was done by Microsoft excel. Non-parametric one sample Chi-square test was employed to test the heterogeneity of respondent's socio-demographic characteristics (nominal scales) such as gender, marital status, religion, fishermen categories, means of livelihood, purpose of fishing, fishing gear and boat possession, marketing system of fish products, number of fishermen per the fishing sites, family size, age of the respondents, educational level of the respondents and perception of the respondents. One sample Chi square test was performed for a count data. An independent paired t-test was also employed to test the total annual production and total annual income variations between landing facilities owners and those have landing facilities. One way ANOVA was also used to test the mean spatial and seasonal variation of fish prices, and the fish catch variations among the landing sites. All of the collected data were analyzed by SPSS software version 20.0 and PAST version 3.08 software.

7.3 Results

7.3.1 Socio-demographic characteristics

A total of 180 fishermen (males (96.1%) and females (3.9%)) were interviewed for the present study. About 68.9% of them were married and have families. Muslim religion followers dominated the respondents (45.0%) followed by Christian orthodox followers (28.3%). Educational status of the respondents also showed that 11.7% were illiterate, 47.2% of them got adult education, and the rest of them (41.1%) have received formal education (grade 1-10). However, none of them joined college or university. Their family sizes ranged from a minimum of 2 people to a maximum of 12 people per familywith the modal family size of 5.6 people per family. The minimum and maximum age of respondents recorded was 17 years and 59 years old with modal age of 34.3 years (Table 7.1**)**. Generally, the result of socio-economic and demographic characteristics showed a significantheterogeneity among the interviewed fishermen, except for educational level of the respondents (χ^2, $p<0.05$).

Table 7.1: Summary of statistics and socio-demographic features of the fishermen respondents around Lake Langeno, Ethiopia. Chi-square test was carried out at α =0.05). The astrics indicated a significant heterogeneity (n=180).

Socio-demographic	Category	Total	Percent	Chi-aquare	p-value
Gender	Male	**173**	96.1		
	Female	**7**	3.9	8.04	0.000**
Marital status	Married	124	68.9	5.76	0.012*
	Unmarried	54	30.0		
	Divorced/widow	2	1.1		
Religion	Muslim	81	45.0	10.01	0.019*
	Orthodox	51	28.3		
	Protestant	31	17.2		
	Wakefata	17	9.4		
Educational level	Non educated	21	11.7	2.01	0.57
	Adult education	85	47.2		
	Primary school	61	33.9		
	Secondary school	13	7.2		
Household family size	<3	8	4.4	5.22	0.032*
	6-9	53	29.4		
	9-12	45	25.0		
	12-Sep	18	10.0		
	>12	2	1.1		
Age	<18 years (teenagers)	16	8.9	11.02	0.011*
	19-35 years (young)	76	42.2		
	36-50 years (adult)	79	43.9		
	>50 years (elderly)	9	5.0		

Majority of the respondents (61.7%) were part time fishers, which showed a significant heterogeneity (χ^2, $p<0.05$). The frequency of fishing per week ranges from 1 to 7 days per week with the mode of 5.2 fishing days per week. The fishing experience of respondents also ranged from 1 to 22 years with the mean fishing experience of 10.7 years. Majority of them (65.0%) had fishing experience of more than ten years. Of all the respondents, about 45.0% (n=81) of them were involved in the fishermen cooperative associations (Table 7.2).The result showed a significant heterogeneity among the respondents for all of the considered activities (χ^2, $p<0.05$)

Table 7.2: Fishing activities, membership, frequency of fishing per week and experience of fishing by respondents in Lake Langeno, Ethiopia (n=180). Chi-square test was carried out at α=0.05. The astrics indicated a significant heterogeneity.

Fishing activities	Category	Total	Percent	Chi-square	p-value
Fishers categories	Part time	111	61.7	12.80	0.003*
	Fulltime	57	31.7		
	Occasional	12	6.7		
Frequency of fishing (days per week)	Daily	19	10.6	6.22	0.043*
	5-7 days/week	72	40.0		
	3-5 days/week	54	30.0		
	1-3 days/week	28	15.6		
	Occasional	7	3.9		
Fishing experience	<1 year experience	12	6.7	5.21	0.048*
	1-5 years' experience	51	28.3		
	5-10 years' experience	63	35.0		
	10-15 years' experience	36	20.0		
	>15 years' experience	18	10.0		
Cooperative name	Hoitu Langeno	19	10.6	2.4	0.087*
	Daka Hora-Kelo	14	7.8		
	Dole	16	8.9		
	Kararu	13	7.2[a]		
	Tufa	10	5.6[a]		
	Buku Walda	9	5.0		
	Non-member	99	55.0		

In addition, a total of 30 key informants and focus group discussants (87% (n=26) males and 13% (n=4) females) from different organizations have participated in focus group discussions (Table 7.3).

Table 7.3: Statistics and socio-demographic features of focus groups and stakeholder respondents (n=30).

Name of organization	Number interviewed			Percent (%)
	Male	Female	Total	
Fishermen cooperatives	12	0	12	14.6

Kebele administrative and DA workers	20	4	24	29.3
District's office of livestock and fishery	4	2	6	7.3
Fishery corporation	1	0	1	1.2
ZFRRC	2	0	2	2.4
At landing sites with fishermen	36	1	37	45.1
Total	**26**	**4**	**30**	**100**

7.3.2 Catch composition

The catch composition from the lake includes *O. niloticus*, *C. gariepinus*, *C. carpio* and L. *intermedius*. For instance, the catch statistics in 2015/2016 showed that 87.6% of the catch was *O. niloticus*, 5.9% *C. gariepinus*, 4.9% *C. carpio* and 1.6% *L. intermedius* (Fig. 7.2). The catch of *C. carpio* and *L. intermedius* started to appear since 2000. However, *O. niloticus* has remained the most targeted species due to its high dominance in the lake, and its high acceptability in the market.

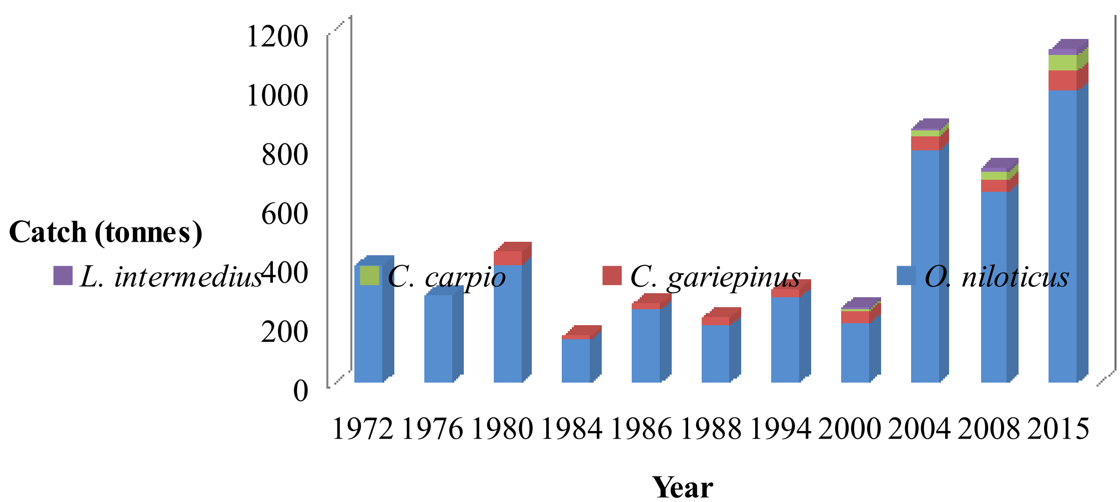


Figure 7.2: Catch composition of fish species in Lake Langeno from 1972 to 2015 (Sources: LFDP, 1997; Fishery corporation enterprise Zeway branch and the current study).

7.3.3 Livelihood means of the fishing community

The means of livelihood of the interviewed fishermen were both fishing and farming (50.0%) followed by full time fishing activities (22.8%). There was a significance heterogeneity in means of livelihood among the interviewed fishermen respondents (χ^2=6.62, p=0.045). The result also showed a significant heterogeneity in purpose of fishing among the interviewed respondents (χ^2=7.64, p<0.038). Majority of the respondents (57.2%) are catching fish both for food and for market (Fig. 7.3).

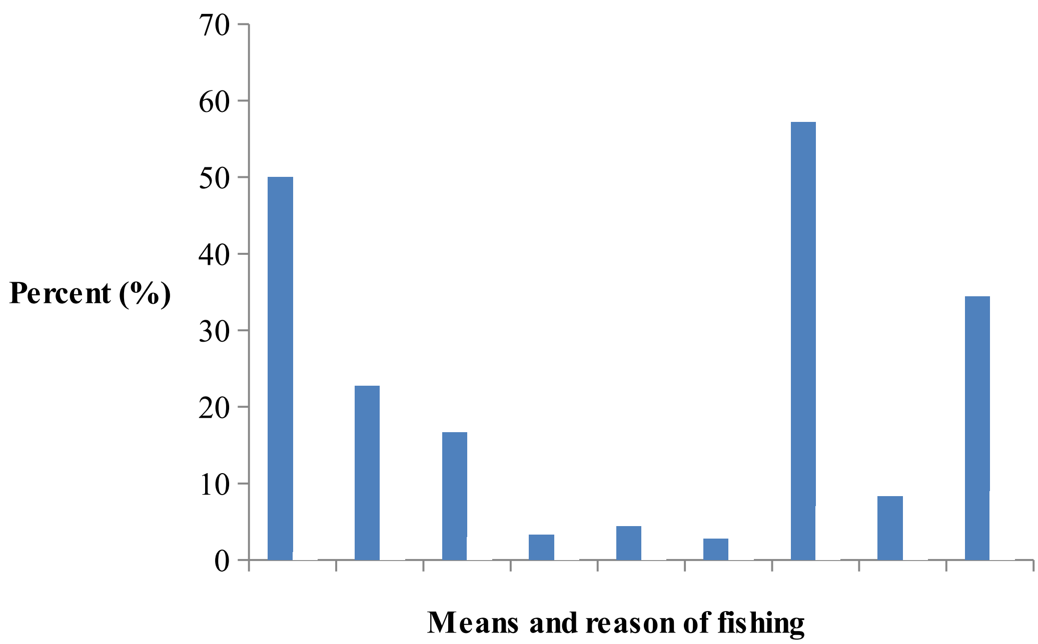


Figure 7.3: Means of livelihood and reason for engaging in fishing for the surveyed fishermen respondents (%) in Lake Langeno, Ethiopia.

7.3.4 Fishery cooperatives and their fishing facilities

Currently, there are six fishermen cooperatives working on the lake. Except Hoitu Langeno fishermen cooperative, all are located in Arsi Negelle District. The total number of the cooperatives members was 195. Hoitu Langeno and Dole fishermen cooperatives had more members than the others. In addition, there were many illegal fishermen fishing in the lake. Totally, more than 1100 people are fishing on the lake including both the licensed and illegal fishermen. The number can escalate more in fasting season.

Fishing gears possessed by the fishers were predominantly beach seine and long lines. There were also very few gillnets used by some fishermen. In general, about 241 beach seines, 26 gillnets and 153 long lines are owned by all of the cooperative members. Wooden boat operated manually is the most commonly used type of boat. There are about 147 wooden boats, 2 raft boats and 1 motorized boat (owned by Hoitu Langeno cooperative) were owned by all of the cooperatives. Additionally, 16 raft boats, 6 gillnet and 42 long lines belonging to unlicensed fishermen were recorded during the study period. In total, about 166 boats and 468 fishing gears are operating on the lake (Table 7.4).

Table 7.4: Fishermen cooperatives, total number of members and fishing facilities possessed by the fishermen cooperative in Lake Langeno, Ethiopia.

Cooperative's name	Members (No.)	Wooden boat (No.)	Legal raft boat (No.)	Illegal raft boat (No.)	Motor boat (No.)	Beach seine (No.)	Legal gillnet (No.)	Illegal gillnet (No.)	Legal long lines (No)	Illegal long lines (No)	Estimated number of total fishermen
Hoitu Langeno	56	40	1	4	1	56	8	2	64	11	307
Daka Hora-Kelo	27	31	-	2	-	43	3	1	11	4	232
Dole	49	36	1	3	-	68	5	1	32	9	270
Kararu	25	15	-	2	-	32	3	1	17	5	112
Tufa	20	11	-	3	-	21	4	1	13	7	82
Buku-Wald	18	13	-	2	-	21	3	-	16	6	97
Total	**195**	**147**	**2**	**16**	**1**	**241**	**26**	**6**	**153**	42	1100

7.3.5 Fishing gears and boats possession by interviewed respondents

Of the 180 fishermen interviewed, 74.4% of them had no boat. However, 60.0% of them had fishing gears, i.e. either beach seine, long lines or gillnet. Of these, only 16.7% of them owned both boat and fishing gears (Table 7.5). There was a significant heterogeneity in the ownership of fishing gears and boats among the interviewed fishermen (χ^2, $p<0.05$).

Table 7.5: Percentages of fishing gears and boats possessed by interviewed fishermen respondents in Lake Langeno, Ethiopia. Chi-square test was carried out at α=0.05. Astrics indicated the significant heterogeneity.

Specific question	Number (N)	Percent (%)	Chi-square	p-value*
Gillnet	36	20.0		
Beach Seine	9	5.0		
Long lines	45	25.0	7.61	0.042
Beach Seine, gillnet, long lines and boat	18	10.0		
Have no fishing facilities	72	35.0		
Wooden hand operated boat	41	22.8		
Motorized boat	1	0.6		
Papyrus made boat	4	2.2		
Have no boat	134	74.4	9.64	0.011

7.3.6 Marketing and market-chain of Lake Langeno's fishery

The market chains of Lake Langeno's fishery include the local, regional and national networks involving many actors. The major market destinations are capital cities like Addis Ababa and Adama retailer shops, which end at the consumer level. There are also some local market destinations, such as Zeway, Arsi Negelle, Dole, Bulbula and Munesa towns. Fishermen cooperatives and fishery corporation enterprise are the two major middle actors actively involved in fish markets. However, fishermen cooperatives sell their products to the fishery corporation that directly sells it to the Addis Ababa and Adama retailers, shops, hotels and supermarkets (Fig. 7.4).

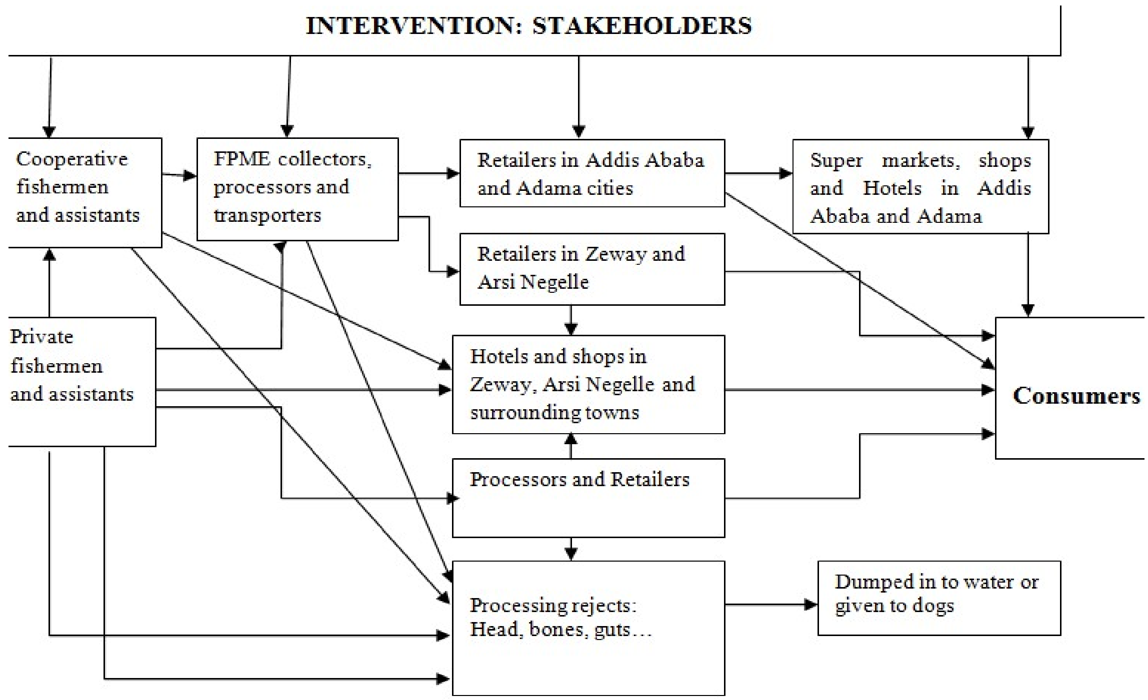


Figure 7.4: The fish market chain in Lake Langeno, Ethiopia (Adopted from Brook Lemma, 2012).

Majority of the fishermen (79.1%) sell their catches to the fishery cooperatives and 15.7% of them sell to Fishery Corporation at landing sites. Only a few of them (5.2%) sell fish directly to consumers, local markets, hotels and shops (Fig. 7.5). However, the result showed a significant heterogeneity in fish marketing among the respondents (χ^2=36.7, p=0.001).

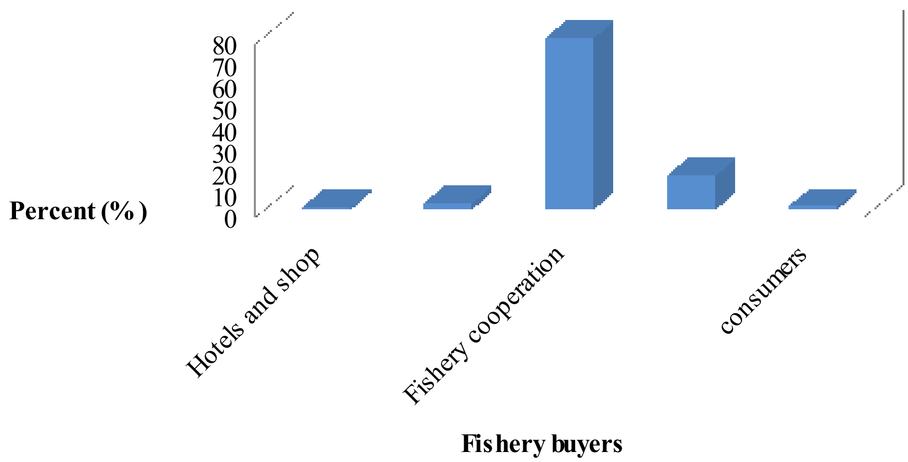


Figure 7.5: The fish product buyers from fishermen of Lake Langeno, Ethiopia

7.3.7 Seasonal and spatial variation of fish prices

The price of 1 kg filleted fish ranged from 13.62 to 50.20 ETB kg^{-1} with the average price of 33.26 ETB (1.22USD) kg^{-1}) at landing sites, 59.50 to 71.70 ETB $kg^{-1}$with the mean price of 67.48 ETB (2.48USD) kg^{-1}) at the retailer shops and 75.00 ETB to 100.00 ETB kg^{-1} with mean of 84.80 ETB (3.12USD) kg^{-1} at hotels. The maximum and minimum prices were recorded in months from March to May and June to August, respectively. Generally, the mean price of filleted fish showed about 72.87% seasonal variation at landing sites and 17.01% variation at retailer shops (Table 7.6). In addition, the price of filleted fish kg^{-1} ranged from 14.70 to 55.00 ETB with the mean of 34.60 ETB at Hoitu, Dole and Hora-kelo sites, and 8 to 50 ETB with the mean of 28.40 ETB in other sites.

Table 7.6: The mean price (ETB kg^{-1}) of filleted fish at the landing sites of Lake Langeno, retailer shops and hotels from March 2015 through February 2016 (1 USD=27.18 ETB at the time of data collection, SD=Standard deviation). ANOVA was computed at α=0.05. Astrics indicated a significant difference.

Month	At landing site		At shop		At hotel	
	Range (Birr)	Mean±SD	Range (Birr)	Mean±SD	Range (Birr)	Mean±SD
June - August	8-25	13.6±6.2	50-65	59.5±2.2	75-100	84.8±4.3
September - November	23-40	30.4±2.3	60-70	67.4±1.9	75-100	84.8±4.3
December -February	45-55	50.2±2.0	65-80	71.7±2.4	75-100	84.8±4.3
March - May	30-50	38.8±3.3	65-75	70.3±1.9	75-100	84.8±4.3
Average		33.3 ±4.3(1.23USD)		67.5±4.1(2.48USD)		84.8±4.3 (3.12USD)
P value		0.031		0.062		-

7.3.8 Socio-economic contribution of fisheries

7.3.8.1 Estimated annual production and gross annual income by cooperatives

The number of fishermen working per boat ranged from 3 people in Buku Walda fishermen cooperative to 10 people in Hoitu Langeno fishermen cooperative with the mean of 6.1 people per boat. The result showed a significant difference in number of fishermen among the cooperative associations (ANOVA, $p<0.05$).

The highest fish catch per day was observed at Hoitu Langeno cooperative (1,150 kg day^{-1}) and the least catch was observed at Tufa fishery cooperative association (351 kg day^{-1}). The daily fish production was significantly different among the fishermen cooperatives (ANOVA, $p<0.05$). Generally, the mean total annual production from the entire lake was estimated to be about 1,137.7 tonnes.

The mean price of filleted fish per kilogram at the Hoitu Langeno, Daka Hora-kelo and Dole fishery cooperative sites was comparatively highest (8.5 ETB kg^{-1} or 0.31 USD), whereas it was about 6.5 ETB (0.24 USD) at the other landing sites. However, the price did not show a significant variation among the sites (ANOVA, $p>0.05$). In general, the mean gross annual income from fishery for all of the fishery cooperatives was estimated to be 8,622,158 ETB (317224.37 USD), where Hoitu Langeno and Dole fishery cooperatives takes the largest share (Tables 7.7).

Table 7.7: Summary of the mean annual catch, fishing days per year, mean prices and mean annual income from fishery in Lake Langeno, Ethiopia from March 2015 through February 2016(1 USD=27.18 ETB at the time of data collection, SD=Standard deviation. *ANOVA test was carried out at α=0.05.Astrics indicated a significant difference.

Cooperative name	**No of people / boat**		**Fishing Days/ yr.**		**Production/day (kg)**		**Mean prod./ yr. (Ton)**	**Price/day (ETB) at Landing Site**		**Estimation of mean income/ yr. (ETB)**
	Range	**Mean**	**Range**	**Mean**	**Range**	**Mean±SD**		**Range**	**Mean±SD**	
Hoitu Lang.	4-12	7.0±1.9^{a}	252-300	276±14.4^{a}	700-30,000	1,150.0±8321.1^{a}	427.8	2-13	8.5±3.5^{a}	2,697,900^{a}
Daka HK	3-9	5.0±1.6^{b}	240-264	252±3.3^{b}	200-15,000	712.5±4073.6^{b}	179.6	2-13	8.5±3.5^{a}	1,526,175^{b}
Dole	4-10	6.0±1.6^{a}	252-288	270±10.2^{a}	300-20,000	1,087.0±5931.9^{a}	347.5	2-13	8.5±3.3^{a}	2,494,665^{a}
Keraru	3-8	4.5±1.3^{b}	216-256	236±16.1^{c}	70-9,000	502.0±2919.2^{c}	118.4	3-10	6.5±3.2^{a}	770,068^{c}
Tufa	3-7	4.3±1.0^{b}	192-252	224±11.4^{c}	60-7,000	351.0±2299.2^{d}	78.6	3-10	6.5±3.2^{a}	51,1056^{d}
BW	3-6	3.5±1.0^{c}	180-264	222±24.4^{c}	50-8,000	431.3±2164.9^{d}	95.7	3-10	6.5±3.3^{a}	622,293.8^{c}
Average total							**1,137.7**			**8,622,158** (317224.37 USD)
P-value*	-	0.048*		0.062*	-	0.012*	0.012*	-	0.381	0.041*

7.3.8.2 Extrapolation of annual production and annual income by fishermen

The total annual production for the fishing facilities owners ranged between 28,44-53,088 kg $year^{-1}$ with the mean production of 26,010.75 kg $year^{-1}$ (26.01 tonnes), whereas for those who have no landing facilities, it ranged between 326-3,200 kg $year^{-1}$ with the mean annual production of 692.75 kg (0.69 tonnes). In terms of income, the gross annual income for fishing facilities owners ranged from 20,619-384,888 ETB with the mean annual income of 123,981.81 ETB (4561.51 USD), while for those who have no fishing facilities, it was about 2,363.5-23,200.00 ETB with the mean annual income of 6,203.78 ETB (228.25 USD) (Table 7.8). The result showed a significant variation of mean annual catch and income among the landing facility owners and those who have no landing facilities (T-test, $p<0.05$).

Table 7.8: Extrapolation of annual catch and annual income differences among owners of the landing facilities and those who have no landing facilities in Lake Langeno, Ethiopia from March 2015 through February 2016(1 USD=27.18 ETB at the time of data collection, SD= Standard deviation, ANOVA test was carried out at α=0.05, astrics indicated a significant difference).

Items	**Unit**	**Have no fishing facilities**		**Have fishing facilities**		**T-value**	**p-value**
		Range	**Mean**±SD	**Range**	**Mean**± **SD**		
Days of fishing year^{-1}	No	192-312	237.0±37.1	96-208	163.0±30.3	4.23	<0.05**
Production/ day^{-1}	Kg	12-225	109.8±58.9	2-20	5.3±3.8	5.12	<0.05**
Production year^{-1}	Kg	2,844-53,088	2,6010.8±14,303.9	326-3,200	692.8±609.6	4.48	<0.05**
Average price kg^{-1}	ETB	2-14	7.3±3.0	2-14	7.3±2.9	6.27	<0.05**
Average income day^{-1}	ETB	87-1624	523.1±460.3	14.5-145	38.1±25.7	6.11	<0.05**
Gross income year^{-1}	ETB	20,619-384,888	123,981.8 (4561.51 USD)	2,363.5-23,200	6,203.8 (228.25 USD)	6.21	<0.05**

The total annual catch for full time fishermen was 2,340-7,020 kg $year^{-1}$ with the mean catch of 3,088.8 kg $year^{-1}$, while for part time fishermen; it ranged from 304-2,280 kg $year^{-1}$with the mean annual catch of 790.4 kg $year^{-1}$. The mean daily income for full-time fishermen was 72.50 ETB to 217.50 ETB with the mean daily income of 95.70 ETB (3.52 USD), whereas for part time fishermen, it ranged from 14.50 to 108.75 ETB day^{-1} with the mean daily income of 37.70 ETB (1.39 USD). Generally, the calculated gross annual income was about 22,393.80 ETB (823.91USD) for full-time fishermen, and 5,730.40 ETB $year^{-1}$ (210.83 USD) for part time fishermen (Table7.9). The general mean gross annual income for all fishermen was estimated to be 6,820 ETB (250.92 USD).

Table 7.9: Extrapolation of annual catch and annual income differences among the fulltime and part time fishermen respondents in Lake Langeno, Ethiopia from March 2014 to February 2016 (SD= Standard deviation, 1 USD=27.18 ETB at the time of data collection).

Items	Unit	Full-time		Part time	
		Range	**Mean±SD**	**Range**	**Mean±SD**
Days of fishingyr.$^{-1}$.	No	220-300	234.0±22.7	96-240	152.0±42.5
Production day^{-1}	Kg	10-30	13.2±3.7	2-15	5.2±3.7
Production yr.$^{-1}$	Kg	2340-7020	3,088.8±9,81.1	304-2280	790.4±536.1
Price kg^{-1}	ETB	2-14	7.3±3.71	2-14	7.3±30.1
Gross income day^{-1}	ETB	72.5-217.5	95.7±38.40 (3.52 USD)	14.5-108.8	37.7±25.10 (1.39 USD)
Gross income yr.$^{-1}$	**ETB**	**16,965-50,895**	**22,393.80 (823.91 USD)**	**2,204-16,530**	**5,730.40 (210.83 USD)**

7.3.9 Fish consumption

The frequency of eating fish ranged from 0 to 3 times day^{-1} with the mean of 1.0 day^{-1}. About 51.7% of the respondents eat fish only once day^{-1}, 21.7% of them eat 1-2 time day^{-1}and 12.5% of them eat 2-3 time day^{-1}and 14.7% of them eat fish occasionally. The frequency of eating fish per day showed a significant heterogeneity among the interviewd fishermen (χ^2, $p<0.05$). The amount of fish consumption per family ranged between 0.3 and 1.5 kg/ day with the mean consumption of 0.5 kg day^{-1}. Majority of the respondents (75%) mentioned that their family's home consumption was less than 1 kg day^{-1}, while 25% of them said that it was 1.0-1.5 kg day^{-1}. In general, the mean consumption of fish for each household was about 131.7 kg year^{-1}. With a mode family size of 5.6 (presented in Table-6.1), the per capita annual consumption of fish was about 23.7 kg (0.0.1 kg person^{-1} day^{-1}) (Table 7.10).

Table 7.10: The mean annual per capita consumption of fish among the fishermen respondents of Lake Langeno fishermen from March 2014 to February 2016 (SD= Standard deviation).

Fish consumption	**Unit**	**Range**	**Mean±SD**
Frequency of eating day^{-1}	No.	0-3	1.1±0.9
Consumption/day $household^{-1}$	Kg	0.25-1	0.5±0.2
No. of days consume fish $year^{-1}$	No.	240-288	274.4±13.9
Consumption/year $household^{-1}$	Kg	122.4-146.8	131.7±7.1
No. of family members	No.	1-12	5.6±3.2
Annual per capita consumption	Kg		**23.7**

7.3.10 Management, follow-up and perception of respondents towards the lake's fishery

7.3.10.1 Respondents opinion regarding the status of fishes and fishing gears

The majority of the fishermen respondents (75%), focus group discussants and key informants agreed on the decreasing in size and number of fishes in Lake Langeno. In addition, all of them (100%) confirmed the increasing of fishermen. Most of the respondents (60%) also responded on the absence of follow-up by the concerned bodies. About 76.11% of them had also not received any training in their life concerning fishing and fisheries.

About 55% of the respondents mentioned that reduction in size of fishing gears is the main factor for destruction of fish resources in the lake. The minimum mesh size recommended for beach seine and gillnet is 6 cm and 8 cm, respectively (Office of livestock and Fishery of Adami Tulu Jido Kombolcha, 2016). However, only 28% of them are following the recommended mesh size, whereas 38% are changing their gear size depending on the size of fishes. The result showed a significant heterogeneity in opinion of respondents in all of these ideas (χ^2, $p<0.05$) (Fig. 7.6).

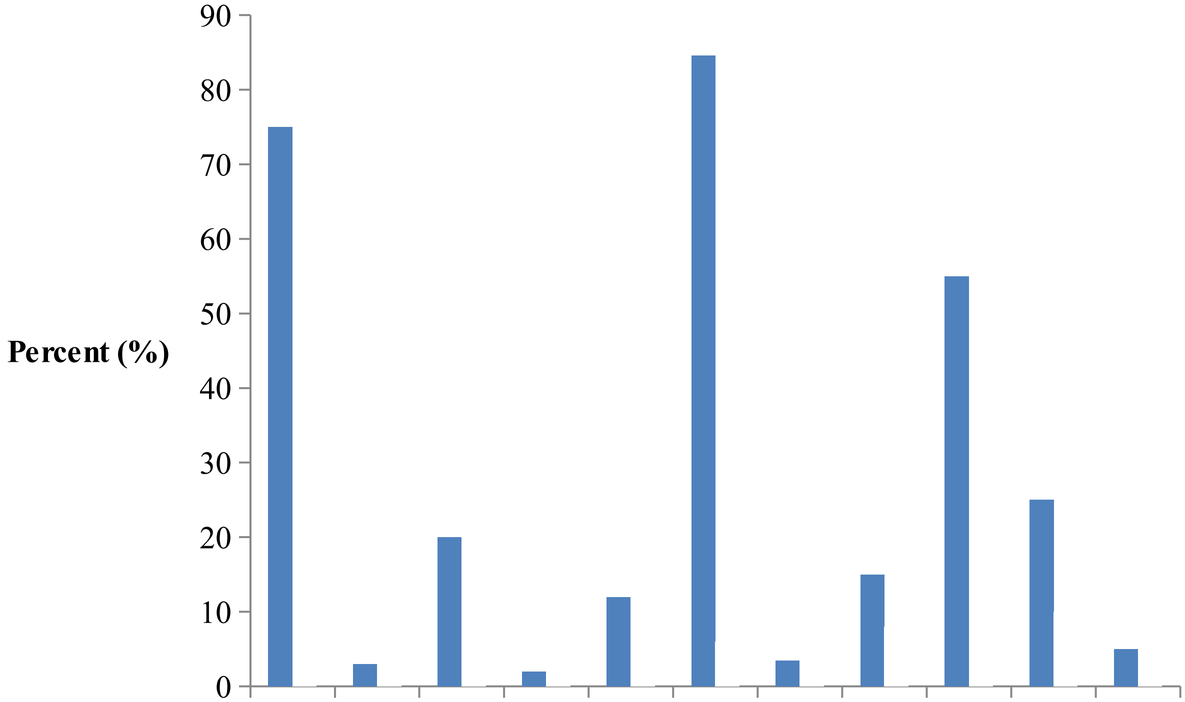


Figure 7.6: Fishermen respondents' opinion regarding the status of fishes in Lake Langeno, reasons for not getting training and reasons for not following the recommended mesh size of the fishing gears in Lake Langeno, Ethiopia (RMS=recommended mesh size).

7.3.10.2 Respondent's opinion regarding the Lake Langeno's fisheries management

Most of the respondents (35%) confirmed that local community is the most responsible body in the management of fishes, and few of them (25%) agreed that government is the top responsible body. However, about 30% of them responded that fishery cooperatives and local communities should be the most responsible bodies. Priority challenges mentioned by most of the fishermen respondents were illegal fishing (38%) and lack of extension support from the government (32.2%). The result does not showed a significant heterogeneity in perception of the respondents (χ^2=1.7, p=0.78) (Fig. 7.7).

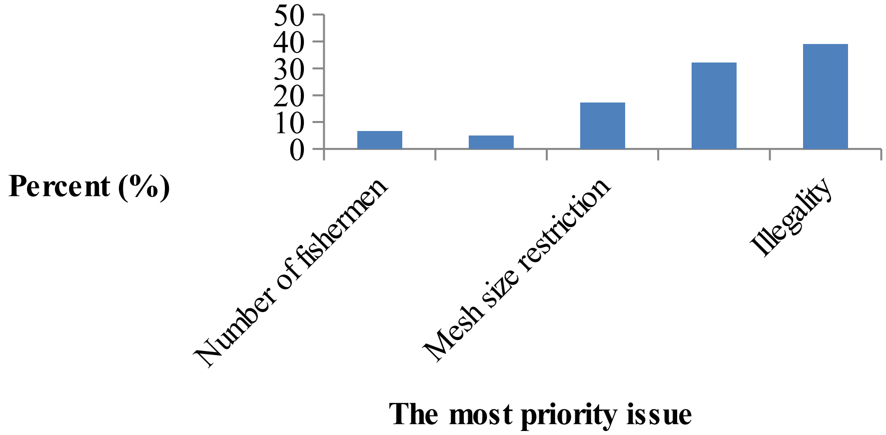


Figure 7.7: Perception of fishermen about management issues of fishes in Lake Langeno, Ethiopia.

Based on these problems, most of the fishermen strongly agreed on the idea of limiting the gears size (80%), limiting the number of people involved in fishing (60%) and prohibition of other fishing gears rather than beach seine (65%). However, they disagreed on measures, such as closed seasons/ times, permanently closed areas/ places, restriction of beach seines to operate only in some places and complete prohibition of beach seines (Table 7.11). The perceptions of all fishermen respondents were highly dissimilar (χ^2, $p<0.05$).

Table 7.11: Perception of fishermen respondents on fisheries management in Lake Langeno, Ethiopia (Chi-square test was carried out at α=0.05, astrics indicated a significant heterogeneity).

Management ideas	Strongly agree	Agree	Disagree	Strongly disagree	p-value
Closed seasons/ times	20 (11.11%)	45 (25%)	99 (55%)	16 (8.89%)	0.001**
Permanent closed areas/ places	27 (15%)	9 (5%)	36 (20%)	108 (60%)	0.031*
Limit on the number of people	108 (60%)	36 (20%)	27 (15%)	18 (10%)	0.001**
Restriction of beach seines to operate only in some places	51 (28.33%)	29 (16.11%)	57 (31.67%)	43 (23.89%)	0.000***
Restriction on mesh size	144 (8%)	27 (15%)	9 (5%)	0	0.042*
Prohibition of beach seine	6 (3.33%)	5 (2.78%)	15 (8.33%)	154 (85.56%)	0.051*
Prohibition of other gears	117 (65%)	9 (5%)	18 (10%)	36 (20%)	0.048*

7.3.10.3 Focus group discussion and key informants

Both focus group discussants and key informants who participated in the discussion mentioned that a combination of many factors, such as overfishing, increasing in number, lack of follow-up, illegal fishermen, use of very small sized beach seines, lack of knowhow on how to use the resources sustainably, absence of quota on the amount of catch, absence of support to fishing imput supply and unemployment are the major challenges affecting the lake's fishery. They also stated that lack of fishing gears, boats; cool storage facilities and efficient market to sell their product especially during the non-fasting season are affecting the sector. In addition, human factors, institutional factors and natural factors are hindering them to monitor the resources effectively. In particular, there are no qualified extension workers to work on fisheries at local and district administrative levels. Finally, majority of them (43.33%) agreed that further encouragement of fishery cooperatives is their major priority plan in the future (χ^2, $p<0.05$) (Fig. 7.8).

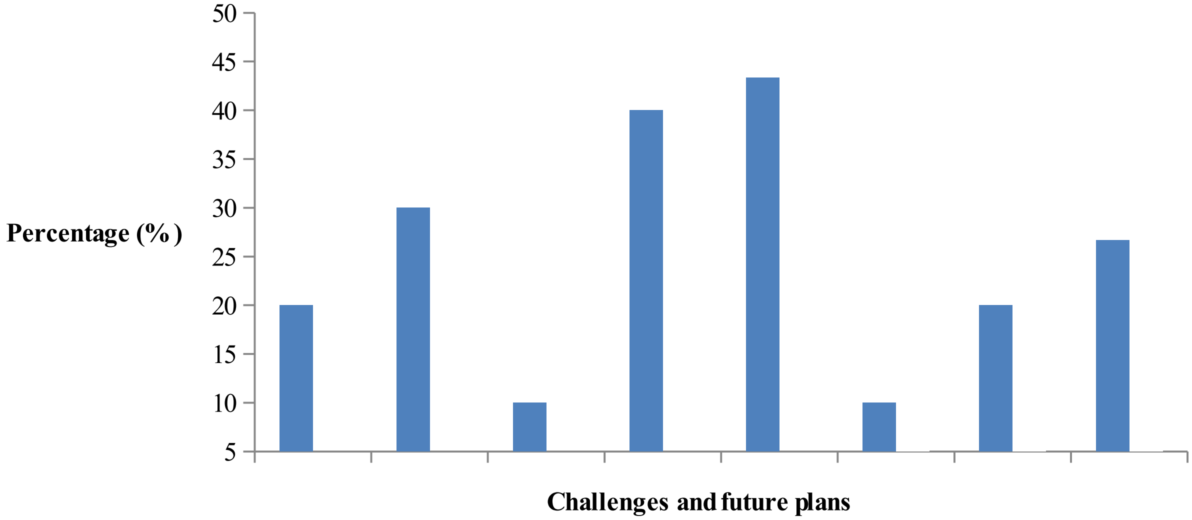


Figure 7.8: The challenges and future plans of key informants in management of fish resources in Lake Langeno, Ethiopia.

7.4 Discussion

7.4.1 Socio-demographic characteristics and fishery categories

The socio-demographic characteristics of the respondents were described in Table 7.1, 7.2 and 7.3.The result showed that majority of the fishermen respondents were males. This could be attributed to the culture, which gives males priority for domination of any activities outside the home including fishing. Finding of this study is in agreement with the reports made in different parts of Ethiopia (Dawit Garoma *et al.,* 2014; Dereje Tewabe, 2014; Erkie Asmare *at al.,* 2016; Shewit Gebremedhin *et al*., 2013; Tsegay Teame *et al.,* 2016b). Married house head groups dominated the marital status of respondents. This could be due to the burden and responsibilities they have in their families to cover expenses for their children's health, education and other basic needs. The mean family sizes of respondents were 5.6 people per family with a minimum of 2 per family and maximum of 12 per family. This is slightly higher than the regional average household size of the family (4.3) (CSA, 2014). This might due to the domination Muslim communities in the area, which allow them to have more than one wife (polygamy).

The educational backgrounds of respondents indicated that the majority of the respondents (88.3%) can at least read and write. In contrast to our finding, Mulugeta Wakjira (2016) reported that majority of the fishermen in lower Omo basin (80%) had no any education at all with a negative implication on fisheries management. However, none of the respondents in this study joined College or University, which shows that educational level amongst the fishing community, is still relatively low. This is in agreement with the report of Megersa Endebu *et al.* (2016) from Lake Zeway.

The modal age of fishermen respondents were 34.3 years old. This indicates that majority of the fishermen were dominated by adult age groups. However, the proportion of elders and teenagers were very few. This might be due to the problem of using traditional fishing technology, which is very labor intensive and hence exclude elderly people (Shewit Gebremedhin *et al.,* 2013; Mberengwa and Zelalem Bacha, 2011).

Three different groups of fishermen namely: full time, part time and occasional fishermen were observed in the present study. Some of the fishermen were fully engaging in fishing with absolute reliance on fisheries for their livelihood. The majority of them (61.7%) were part-time fishers, who depend on fishing as an important part of their income, but also had other means of livelihood to sustain their living (Table 7.2). The mean frequency of fishing days week^{-1} was 5.22 days. This shows that fishing is serving as a regular means of livelihood for most of the fishermen either as fulltime or part time activities. Most of them were not involved in fishermen cooperatives, because the business performances of the cooperatives were quite poor to attract more members. Therefore, most of them were not interested to be involved in fishery cooperatives. In addition, due to the poorly organized fisheries managers and lack of follow-up, the fishermen cooperative organizations are very weak, which is also confirmed by many researchers in many parts of Ethiopia (Aytegeb Anteneh, 2013; Lemma Abera, 2016; Mulugeta Wakjira, 2016; Tsegay Teame *et al*., 2016b).

7.4.2 Catch composition, livelihood background of respondents and the purpose of fishing

The fishermen were largely dependent on a few commercially important fish species. The bulk of fish catch in the lake was *O. niloticus* (Fig. 7.2), which is very similar with the findings elsewhere in Ethiopia (Lemma Abera, 2016; Megeresa Endebu *et al.*, 2016; Erkie Asmare *et al.,* 2016; Samson Debebe, 2015). *Oreochromis niloticus* is the most preferred fish food in Ethiopian markets (Asefa Mitike, 2014; Gashaw Tesfaye and Wolff, 2014). However, size and volume of the catch in natural waters including Lake Langeno is declining due to overfishing (Gashaw Tesfaye and Wolff, 2014). It has been known that *C. carpio* is stocked into Lake Langeno by European Union (EU) funded Lake Fisheries Development Project in the 1980s (LFDP, 1997). In recent years, *C. carpio* and *C. gariepinus* are becoming a part of fishery catch due to the highly increasing of the two species acceptance in the market.

The main means of livelihood of the fishermen were both farming and fishing (Fig. 7.3). Although they are relying on both activities, fishing is the main source of income for their livelhood. Langeno is one of the food insecure areas in Oromiya region (OFSDPPC, 2005). Inadequate precipitation, irregularities of climate, poor soil fertility and population pressure are the major reasons (Dawit Garoma *et al*., 2013; OFSDPPC, 2005). Therefore, most of them are engaged in fishing either legally or illegally for their livelihood (Dawit Garoma *et al*., 2013). Similarly, both farming and fishing are overwhelmingly the most important activities for food supply, and serving as a source of income in some parts Ethiopia (Erkie Asmare, 2016; Lemma Abera, 2016; Mulugeta Wakjira, 2016) and in other tropical countries (Moni and Khan, 2014), where fisheries take the largest part.

7.4.3 Fishery cooperatives, fishing facilities possession and number of fishermen

Similar to other cooperatives, fishery cooperatives provide an employment opportunity to the fishing community through fishing and marketing of fish, and provide a better way for conservation and use of water resources (Veerakumaran, 2007). In this study, only 195 fishermen were organized in six fishermen cooperatives (Table 7.4). About 15 years ago, only two fishery cooperatives (Hoitu and Dole) were there with the total membership of 216 and 72 fishermen, respectively (LFDP, 1997). However, the number of members declined to 62 and 56 in each of the two cooperatives, respectively and today it is reduced to 195 members. This shows that even though the number of cooperatives increased, illegality is increasing.

The fisheries in Lake Langeno are characterized by small-scale fishery dominated by beach seine and hand operated wooden boat (LFDP, 1997 and the present study). This is contradicting with many of the Ethiopian small-scale fisheries, which are operated by gillnets (Aytegeb Anteneh, 2013; Hussien Abegaz *et al.,* 2010a; Mulugeta Wakjira, 2016; Shewit Gebremedhin *et al*., 2013; Tsegay Teame *et al*., 2016a). There are also some fishermen using gillnets and long lines, and the number of these fishing gears are rapidly increasing in the lake as compared to LFDP (1997) report. This might be associated with the increasing of *C. gariepinus* and *C. carpio,* and reduction of *O. niloticus* in the lake (Lemma Abera, 2016).

The total number of fishing gears operating on the lake is also increasing dramatically. For instance, LFDP (1997) reported 36 beach seines operating in the lake area, but today about 241 beach seines, and more than 62 gillnets and 164 long lines are operating in the lake (Table 7.4). Similarly, the number of fishermen is increasing parallel to the increasing of landing facilities. The number of fishermen was, for instance, increased by 4.28 times (248 to 1,061) as compared to the report of LFDP (1997), which showed a similar trend with the finding from Lake Zeway (Lemma Abera, 2016). Generally, the increase of fishing gears also indicates an increasing of human pressure (Mberengwa and Zelalem Bacha, 2011).

Some fishermen owned more than one type of fishing gears to target different fish species (Table 7.5). Long lines mainly belong to mostly individual fishermen (both legal and non-legal fishermen), whereas beach seine and wooden boat are owned by the fishermen organized in fishermen cooperative associations who have enough capital to invest in the gears and vessels.

Majority of them had no fishing facilities, because most of the landing facilities are expensive to purchase and beyond the capacity of fishermen (Dawit Garoma *et al*., 2014; Lemma Abera, 2016). For instance, the price of the beach seine is 14,000 – 16,000 ETB and the price of wooden boat is 4,500 – 5,500 ETB (Dawit Garoma *et al*., 2014 and the present study), which is beyond their capacity.

7.4.4 Market and value-chain of fishery in Lake Langeno

The chain of fish market in Lake Langeno includes the regional and national networks involving many actors (Fig. 7.4 and 7.5).The major route of fish market is toward the Addis Ababa preservation shops and supermarkets via fishery corporation enterprise. Fishery cooperative associations and Fishery Corporation enterprise of Zeway branch are the two middlemen buying fish from fishermen. This is largely taking place at landing sites with low prices, which agrees with report of Assefa Mitike (2016) and Dawit Garoma *et al.* (2014). However, the two middlemenare working actively only during the fasting season of the Ethiopian Orthodox Christians that permits the eating of fish meat during the fasting season whereby eating other animal products is prohibited. During the non-fasting season, only a few of the fishermen supply fresh fish products directly to local markets, hotels and retailers. In general, the seasonal pattern of fish consumption is affecting the markets of Lake Langeno's fisheries. According to Gordon *et al*. (2007), fish consumption is heavily biased towards quite limited geographical areas, and fasting days (Wednesdays and Fridays) and/or fasting seasons (55 days in March/April and 15 days in August) in Ethiopia. As a result, the fish demand and fish market is highly fluctuating throughout the year, and the fish price is also fluctuating seasonally. This result is in corroboration with the reports made in some other rift valley lakes (Assefa Mitike, 2016; Lemma

Abera, 2016; Samson Debebe, 2015) and other parts of Ethiopia (Gashaw Tesfaye and Wolff, 2014; Shewit Gebremedhen *et al*., 2014).

7.4.5 Seasonal and spatial variation of fish prices

The price of filleted fish in the present study significantly varied both with time and site (Table 7.6). The highest fish price was recorded during the Ethiopian Orthodox Christians fasting season, and the price is highly reduced during the non-fasting periods. This gives priority to fishery corporation enterprises in determining the producers' price at a very low level in non-fasting season, because the seasonal fluctuation of fish demand limits the number of local fish traders who monopolize the market (Asefa Mitike, 2014; Erkie Asmare *et al.,* 2016). Many similar studies have also indicated a clear seasonality of fish prices in Ethiopia (Abduraman Kelil, 2002; Erkie Asmare *et al.,* 2016; Lemma Abera, 2016; Megersa Endebu *et al*., 2016; Shewit Gebremedhin *et al*., 2013; Tsegay Teame *et al.,* 2016b).

In this study, the price of filleted fish was very low at landing sites as compared to the prices at hotels and wholesalers (Table 7.6). This fact causes low prices for fishermen by 50.7 % than wholesalers (retailer shops), and by 60.8% than the hotels. Gashaw Tesfaye and Wolff (2014) stated that lack of transportation, lack of postharvest safe transporting system and inadequate technological know-how on fish processing are the major problems enforcing the fishermen to sell their catches with a very low prices at the landing sites. Assefa Mitike (2016) also indicated low prices of fish at landing site (0.17 USD (4.62 ETB) kg^{-1}) and higher prices at wholesalers level (1.72 USD (46.75 ETB) kg^{-1}) from Lake Zeway.

7.4.6 Annual production, socio-economic contribution and fish consumption

The mean annual production obtained in this study was estimated to be about 1137.7 tonnes year^{-1} (Table 7.7), which is very close to the maximum production potential of the lake (1300 tonnes yr^{-1}) (FAO, 1995). The present mean annual production is 3.6 times greater than the report of FAO (1995) (320 tonnes yr^{-1}). According to MoARD (2009), the amount of fish exploitation from Lake Langeno reached 63.0% of its potential. However, exploitation rate of the lake was found to be exceeding 87.5% in this study, which showed the highly increasing fishing efforts in the lake. The gross total annual income estimated from the lake's fishery was estimated to be 8,622,158 ETB (317224.37 USD). These values are low as compared to the report of Shewit Gebremedhin *et al.* (2013) from Lake Tana (65 million ETB year^{-1}). This might have attributed to the less number of people participating in fishing and less surface area of the lake as compared to Lake Tana.

The result of this study showed that the highest mean annual catch and mean annual income belongs to the owners of the fishing facilities (Table 7.8). Majority of the fishermen respondents (74.4%) were working as daily labourers due to lack of ownership of fishing facilities. Accordingly, half of the catch is given to the fishing facilities owners (boat and beach seine), and the remaining half is shared equally among all fishermen including the owners of the fishing gears and vessels. Since majority of the catches belong to the fishing facilities owners, those who have no fishing facilities are getting only 2.7% of the annual income as compared to the facilities owners. Shewit Gebremedhin *et al*. (2013) also reported that the number of fishing equipment's that fishermen own determine the level of their income from Lake Tana.

Even though fishing is serving as the major means of livelihood for both full time and part time fishermen, the highest annual production and gross income was attributed to the fulltime fishermen (3,088.8 kg year^{-1} and 22,393.8 ETB (823.91 USD) than part time fishermen (790.4 kg year^{-1} and 5,730.4 ETB (210.83 USD) (Table 6.9). This is because the fulltime fishermen are investing most of their time in fishing as an important means of their livelihood. Similarly, fishermen performing daily fishing activities are earning almost twice as much income as occasional fishers from Lake Tana (Shewit Gebremedhin *et al*., 2013).

The estimated mean gross annual income by all fishermen was about 6820.00 ETB year^{-1} (250.92 USD), which is greater than the report of Dawit Garoma *et al*. (2014) (5,500.10 ETB year^{-1} (202.36 USD)) from the same lake and Mberengwa and Zelalem Bacha (2011) (5,940.80 ETB year^{-1} (218.57 USD)) from Lake Zeway. According to Shewit Gebremedhin *et al*. (2013), the income from fishery is determined by various factors, such as fishing equipment's, fishing methods, fishing frequency and distance from the market.

Additionally, fish is playing a significant role in the food security of the people living around Lake Langeno (Table 7.10). The mean frequency of fish consumption per family was 1.04 times day^{-1}. The frequency of daily fish consumption per family varied greatly, but it was generally observed that majority of the fishermen consume a lower proportion and sell most of the catches to purchase other staple food items, and pay for other expenses for their families. However, the mean annual per capita consumption of fish obtained in this study (23.7 kg person^{-1} year^{-1}) was much higher as compared to the national fish consumption figure (FAO, 2012) (240 g person^{-1} year^{-1}). It was also greater than the reports of Dawit Garoma *et al*. (2014) (17 kgperson^{-1} year^{-1}) from the same lake and Samson Debebe (2015) (2.7 kgperson^{-1} year^{-1}) from Lake Abaya. The shortage of agricultural products due to El-Niño during this study time may have aggravated the situation. The study conducted on fish consumption pattern in Asella town indicated that majority the people (60%) do not eat fish at all (Sintayehu Bedada and Seblewengel Lemma, 2017). Similarly, many studies confirmed that fish has not been integrated into the diet of many people in most parts of the country (Abduraman Kelil, 2002; Asefa Mitike, 2014; Gashaw Tesfaye and Wolff, 2014). Therefore, the current study indicated that fish is highly contributing to food security of the people engaging in Lake Langeno's fisheries. Though Mulugeta Wakjira (2016) reported higher annual per capita fish consumption (63 kg $person^{-1}$ $years^{-1}$) in lower Omo basin; they are mainly relaying on Nile perch. In general, the fish consumption pattern at the household level depends on the access, location, personal preferences of families and income of the fishermen, which is determined by location, season and price of fish (Beveridge *et al*., 2013).

7.4.7 Management, follow-up and perception of respondents towards fishery management

Majority of the fishermen respondents (75%), focus group discussants (96%) and key informants (100%) agreed that fish stock in the lake is decreasing both in production and size (Fig. 7.6), which is strongly associated with our results in Chapter three, section 3.4.1**.** According to the respondents, increase in number is the main factor for reduction in size and number of fishes. The increasing number of fishermen often shows to the increasing of fishing pressure on the resources (Abduraman Kelil, 2002; Alebachew Tilahun *et al.,* 2016; Erkie Asmare *et al.,* 2016).

Absence of resources monitoring is the other major problem mentioned by most of the respondents (Fig. 7.6). Regulations, such as licensing, closed areas/ seasons and ban on the use of destructive gears are there, but access the lake's fisheries is open to anybody with enough capital and necessary skills. Especially, for those who have a legal license, there is no limitation on the quantity and size of the catch. According to Alebachew Tilahun *et al*. (2016), lack of follow-up causes the increasing of competition for the open access resources, which led to the reduction of fish communities in the water. Many similar studies confirmed the same problem in other lakes of Ethiopia (Abduraman Kelil, 2002; Dawit Garoma *et al*., 2014; Gashaw Tesfaye and Wolff, 2014) and in Lake Victoria (Eggert and Greaker, 2009).

Beach seine, long lines and gillnet are fishing gears used in the lake. Beach seine make up a significant contribution to the total landings, which agrees with the report of LFDP (1997), and majority of the respondents confirmed the decreasing of beach seines mesh sizes. The recommended size for beach seine to operate in the lake is 100-200 m in length, ≤430 m draglines and 80 mm stretched mesh size (Office of livestock and fishery of Arsi Negelle District, 2016). However, the discussion made with the key informants revealed that majority of the beach seine operating in the lake have 500-1000 m length, 500-800 m draglines and ≤60mm mesh size. Personal information also confirmed the same result. Generally, involvement of the central and regional government in fisheries management is very low and provision of technical and professional support is very weak. Therefore, the lake is an open access resources for anybody who want to involve in fishing. Similarly, many researchers confirmed the reduction of gear size in different parts of Ethiopia with the negative implication on capture fisheries (Erkie Asmare *et al*., 2016; Lemma Abera, 2016, Samson Debebe, 2015; Shewit Gebremedhin *et al.,* 2013).

Most of the interviewed fishermen had positive attitude towards the management of fish resources in the lake (Table 7.11). Majority of them perceived that local community, fishery cooperatives and government have responsibility in the management of the lake's fishery. This indicates the readiness of the resource users to support management measures, but lack incentive for compliance due to the absence of follow up (Abduraman Kelil, 2002).

In general, the management options, such as restriction of mesh size, limiting the number of fishermen and prohibition of other gears other than beach seine get a solid support from respondents. However, they disagreed on the management ideas, such as using of closed seasons, permanently closing of some reproductive places, allowing beach seines to operate only in some specific places and completely avoid the use of beach seines in the lake (Table 7.11). The disagreement could be due to lack of other jobs by most of fishers (Abduraman Kelil, 2002). According to Spliethoff *et al.* (2009), fisheries management measures such as closed seasons, closed fishing areas, mesh size restriction, restriction of beach seines and banning beach seines may all be acceptable options, but the control should be effective if preferably based on the cooperation by the fishermen themselves. Therefore, management principles should have to include their responses and motivation as part of the system to be studied and managed (Gashaw Tesfaye and Wolff, 2014).

CHAPTER EIGHT

8. GENERAL CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Lake Langeno showed some considerable changes both in its physico-chemical and ichthyofauna diversity. Family Cyprinidae dominates the fish fauna of the lake. *Oreochromis niloticus* and *E. paludinosus* were the most abundant species, whereas *C. carassius* and *G. dembecha* were the least abundant fish species. High number of catch was collected from the northern part (Site Tufa) and southern part (Site Dole) of the lake, whereas very small number was collected from the Site Middle. *Oreochromis niloticus* was the most important fish species at all landing sites, whereas *C. gariepinus* was the most dominant fish species at Site Tufa, Wabishebele and Dole, and *C. carpio* was the most dominant fish species at Sites Hora-Kelo and Hoitu. The distribution of fish species in the lake was mainly influenced by the morphology of Lake Basin, depth variation over the seasons and temperature of the water. The abundance of *O. niloticus* decreased and others except *C. carassius* and *G. dembecha* slightly increased during the data collection, which showed a considerable change over time.

The maximum length and weight recorded for *O. niloticus* and *C. gariepinus* observed in this study showed a slight decrease as compared to the previous reports. Majority of the catches (mainly *O. niloticus* and *L. intermedius*) was dominated by small sized fishes. This indicated that it is either overfished or changed via the changing of environment. The result obtained for their length-weight relationship showed that *O. niloticus*, *C. gariepinus* and *C. carpio* had isometric growth, which obeyed cubic cube law of Bagenal and Tesch (1978), whereas *E. paludinosus* and

L. intermedius had shown negative allometric growth. Most of the fish species had a poor body condition as compared to some previous reports from the same study area and from other similar lakes. *Oreochromis niloticus, C. gariepinus* and *L .intermedius* had a better body condition in dry season (October to May, August to December and November to May, respectively), but *C. carpio* had a better body condition in wet season (June to December).

The overall sex ratio of all fish species were significantly different from 1:1, where females were dominant than males. All of the fish species breed throughout the year. However, each of them had their own peak breeding time. For instance, the peak breedint time of *O. niloticus, C. gariepinus, L. intermedius* and *C. carpio*was from April to June, June to July, June to August and March to May for, respectively. The peek breeding time of all fish species were strongly associated with rainfall, water temperature change and water level fluctuation. The lengths L_{50}% of some species was also very small as compared to the previous report of the same species in the same study area and in other lakes. The mean fecundity of most species was also very low as compared to the fecundity of the same fishes in other lakes. Fecundity of *O. niloticus* and *C. carpio* in this study were strongly associated with their weight and length. However, through the fecundity there have a relationship with their total length and total weight, fecundity of *L. intermedius* was strongly depeent on its weight than its length and that of *C. gariepinus* was associated with its length than its weight.

The study of feeding biology of *O. niloticus* showed that food items of plant origin were the most important food items. Phytoplankton and detritus mainly contributed the highest volume of the stomach contents. Phytoplankton was the dominant food type in dry season, whereas zooplankton and detritus were mainly consumed in wet season. The occurrence of food items did not show seasonal variation, but the volume of consumed preys significantly varied. The types of food items also varied with the increasing of fish total length. Smaller fish mainly consumed phytoplankton and zooplankton, whereas larger fish mainly feed on detritus and macrophytes. This shows less competition among the different age and length groups for the same food item, and a possible ontogenic shift as the fish becomes larger.

Our result also indicated that fish is playing a crucial role in the life of people living along the shore of the lake via direct consumption, income generation and as an employment opportunity. The small-scale fishery based on beach seine and traditional wood boat is the type of fishing activity being carried out in Lake Langeno, which is integrated with other agricultural activities either as full time or part time activities. The fishery cooperatives are working on fishing from the lake aimed at exploiting, marketing and managing of the resource with weak performance. The trend of the fisheries in the lake shows that fish population in the lake is decreasing due to increasing number of fishermen, decreasing sizes and efficiency of fishing crafts, lack of knowledge, poverty and lack of appropriate follow up by concerned bodies.

8.2 Recommendations

Based on the above findings, the following recommendations were made:

- Since the abundance of *E. paludinosus* is appreciably increasing in the lake, further study is required on their potential for food production, their ecological and behavioral change and their role in ecosystem of the lake.
- Further follow up and monitoring of some anthropogenic activities are required to protect the lake from pollution, this is due to the apparent change recorded in this water quality of the lake.
- With the increasing of fishing efforts in the lake, economically important fish species in the lake are decreasing in size and number. For instance, the catches are dominated by small

sized groups with the small length at $L_{50}\%$ and comparatively they have a poor body condition. Therefore, monitoring, further follow up and effective management, which focus on the legality of fishermen and conservation the resources are highly recommended

- High dependence on fishery activities has also posed a serious threat to the fish resource. Therefore, diversification and strengthening of the other livelihood sources can be a good alternative for better income generation.
- The development of aquaculture and other related alternative fisheries (Integrated-fish horticulture-poultry farming and Aquaponics technology) to reduce the pressure on the natural system should be encouraged.
- The management tools, such as closed seasons, catch quota restriction, regulation of mesh sizes, gear restriction and limit the number of fishers can be good methods for sustainable exploitation of the stocks.
- Promotion of credit arrangements should be given due attention to encourage fishermen to access modern fishing equipment and maintain their fishing gears.
- Implementation of the existing regional, and national fishery rule and regulation is also very essential for sustainable utilization of Lake Langeno fishery resources
- Encouraging community participation in the fishery management and including their positive attitudes in the management system is considered to be very important.

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ANNEXES

ANNEX 1: The water bodies, fish distribution and fish production in Ethiopia

Table 1: Fish diversities in six major drainage basins of Ethiopia (Golubtsov and Darkov, 2008)

No.	Drainage system	Number			
		Family	**Genera**	**Species**	**Indemic spp.**
1	Baro-Akobo (White Nile)	26	60	113	1
2	Omo-Turkana	20	42	76-79	2
3	Abay (Blue Nile)	16	37	77	23
4	Tekeze-Atbara	10	22	34	-
5	Rift Valley	11	18	28-31	7
6	Wabishebele and Ghenale (Juba)	12	21	33	4

Table 2: Summary of Ethiopian water bodies and their fish production potential (Gashaw Tesfaye and Wolff, 2014).

Water body type	Area (km^2)	Length (km)	Fishery potential (Tonne/ year)
Major lakes	7,740		39,262

Major reservoirs	1,447		7,879
Small water bodies	4,450		25,996
Rivers		8,065	21,405
Total	**13,637**	**8,065**	**94,541**

Table 3: Percentage contribution of Ethiopian major lakes to capture fishery (Gashaw Tesfaye and Wolff, 2014).

No	Lake	Percentage contribution (%)
1	Chamo	29
2	Zeway	19
3	Tana	17
4	Abaya	8
5	Langeno	7
6	Hawassa	7
7	Koka	7
8	Turkana	4
9	South Wollo lakes	2

ANNEX 2: Summary of the statistical analysis of spatial and seasonal variation of environmental variables in Lake Langeno, Ethiopia

Table 1: Summary of the statistical analysis of theenvironmental parameters variation among the sites of Lake Langeno, Ethiopia.

Parameter	Wilk's Λ	F(1, 4)-ratio	r- value	p-value
Secchi depth	0.91	0.39	0.29	0.56
DO	0.98	0.07	0.13	0.80
Temperature	0.81	0.91	-0.43	0.39
pH	1.00	0.01	-0.01	0.99
TDS	0.99	0.03	0.03	0.95
Conductivity	0.98	0.04	0.11	0.84
Chloropyhll-*a*	0.98	0.06	0.12	0.81

Table 2: Summary of the statistical analysis of the environmental parameters variation among the months of Lake Langeno, Ethiopia.

Parameter	Wilk's Λ	F(1, 10)-ratio	r value	p value
Secchi	0.41	13.94	0.76	0.004
DO	0.63	5.23	0.62	0.046
Temp	0.39	15.62	0.78	0.003
pH	0.61	5.02	0.53	0.049
TDS	0.51	6.32	0.69	0.004
Conductivity	0.67	10.71	0.57	0.003
Chlorophyll-*a*	0.59	5.43	0.59	0.049

ANNEX 3: Description of the collected fish species from Lake Langeno, Ethiopia

A. *Oreochromis niloticus* (Linnaeus, 1757)(Fig. a)

Local name: Qoroso (ቆሮሶ)

Common name: Nile tilapia

Distribution: The species was widely distributed in all sampling sites

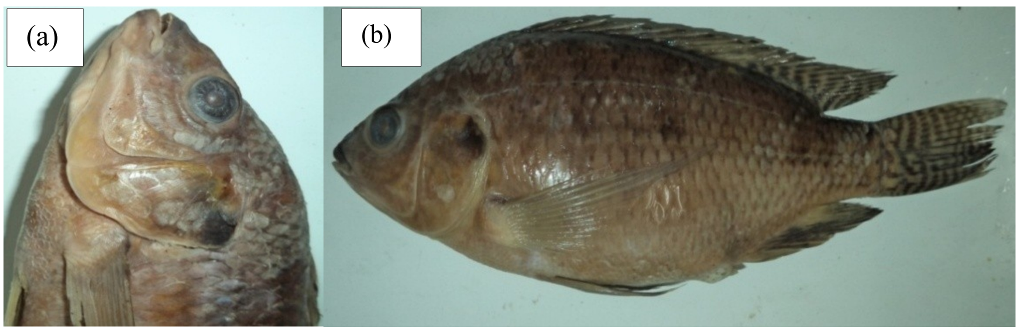

Figure a: Lateral view of *Oreochromis niloticus*(Golubtsov *et al*., 1995; Okaronon *et al.,* 1998; Redeate Habtasillasie, 2012).

B. *Enteromius paludinosus* (Peters, 1864) (Fig. b).

Distribution: The species was found widely distributed at all of the study sites

Figure b: Lateral view (a) and Ventro lateral view of the mouth (b) of *E. paludinosus*(Golubtsov *et al*., 1995; Okaronon *et al.,* 1998; Redeate Habtasillasie, 2012).

Clarias gariepinus (Burchell, 1822) **(Fig. c)**

Local name: Ambazza (አምባዛ)

Distribution: The species is distributed in all of study sites, but rare at the middle site.

Figure c. Dorsal view of head (a) and Lateral view (b) of *C. gariepinus*

C. ***Labeobarbus intermedius*** **(Ruppell 1836)** (**Fig. d**)(Golubtsov *et al*., 1995; Okaronon *et al.,* 1998; Redeate Habtasillasie, 2012).

Local name: Bilcha (ብልጫ)

Distribution: The species was widely distributed in all sampling sites, but rare at middle site.

Figure d: (a) Side view of the mouth and (b) Lateral view of *L. intermedius*(Golubtsov *et al*., 1995; Okaronon *et al.,* 1998; Redeate Habtasillasie, 2012).

D. ***Cyprinus carpio*** (Linnaeus, 1758) (**Fig. e**):

Local name: Abba Samuel (አባሳሙኤል)

Distribution: The fish was distributed in all the sampling sites, but rare at the middle site

Figure e: Ventral position of the mouth and (d) Lateral view of *C. carpio*

E. ***Carassius carassius*** (Linnaeus, 1758) (**Fig. f**)

Local name: Jape (ጃፔ)

Distribution: The fish was found in all the sampling sites except at the middle site.

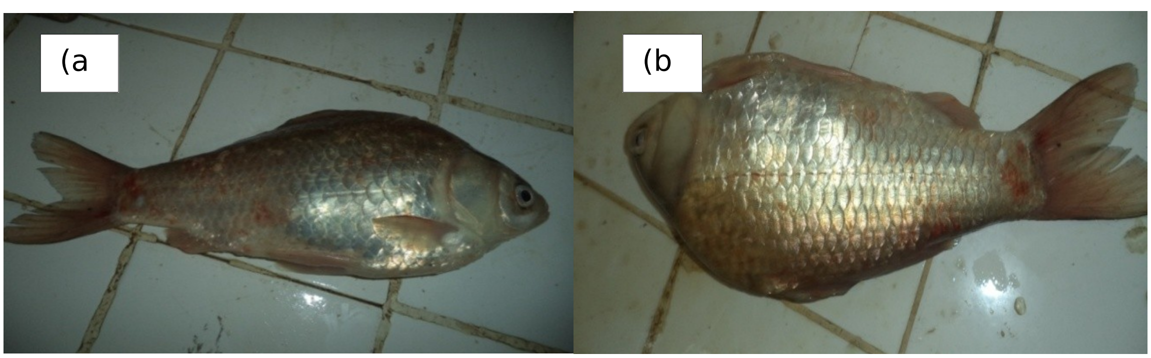

Figure f: Lateral view of *Carassius carassius*(Golubtsov *et al*., 1995; Okaronon *et al.,* 1998; Redeate Habtasillasie, 2012).

Garra dembecha (Abebe Getahun &Stiassny , 2007) (**Fig. g**):

Local name: ….

Distribution: Distributed in part of the lake except the middle site.

Figure g: (a) Lateral view and (b) Ventral view of the mouth of *Garra dembecha***(**Golubtsov *et al*., 1995; Okaronon *et al.,* 1998; Redeate Habtasillasie, 2012).

ANNEX 4: Gonad maturity stages and descriptions of fish families collected from Lake Langeno, Ethiopia.

Table 1: Gonad maturity stages and descriptions for cyprinidae (Armstrong *et al.,* 2004; Demeke Admassu, 1996).

Gonad stage	Male	Female
I	Immature, impossible to distinguish females from males, gonads are a pair of transparent strings running along the body cavity	Immature, impossible to distinguish females from males, gonads are a pair of transparent strings running along the body cavity
II	Unambiguously male, very small testes, white reddish, not lobed, tube shaped strings	Unambiguously female, very small ovaries, tube shaped and reddish, eggs not visible
III	Larger testes, white reddish, somewhat lobed starting to flatten sideways	Ovaries somewhat larger and starting to flatten sideways, eggs visible, but not visible
IV	larger testes, white reddish, lobed, flattened sideway	Larger Ovary, flattened sideways, almost covering body cavity wall, eggs yellowish
V	Large, white testes, some sperms runs out when test is cut	Larger and full ovary, completely covering body cavity, yellowish eggs run out when ovary is cut
VI	Large white testes, running, large amount of sperm runs out when test is cut	Running, yellow eggs can be extruded by putting pressure on the abdomen
VII	Spent, empty testes, reddish and wrinkled	Spent, wrinkled ovary, reddish, containing a few yellow eggs

Table 2: Criteria used in determining the sexual maturity stages of Cichlidae and Clariidae (Hörstgen-Schwark and Langhölz, 1998).

Female Maturity Stage	**Appearance of ovaries**
Immature/inactive	No egg visible
Inactive-active	< 20 eggs visible, size < 0.2 mm
Active	> 20 eggs visible, size < 0.2 mm
Active - ripe	Eggs yellow, size 0.2 – 1.1 mm
Ripe-ripe running	Eggs yellow, size > 1.1 mm
Spent	Absorption of yolk material, egg white
Male Maturity Stage	**Appearance of testis**
Immature	Thread-like, colorless
Inactive	Translucent, wider than above
Inactive	Flesh color, still thin
Inactive - active	White/yellowish, thickened, no milt apparent when cut
Active - ripe	Cream colored, thick and enlarged
Ripe	Distended fully over visceral cavity, milt evident if testis cut
Ripe - running	White/silvery, milt runs freely under pressure

ANNEX 5: **Prey items identified in the gut of *O. niloticus* in Lake Langeno**(Baker and Fabbro, 2002; Botes, 2003; Carling *et al.,* 2004; Shiel, 1995; Vuuren *et al*., 2006; Witty, 2004).

Table1: Phytoplankton prey items identified in the diet of *O. niloticus* in Lake Langeno

Food item		**%FO**	**OV**	**IR**	**%IR**
Cyanophyta (Blue Green algae)	*Mycrosisti spp.*	100	1.1	1810	24.89
	Anabaena	8.7	1.1	9.57	0.13
	Chroococcus spp.	92	7.2	662.4	9.11
	Arthrospira spp.	13.2	0.9	11.88	0.16
	Aphanothece	6.7	0.7	4.69	0.06
	Oscillatoria spp.	12.9	0.8	10.32	0.14
	Gloeotrichia	4.8	0.4	1.92	0.03
	Trichodesmium iwanoffianum Nygaard	3.7	0.5	1.85	0.03
Bacillariophyta (Diatom)	*Cyclotella ocellata Pantocsek*	99.5	2.6	258.7	3.56
	Surirella spp.	98	1.3	127.4	1.75
	Navicula spp.	90	1.2	108	1.49
	Cymbella spp.	92	2.1	193.2	2.66
	Fragilaria ulna (Nitzschia)	64	0.9	57.6	0.79
	Diatoma vulgaris Bory	24	0.9	21.6	0.30
	Gomphonema spp.	32	0.7	22.4	0.31
	Nitzschia spp.	38	0.9	34.2	0.47
	Pinnularia Ehrenberg	76	0.7	53.2	0.73
	Amphora spp.	14	0.4	5.6	0.08
	Cocconeis Ehrenberg	26	0.3	7.8	0.11
	Synedra Ehrenberg	12.3	0.6	7.38	0.10
	Tabellaria Ehrenberg	31	1.12	34.72	0.48
	Thalassionema	**8**	0.4	3.2	0.04
Chlorophyta (Green algae)	*Chlamydomonas Ehrenberg*	56	1.2	67.2	0.92
	Oocystis pusilla Hansgirg	78	2.3	179.4	2.47
	Botryococcus braunii Kützing	52	1.8	93.6	1.29
	Chlorella Beijerinck	76	1.01	76.76	1.06
	Spirogyra Link	7.6	0.7	5.32	0.07
	Microspora	13.2	0.6	7.92	0.11
	Volvox Linnaeus	15.3	0.3	4.59	0.06
	Crucigenia	8.2	0.2	1.64	0.02
	Ankistrodesmus	4.5	0.3	1.35	0.02
	Pleurococcus	3.2	0.2	0.64	0.01
	Stigeoclonium	5.3	0.2	1.06	0.01
	Closterium spp.	13.2	0.5	6.6	0.09
Chrysophyta	*Dinobyron sertularia Ehrenberg*	**32.4**	0.6	3.63	0.05
	Uroglena Ehrenberg	12.1	0.3	76.176	1.05
Cryptophyta	*Cryptomonas ovata Ehrenberg*	**47.6**	1.6	0	0.00
Dinophyta	*Peridinium spp.*	72.6	1.4	101.64	1.40

	Ceratium Schrank	61.2	0.9	55.08	0.76
Rhodophyta	*Lemanea*	**16.8**	0.7	11.788	0.16
Euglenophyta	*Trachelomonas spp.*	74.8	3.9	291.72	4.01
	Euglena spp. (Euglena Ehrenberg)	34.6	2.4	83.04	1.14
Heterokontophyta	*Mallomonas*	**14.4**	0.6	8.64	0.12

Table2: Zooplankton prey items identified in the diet of *O. niloticus* in Lake Langeno (Baker and Fabbro, 2002; Botes, 2003; Carling *et al.,* 2004; Shiel, 1995; Vuuren *et al*., 2006; Witty, 2004).

Order	**Species**
Anomopoda	*Bosmina*
Cladoceran	*Daphnia spp.*
Ctenopoda	*Sididae spp.*
Copepod	*Calanoid*
	Cyclopid spp.
Rotifera	*Rotifer spp.*
Ostracoids	Ostracoids

Table 3: Insect prey items identified in the diet of *O. niloticus* in Lake Langeno (Baker and Fabbro, 2002; Botes, 2003; Carling *et al.,* 2004; Shiel, 1995; Vuuren *et al*., 2006; Witty, 2004).

Insects	**Common name**	**Scientific name**
Dipteran	Mosquito	
	Biting midge	
Plecoptera	Stone flies	
Trichoptera	Caddis flies	
Chilopoda	Centipedes	
Coleoptera	Water beetle	
	Beetle larvae	
Odonata	Dragonfly	
	Damselfly	
Hemiptera	Creeping water bug	
	Water strider	
Ephemeroptera	Mayfly	
Hymenoptera	Aunts	

ANNEX 6: Questionnaire to be filled by fishermen

Dear respondents

I am a PhD student at Addis Ababa University in the field of Fisheries and Aquatic Sciences. Fish are one of the aquatic vertebrate animals serving as a livelihood for a good number of people around the world. The purpose of this study is to collect some basic information on status and trends in fish and fisheries in Lake Langeno, Ethiopiafor the management and sustainability of the resources in the future. Therefore, the accomplishment of this work is impossible without your keen cooperation. Provide your opinions freely on the space provided. Thank you in advance for your cooperation.

PART I: Personal information

Instruction: Mark 'X' sign in the given box or encircle your idea from the provided alternatives and write your opinion on the space provided.

1. Name of respondent/Cooperative ____
2. Address of respondent/Cooperative ____
3. Site ____
4. Date ____
5. Sex Male ☐ Female ☐
6. Age <10 ☐ 10-20 ☐ 20-40 ☐ 40-50 ☐ 50-60 ☐ 60 ☐
7. Marital status Married ☐ Single ☐
8. Educational back ground illiterate ☐ Elementary ☐ secondary ☐ High school ☐ College ☐ University ☐ if other specify ____________________

9. Religion: Christian Orthodox ☐ Christian Protestant ☐ Christian Catholic ☐ Muslim ☐ if other specify it ______________________________

10. Occupation: Fisherman ☐ farmer ☐ Government employer ☐ Merchant ☐ if other specify ______________________________

11. Total number of children ______________________________

12. Children less than 18years Males _______ Females _______

13. No of other dependants Males _______ Females _______

14. Your current position in your cooperation/group ______________________________

PART II: LAKE LANGENO FISHING INFORMATION

1. Are you involving in full-time fishing? Yes ☐ No ☐
2. How long have you been involved in fishing? (Specify) ______Years.
3. For what purpose do you fish? Food ☐ market ☐ both food ☐ and market recreation ☐ if other specify ______________________________
4. Why did you start fishing? (Specify reason) ______________________________
5. What types of gears being used for fishing from the Lake? Rank them!
   a) Hand line ______________
   b) Long line ______________
   c) Gillnet ______________
   d) Cast net ______________
   e) Beach seines ______________
   f) Others (specify) ___________
6. What is the size of its mesh?
   a) Hand line ______________
   b) Long line ______________
   c) Gillnet ______________
   d) Cast net ______________
   e) Beach seines ______________
   f) For others ______________

7. Is the size and type of your gears limited by the government? Yes ☐ No ☐

8. If your answer is 'yes' which gears of the following are recommended and what is their legally recommended sizes to your Lake?

   a) Hand line ____________ d) Cast net ______________

   b) Long line _____________ e) Beach seines __________

   c) Gillnet ______________ f) Others ___________

9. If your answer for Qn No '7' is 'yes', are you following the recommended size?

10. ☐es ☐o I do not ☐w

11. If your answer is ''no'' what hindered you to do so?

   a) Absence of follow up

   b) Decreasing of the fish through time

   c) Availability of the gears at local market

   d) Diversity of fish in the Lake by size and species

   e) Absence of knowledge on the effect of fishing gears on the fish diversity

   f) If other specify it ____

12. How many fish species do you know before and after 10 years in this lake? List them

13. Before 10 years **After 10 years**

a) ___________________________________ a ___________________________________

b) ___________________________________ b. ___________________________________

c) ___________________________________ c. ___________________________________

d) ___________________________________ d. ___________________________________

e) ___________________________________ e. ___________________________________

14. What is your target species? ____

15. Why?

____

16. Is your landing site a newly emerged site? Yes ☐ No ☐ I don't know ☐

17. How many years it dated?

____

18. How long have you been involved in fishing at this landing site? _________________

19. Why you preferred this landing site? _______________________________________

20. Which fish species is more preferred in the market. Rank them!

a. *Oreochromis niloticus* (Qorosso)
b. *Carassius carassius*
c. *Carassius auratus*
d. *Cyprinus carpio* (Dubba)
e. *Clarius gariepinus* (Ambazza)
f. Others: Specify and rank them together with the above _______________________

21. How many times do you throw your gears to the lake per day? ____________________

22. How many fishes do you collect per one catch in average?

a. By hand line ___________
b. By long line ____________
c. By gillnet ____________
d. By beach seines ________
e. By others _____________

23. Which season is the highest catching period? __________________________________

24. Is there any part of the lake shoreline not allowed for local Communities/Cooperatives to use as landing site for fishing?

25. Y☐ ☐o I do not k☐w

26. If your answer is 'yes', which parts of the lake are not allowed and why? ____________

27. How much of your catch do you use at home? ___________________________________

28. Which species of fish is most consumed at home? ________________________________

29. How often do you eat fish at home? ____

30. Is there sufficient market to sell your product? Yes ☐ No ☐ I don't know ☐

31. If your answer is 'yes', to whom and where do you sell your catch?

a) Fish processing Enterprise
b) Consumer direct
c) Local market
d) Not to be sold
e) If others specify _______________

32. What is the cost of each species per kilogram at the landing site?

a) *Oreochromis niloticus* (Qorosso) __
b) *Carassius carassius* _____________
c) *Carassius auratus* _______________
d) *Cyprinus carpio* (Dubba) _________
e) *Clarius gariepinus* (Ambazza) ____

33. What is the cost of each species per kilogram when sold to fish traders?

a. *Oreochromis niloticus* (Qorosso) __
b. *Carassius carassius* _____________
c. *Carassius auratus* _______________
d. *Cyprinus carpio* (Dubba) _________
e. *Clarius gariepinus* (Ambazza) _____

34. What is the reason for their difference in importance? ________________________________

35. How many Birr do you getting from fish selling?

a) Per day ________________
b) Per week _______________
c) Per month _____________
d) Per year? ______________

36. Ever since you started fishing, what do you think about the fish in lake Langeno?

a) Increasing
b) Decreasing
c) Stay the same
d) No opinion

37. Do you think that the catches over the next 5-years will:

a. Increase
b. Decrease
c. Stay the same
d. No opinion
e. Why? ____

38. How far do you travel to get the most preferred fishes? ____________________

39. Do you have a sufficient landing facility? Yes ☐ No ☐ I don't know ☐

40. If your answer is 'yes' list the landing facilities you are using! ____________________

41. Do you use wooden hand operated boats? Yes ☐ No ☐

a) If 'yes' how many people work on this boat? ____________________
b) How long does it take to get to the fishing ground and back? ____________________
c) How much did it cost to buy your boat? ____________________
d) How many such boats do you have? ____________________
e) How many supportive workers do you have? ____________________
f) How much do you pay for each? ____________________

42. Do you use outboard engine? Yes ☐ No ☐

a) If 'yes' how many such boats and engines do you have? ____________________
b) How long does it take to get to the fishing ground and back? ____________________
c) How much did it cost to buy your boat? ____________________
d) How many supportive workers do you have? ____________________
e) How much do you pay for each? ____________________
f) If your answer is 'No' why? ____________________

43. Do you process the fish? Yes ☐ No ☐

a. If yes, what type? Rank according to most priority____________________

b. If No, why? ____

44. How do you prepare and dry out your product for market?

a. On the ground
b. On e stones
c. On the table
d. By fire
e. Sold fresh without drying
f. If other specify it ___________

45. How do you transport your product to the market?

a. back or head carrying
b. By domestic animals
c. By car
d. Sell your product at landing sites
e. If other specify _______________

46. What are the preservation facilities you are using?

a) Icebox
b) Refrigerator
c) Plastic bags
d) Transport without any preservation
e) If other specify it ____________

47. If you have no any preservation facilities, why?

a) Lack of finance to buy it
b) Lack of knowledge to operate it
c) Unavailability of the facilities in the local markets
d) Suitability of the environment to stay without deterioration
e) If other specify it ____

48. Do you think that everybody can catch as much as they like?

f) Yes ☐ No ☐ I don't know ☐

g) If your answer is 'no' why? ____

49. Do you have any idea about how fish breed and grow? ___________________________

50. Do you know how, when and where the following fish breed?

a. *Oreochromis niloticus* (Qorosso) ____

b. *Carassius carassius* ____

c. *Carassius auratus* ____

d. *Cyprinus carpio* (Dubba) ____

e. *Clarius gariepinus* (Ambazza) ____

f. Others: Specify and rank them together with the above ___________________________

h) PART III: OPENION ON FISHERY MANAGEMENT OF THE LAKE

1. In your opinion, what is wetland? ____
2. What are the main problems associated with wetland management practices around lake Langeno? ____
3. What is your opinion about the trend of wetland degradation over time around Lake Langeno? Would you rate this in different time scales as decreasing, increasing or no
4. Are you being involved in cooperation? Yes ☐ No ☐
5. If your answer is 'yes' why did you join the cooperative? ________________________
6. How many years have you worked in this cooperation?

i) Less than 5 years ☐ from 5 to 10 years ☐

j) From 10 to 15 years ☐ more than15 years ☐

7. Do you get what you expected from the cooperative? Yes ☐ No ☐

k) If 'yes' what do you get?

____

8. If your answer for Qn 4 is ‘No’ why? ______________________________

9. Do you help out your cooperative? Yes ☐ No ☐

10. What help do you give to the cooperative? ______________________________

11. In your opinion, are your cooperative members committed to protect and manage Lake Langeno? Yes ☐ No ☐ If no why? ______________________

12. What are the uses of the lake for local society? ______________________________

13. Have you ever received encouragement from government or other institutions to conduct fishing efficiently? Yes ☐ No ☐

14. If your answer is ‘yes’, what types of encouragement you get?

a) Gears and landing facility assistance

b) Training and technical assistance

c) Financial assistance

d) Transportation assistance

e) Market facility

f) If others write it ______________________________

15. If your answer is ‘gears and landing facility assistance’, from where did you get it?

a) From the government institution

b) From NGOs

c) From local market

d) To be made at household

e) If other specify it ______________________________

16. If your answer for is ‘’from government institution or NGOs’’ list the gears and facilities you get from them ______________________________

17. Is there any training you get on fishery and fishing? Yes ☐ No ☐

18. If your answer is ‘yes’ what types of training did you get?

a. On fishing technique

b. On fishing gears

c. On fishing time and area

d. On fishery management

e. On production fish in controlled environment

f. On post harvesting management

g. If other specify ____

19. Who gave the training? ____

20. If your answer for Qn No 18 is 'No', what is the reason behind?

a) Lack of interest

b) No training given

c) Time constraints

d) If other specify it ______________

h. Is there any follow up by government institution, NGO or research organizations on the fishery management of the lake? ________________________________

21. In your opinion, do you think that the government is now successful in protecting Lake Langeno fishery? Yes ☐ No ☐ I do not know ☐

i. So how do you rate the efforts made by the government in managing and protecting Lake Langeno fishery and its catchment areas?

a) Excellent

b) Very Good

c) Good

d) I don't know

22. Who do you think as the leading institution to work on conservation of lakes' fishery?

a. Local communities

b. Government

c. Private sectors

d. Fishery Cooperative e. Others (specify) _______________

23. Do you think people in the wide watershed of Langeno are responsible for Lake Langeno conservation? Yes ☐ No ☐

j. If your answer is 'yes' how? ______________________________

24. Do you think people misuse the fishes of Lake Langeno? Yes ☐o ☐

25. State and rank the misuses of fishes? ______________________________

26. From your lake area,

a. Which parts of fishes are eaten? ______________________________

b. Which parts are discarded? ______________________________

c. Are eggs of fishes edible? Yes ☐ No ☐

d. Are heads of fishes edible? Yes ☐ No ☐

e. Are juvenile fishes edible? Yes ☐ No ☐

27. Do you think fishermen of the area are too many? ______________________________

28. Should the number of fishermen decreasing or increasing? ______________________________

29. Is the number of fishermen or the type of fishing gears they use is the major problem?

____

k. PART IV: LAWS AND POLICY ISSUES

1. If there is an interference of the government in the future on the management of the lake's fishery, are you voluntarily? Yes ☐ No ☐
2. If 'yes', why? ______________________________
3. What are the most priority issues in Lake Langeno fishes that need intervention?

l. Write the most important and rank them ______________________________

4. Do you think that work in cooperation can conserve the fish resources of the lake?

   m. ☐s ☐o I don't know☐

   n. If 'yes', how?

   ____

5. From the following provided ideas, which one do you think is more essential to manage lake's fishery in the future properly?

   a. Closed seasons/times e.g. certain months to allow fish to breed/grow

      o. Agre☐ Disagree☐ No opinion ☐

   b. Permanent closed areas/places where fishing is never allowed

      p. Agre☐ Disagree ☐ No opinion ☐

   c. If you agree to the idea on 'b' can you suggest any specific areas? (Response)____

   d. Limitation on the number of people who are allowed to fish

      q. Agre☐ Disagre☐ No opinio☐

   e. Restriction on mesh sizes Agree ☐ Disagree ☐ No opinion ☐

   f. If you agree to idea in 'e', particularly for which gear?

      i. For gillnets

      ii. For beach seines

      iii. Long lines, hook number

      iv. For others specify________

   g. Restriction of beach seines to operate only in some places/times

      r. Agree ☐ Disagree☐ No opinion ☐

h. Prohibition of beach seines

s. Agree ☐ Disagree ☐ No opinion ☐

i. Prohibition of other gears

t. Agree ☐ Disagree ☐ No opinion ☐

j. If you have other opinion specify it ____

6. Finally, if you have any additional suggestions for the protection and proper use of Lake Langeno fishery? ____

u. Thank you in advance for your cooperation!

v.

w.

x.

y.

z.

aa.

ab.