FISH DIVERSITY AND PRODUCTION IN TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA

PhD Dissertation

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FISH DIVERSITY AND PRODUCTION IN TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA

A Dissertation Submitted to the Department of Zoological Sciences

In Partial Fulfillment of the Requirement for the Degree of Doctor of Philosophy in Zoological Sciences (Fisheries and Aquatic Sciences)

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GRADUATE PROGRAMS

This is to certify that the dissertation prepared by Shibabaw Gebru entitled, "Fish Diversity and production in Tekeze Reservoir, Tekeze Basin, Ethiopia". Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Zoological Sciences (Fisheries and Aquatic Sciences) complies with the regulations of the university and meets the accepted standards concerning originality and quality.

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ABSTRACT

Fish Diversity and Production in Tekeze Reservoir, Tekeze Basin, Ethiopia

Shibabaw Gebru

Addis Ababa University, 2020

Ethiopia has several freshwater systems from where plenty of aquatic foods could be produced. However, due to poor management practices, the contribution of the fishery to the country's economy is by far little. Tekeze Reservoir has potential in fish production, but little or no detailed and documented scientific information is available about the fish biology and fishing activities. Consequently, the fishery of the reservoir is poorly understood and its sustainability is unpredictable. Therefore, this study aimed to contribute to the management of the reservoir fishery by providing scientific information for sustainable utilization of the aquatic resources. Data was collected using various methods over a period of two years and analyzed using various statistical tools and methods. Fifteen fish species were identified in the present study. The index of relative importance (%IRI) of the key species in the reservoir includes Oreochromis niloticus, (35.5%), Bagrus docmak (22.6%), Labeobarbus intermedius (20.5%), Labeo niloticus (10.6%) and Labeo forskalii (10.2%). However, Clarias gariepinus, Labeobarbus nedgia, Raiamas senegalensis, Labeobarbus crassibarbis, Hetrobranchus longifilis, Garra dembeensis, Bagrus bajad, Labeobarbus bynni, Labeo cylindricus and Labeobarbus beso constitute below 1% of the total catch. The river mouth habitats contributed the most catch composition, while the pelagic habitats contributed the least. Length-weight relationship of O. niloticus, L. intermedius and B. docmak were best expressed by the equations $TW = 0.014TL^{3.054}$ *(*$r^2 = 0.9743$, $P = 0.0001$*),* $TW = 0.0196SL^{2.9493}$ *(*$r^2 = 0.9609$, $P < 0.0001$*) and* $TW = 0.0098SL^{3.0819}$ *(*$r^2 = 0.9678$, $P < 0.0001$*), respectively. The overall mean condition factor was found to be 1.44±0.01 for O. niloticus, 1.88±0.02 for L. intermedius and 0.94±0.01 for B. docmak. The feeding habit of O. niloticus, L. intermedius and B. docmak indicated that both plant and animal origin food items were consumed by the species. However, phytoplankton for O. niloticus, detritus for L. intermedius, fish and fish remains for B. docmak were the most important food types. Although the proportion was different, the studied fish species consumed all food items in all seasons of the study period. In some size classes of O. niloticus and B. docmak, complete ontogenic shifts were observed, but all food items in different proportions were ingested by L. intermedius. The overall sex ratio (female: male) of O. niloticus and B. docmak was significantly deviated from the hypothetical distribution of 1:1(P*

< 0.001). However, the sex ratio of L. intermedius did not significantly deviated. Size (TL) at first maturity of O. niloticus was 24.2 cm for females and 24.87 cm for males. The size at maturity for L. intermedius and B. docmak (SL) were 20.84 and 27.42 cm for females and 22.05 and 26.79 cm for males, respectively. The mean absolute fecundity of the species was 1,513, 4,788 and 92,321 eggs for O. niloticus, L. intermedius and B. docmak, respectively. The studied species had extended spawning period, from July to October with peak spawning in August for O. niloticus and B. docmak and in September for L. intermedius. Labeobarbus intermedius preferred riverine habitats while O. niloticus and B. docmak prefer the littoral habitat for breeding. The catch per unit effort of the fishery ranged from 15.98 kg/boat/day to 3.26 kg/boat/day. The extent of immature fish harvesting by the commercial catch indicated that O. niloticus (33.32%), L. intermedius (37.72%) and B. docmak (42.17%) were caught before they attain their first sexual maturity. A total of 48 fishery associations with 3,174 members were distributed in the reservoir. The average age of the fishers was close to 30 and about 94% of them were males. The majority (67%) of the fishers were full-timers with the average fishing experience of 4 years and 64% of them had taken formal education. Gillnets and longlines were the commonly used fishing gears and operated for 24 hours in the reservoir. Addis Ababa and Mekelle were the major market destinations for filleted fish, but Shire and Humera towns were for the gutted and sun-dried fishes. The fishery contributed to the rural communities as source of nutrition and food security, employment opportunity and source of income. However, due to poor management practices, illegal fishing activities and overexploitation of the resources, the fish production and fishery business have declined. Therefore, to sustain the production and productivity as well as the socio-economic contribution of the reservoir fishery, the federal government and the two regional states such as Tigray and Amhara Regional States should take a responsibility to address the major problems that cause the depletion of the stock in the reservoir.

Keywords/phrases*: Abundance, Body condition, Catch per unit effort, Constraints, Diet composition, Diversity, Fishing gears, Immature fishing, Size at first maturity, socioeconomic, Spawning and Tekeze Reservoir.*

DEDICATION

I dedicate this dissertation to my father Gebru Beyene and my mother Tejey Mekete who are the main reasons for who I am today. I also dedicate it to my wife Selam Misganay for the full responsibility of taking care of our son; Mikias Shibabaw and our daughter; Makda Shibabaw during the study period.

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Shibabaw Gebru

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CHAPTER ONE

1. BACKGROUND

1.1. Surface water resources of Ethiopia

Ethiopia is an agrarian country where agriculture remains the dominant sector of the economy, contributing about 33% of the GDP, 73% of employment, 90% of total export earnings and provide 70% of the raw material for the industry sector (Demese Chanyalew *et al.*, 2010). It has a complex topography, diversified climate and immense water resources (Belete Berhanu *et al.*, 2014). Its elevation ranges from 126 meters below sea level (Afar Triangle) to the highest peak at Ras Dashen in the Semien Mountain Massifs (4, 517 meters). Climatic and environmental difference makes the country a habitat for diverse flora and fauna (Redeat Habteselassie, 2012). The country has several lakes including reservoirs and transboundary rivers.

Rivers are the most important sources of freshwater and play a significant role in economic development and maintaining life-supporting ecosystem services (Mohamed, 2013). Water resources management becomes increasingly critical as new local and national resources of water become scarce, limited, expensive and difficult to exploit (Delli, 1998). Many countries in the arid and semi-arid regions are facing water crises (Biswas, 1997; Elhance, 1999) and increasingly forced to consider the possibility of utilizing the water, which is available in international river basins (Dinar, 2006). Thus, the concerns relating to the use of international water are becoming increasingly more important and complex (Mohamed, 2013). Because most of the remaining major easily exploitable freshwater is now in river basins that are shared by two or more sovereign States (Biswas, 1997).

Ethiopia has twelve drainage basins with a mean annual runoff of 124.4 billion m^3 and a total length of all rivers estimated as 8, 065 km. Of the total basins, eight are river basins, one lake basin and the remaining three are dry basins with no or insignificant flow out of the drainage system (Belete Berhanu *et al.*, 2014). All the rivers are international, but no perennial river crosses into the Ethiopian river drainage system (Seleshi Bekele *et al.*, 2007). Abay (53%), Baro-Akobo (24%), Omo-Gibe (18%) and the remaining river basins (< 10%) contributed to the mean annual runoff.

The main drainages of the country are flowing away from the rift system either toward the Nile system in the west or to the Indian Ocean in the southeast. Almost all of the basins radiate from the central plateau of the country that is separated into two by the rift valley (Belete Berhanu *et al.*, 2014). The Nile Basin (Abay, Baro-Akobo, Tekeze-Atbara and Mereb) covers 33 percent of the country and drains westwards. The Shebelle-Juba Basin (Wabi-Shebelle and Genale-Dawa) also covers 33 percent of the country and drains the southeastern mountains towards Somalia and the Indian Ocean. Rivers draining in the Rift Valley (Awash, Denakil, Omo-Gibe and Central Lakes) cover 28 percent of the country and originate from the adjoining highlands and flow north and south of the uplift in the center of the Ethiopian Rift Valley (Table 1). The North-East Coast (Ogaden and Gulf of Aden basins) covers 6 percent of the country (Seleshi Bekele *et al.*, 2007; Belete Berhanu *et al.*, 2014). The main Ethiopian drainage basins and their sources, catchment area, flowing direction and contribution to the annual runoff is summarized in table 1 below.

Table 1. Summary of the main Ethiopian drainage basins and their characteristics

Basin	**Sources**	**Area (km^2)**	**Flow direction**	**Annual runoff (BM^3)**
Wabi-Shebelle	Bale highland	202, 220	East	4.6
Abay	West and southwest highland	199, 912	West	52.6
Genale-Dawa	Bale highland	172, 259	East	5.8
Awash	Central highland	110, 000	North	4.6
Tekeze	North Wollo highland	82, 350	West	7.6
Denakil	North Wollo highland	64, 380	_	0.86
Ogaden	_	77, 120	_	-
Omo-Gibe	Central and western highland	79, 000	South	17.9
Bar-Akobo	Western highlands	75, 912	West	23.6
Rift Valley Lakes	Arsi and central highland	52, 000	South	_
Mereb	Adi-Grat highland	5, 900	West	0.26
Ayesha	_	2, 223	_	_

Source: Sileshi Bekele *et al*. (2007)

The country has also many lakes, reservoirs, small water bodies and floodplains distributed throughout the country. The surface area of the lakes, reservoirs and the small water bodies are estimated to be 7,740 km^2, 1,447 km^2 and 4,450 km^2 (Gashaw Tesfaye and Wolff, 2014), respectively. This covers a total surface area of about 13,637 km^2, which is about 1.2 percent of the total land surface area. However, taking into consideration the hydropower and irrigation reservoirs, which are constructed in the past few years and under construction (e.g. Ethiopian Great Renaissance Dam, Zarema Mayday Dam, …), the surface area of the major reservoirs estimated to be more than 4,000 km^2.

The Ethiopian lakes are classified into the Highland and Rift Valley lakes. The Ethiopian highland lakes include Lake Tana, Lake Hayq, Lake Ardibo and Lake Hashenge. Lake Tana is the largest lake, which constitutes half of the area of the lakes of the country (De Graaf *et al.*, 2000; Vijverberg *et al.*, 2012). The Ethiopian Rift Valley lakes are the most northern of the African Rift Valley Lakes. Abaya, Chamo, Chew Bahr, Turkana (part of Ethiopia), Hawassa, Shala, Abijata, Langano, Ziway, Beseka, Afdera, Asale and Abbe are found in the Ethiopian Rift Valley (Redeat Habteselassie, 2012). The high plateau of crater lakes such as Lake Hora, Bishoftu, Arenguadie, Kilotes, Pawlo and Chitu are also included in this groups of lakes.

1.2. The Ethiopian Ichthyofauna

Ethiopia has a rich diversity of Ichthyofauna in its lakes, rivers and reservoirs. Although the exact extent of fish diversity is incomplete because of the taxonomic uncertainty (Abebe Getahun and Stiassny, 1998; Abebe Getahun, 2007; Golubtsov and Darkov, 2008), it has been estimated to be a total of 200 fish species, of which, 194 are native and 10 are exotic species. The 194 native fish species belong to 75 genera, 31 families and 12 orders. Forty of the total species are endemic (Redeat Habteselassie, 2012; Abebe Getahun, 2017). The fishes of Ethiopia are dominated by cyprinids, which accounts for nearly 30% of the native fishes occurring in the country.

The species diversity and composition varies within the geographical areas (Golubtsov *et al.*, 1995). Abebe Getahun (2007) and Vijverberg *et al.* (2012) also confirmed the uneven Ichthyofaunal distribution in the main drainage systems of the country. This is mainly because of the amount and nature of the tributaries (Abebe Getahun, 2007). For example, the highest fish diversity has been recorded in the Baro-Akobo Basin followed by Omo-Turkana and Blue Nile Basins (Table 2). However, in the case of endemicity, the Blue Nile and Rift Valley Basins are the highest (Golubtsov and Darkov, 2008).

Table 2. Fish species diversity in the major drainage basins of Ethiopia

Drainage system	Family	Genera	Number of Species
Baro-Akobo	26	60	119
Omo-Turkana	20	42	79
Blue Nile	15	34	62
Rift Valley	11	18	36
Tekeze-Atbara	10	22	35
Shebelle and Genale	12	21	33

Source: Abebe Getahun (2017)

The fish fauna of Ethiopia is a mixture of Nilo-Sudanic, East African highland and endemic forms (Roberts, 1975; Abebe Getahun and Stiassny, 1998). The Nilo-Sudanic forms of fish species related to the West African fish species is represented by the genera *Alestes*, *Bagrus*, *Citharinus*, *Hydrocynus*, *Hyperopisus*, *Labeo*, *Malapterurus*, *Polypterus*, *Protopterus* and *Mormyrus*. They are dominant in many basins particularly in the Nile Basins (Baro-Akobo, Tekeze and the Blue Nile), but they are absent from the northern and central Ethiopian Rift Valley lakes (Abebe Getahun, 2007; Dereje Tewabe, 2008; Mulugeta Wakjira, 2016).

According to Abebe Getahun and Stiassny (1998), the East African highland forms are distributed in the northern and central Rift Valley lakes, Awash Basin, the Highland lakes (Lakes Tana and Hayq) and the tributaries of the Blue Nile Basin. They are represented by the genera *Barbus*, *Clarias*, *Garra*, *Oreochromis* and *Varicorinus*. They are related to eastern and southern Africa and part of the Arabian Peninsula (Golubtsov and Mina, 2003).

The endemic forms are markedly represented by the *Labeobarbus* of Lake Tana. From the total of its 28 fish species, about 75% are endemic (Abebe Getahun, 2007; Golubtsov and Darkov, 2008). However, the Baro-Akobo and Omo-Turkana Basins, which are rich in Ichthyofaunal diversity, contribute insignificant proportions to the country's endemic fauna. Some species of the genus *Garra* adapted to water habitats of the central and northern highlands of the country are also included in the accounts of Ethiopian endemic Ichthyofauna (Abebe Getahun, 2000).

1.3. General description of Tekeze River Basin

1.3.1. Location

Tekeze River basin is situated in the northwest of Ethiopia, between 11° 40' and 15° 12' N and 36° 30' and 39° 50' E (Fig. 1). It is bordered by Mereb River Basin (north), Atbara River Plains (west), Abay River Basin (south) and Danakil Basin (east) (Ermias Hagos *et al.*, 2015). The basin has a total area of 86,510 km^2; a relatively small part of the basin (4,160 km^2) is situated in Eritrea (Getahun Antigegn, 2019). Tekeze River Basin inside Ethiopia has a catchment area of 59,306 km^2 (Mebrahtom Gebrmariam, 2012).

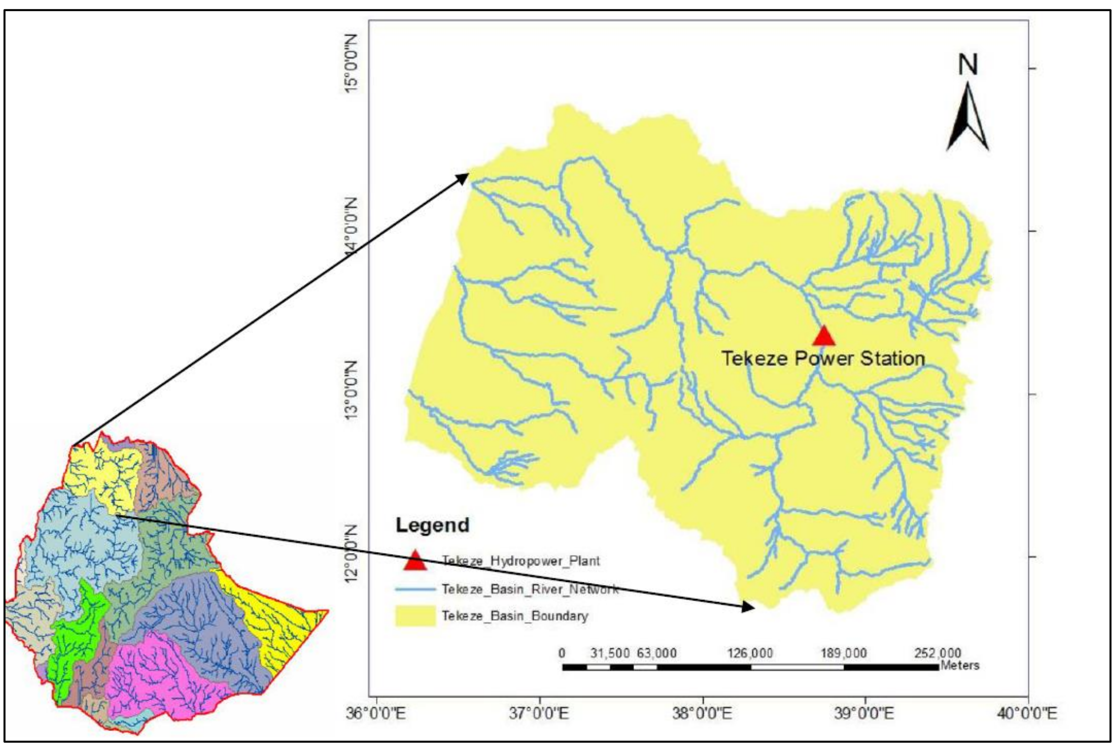

Figure 1. Location of Tekeze River Basin

1.3.2. Topography

The basin has an extremely variable topography (Ermias Hagos *et al.*, 2015). Elevation of the basin varies from 834 meters above sea level at the basin outlet in Embamadre to more than 4,517 meters above sea level in the Ras Dashen Mountains. It is characterized by rugged topography consisting of intermountain valleys, highlands and western lowlands (Tesfay Gebremicael *et al.*, 2017). The low land part of the Tekeze River Basin consists of about 1,500 km^2 areas, which is almost flat land. About 70% of the basin lies in the highlands at an altitude of over 1500 meters above sea level (Ermias Hagos *et al.*, 2015).

1.3.3. Population

The population of the basin is about 6.4 million in the economic basin area and 4.72 million within the hydrographic boundary. Rural inhabitants are estimated to be about 90%. Population densities are below 25 and between 100-120 persons/km^2 in the western and eastern half of the basin, respectively, with the highest density being 220 persons/km^2 in the eastern highland (NEDECO, 1997).

1.3.4. Climate

The general climate of the basin is semi-arid in the east and north and partly humid climate in the south (Tesfay Gebremicael *et al.*, 2017). The mean air temperatures in the basin vary from 10^oC in the Semien Mountains to 22^oC in the highlands and to 26^oC in the lowlands (Kiflom Belete, 2007). The minimum and maximum air temperature ranges are 3-21^oC and 19-43^oC, respectively. The Tekeze Basin has highly variable rainfall concentrated in one or two rainy seasons, separated by a relatively long dry season (Amanuel Zenebe, 2009). Rainfall range from 600 mm/year in the northeast end at Humera to more than 1,200 mm/year in the southwest near Ras Dashen (Kiflom Belete, 2007; Amanuel Zenebe, 2009). More than 70% of the total rainfall falls in July and August (Tesfay Gebremicael *et al.*, 2017). The climatic differences has resulted in the classification of the basin into four traditional agro-ecological zones namely Wurch (very high altitude, Dega (high altitude), Woina Dega (mid-altitude) and Kola (low altitude) (Kiflom Belete, 2007).

1.3.5. Tekeze Reservoir

Tekeze River is a tributary of the Atbara River, which joins the main course of the Nile in some 300 km North of Khartoum. It is originating from the central Ethiopian highland near Lasta. The length of the river from its source down to the border with Sudan is more than 608 km (Ermias Hagos *et al.*, 2015). Following this river, Ethiopia constructed a dam for hydropower generation (Fikru Fentaw, 2018). The water body created due to the construction of the dam is the Tekeze Reservoir, which is the focus of the present study. The dam is a double-curvature arch, which rises 188 meters from the riverbed. It is Africa's largest arch dam and intended primarily for hydropower generation and can produce 300 megawatts.

The study was conducted in Tekeze Reservoir, found at about 938 km north of Addis Ababa, the capital city of Ethiopia and 155 km west of Mekelle, the capital city of the Tigray Regional State. The reservoir is constructed on 2009 over Tekeze River for hydroelectric generation, located at about 1,115 meter above sea level and coordinates of 13^{o} 20' 49″ N and 38° 44' 37″ E. Mana, Tsilare, Seletsa, Avera and Ariqua Rivers are the main tributaries of the Tekeze River that enter into the reservoir. Subsistence and commercial fishing activities are also carried out in the reservoir. It is one of the biggest reservoirs in Ethiopia, with a total water storage capacity of 9,293 million m^3 (Mebrahtom Gebrmariam, 2012). It is fed by Tekeze River, which is one of the longest perennial rivers originating from the highlands of Ethiopia, placed on the Eastern side of the Semien Mountains range (Kidane Welde, 2016; Fikru Fentaw, 2018). The maximum length of the reservoir is almost 75 km at full supply level, with two main branches and a maximum width of 6 km. The reservoir has a considerably large surface area of 160 km^2. It has a catchment area of over

29,404 km^2, with a long-term average annual inflow of 3,750 million m^3 and sedimentation of 30 million m^3 per year (Kiflom Belete, 2007; Kidane Welde, 2016).

Table 3. Summary of the major features of Tekeze Reservoir

Features	Values
Total storage	9,293 million m^3
Maximum length	75 km
Maximum width	6 km
Surface area	160 km^2
Catchment area	29,404 km^2
Average annual inflow	3,750 million m^3
Sedimentation	30 million m^3/year

The reservoir is shared by one district (Tanqua Abergele) of Tigray Regional State and four districts (Tselemt, Abergele, Sahala and Ziquala) of Amhara Regional State.

1.3.6. Ichthyofaunal studies of Tekeze River Basin

Data about the Ichthyofaunal diversity of the Tekeze River Basin system is scarce as compared to other Ethiopian drainage systems (Golubtsov and Mina, 2003). Due to the tremendous seasonal variation of water discharge in the system, the Tekeze Basin is the least diverse in fish species compared to the other parts of the Nile Basin within the limit of Ethiopia (Golubtsov and Mina, 2003). Different authors have reported some genera of fishes in different tributaries (Gendawuha, Guang, Shinfa, Ayima, Angereb and Sanja) of the river basin. For example, Genanaw Tesfaye (2006), Dereje Tewabe (2008) and (Tesfaye Melak, 2009) have reported some interesting Nilo-Sudanic and East African genera from Tekeze River Basin.

Labeo, *Labeobarbus*, *Bagrus*, *Clarias*, *Brycinus*, *Garra*, *Oreochromis*, *Synodontis*, *Varicorinus*, *Mormyrus*, … etc. are some of the identified genera from the river basin. However, there is no specified data for the number and endemism of the species. Recently, Abebe Getahun (2017) documented 35 fish species within 22 genera and 10 families from the river basin. Dereje Tewabe *et al*. (2009) and Tsegay Teame *et al.* (2016b) also assessed the fish diversity of the Tekeze Reservoir. According to these authors, the reservoir has huge potential fisheries resources. Dereje Tewabe *et al*. (2009) identified 18 fish species in 13 genera, 7 families and 5 orders. However, Tsegay Teame *et al*. (2016b) recorded 11 fish species belonging to 8 genera, 4 families and 3 orders in a similar water body (Table 4).

Table 4. Summary of fish species composition reported in two different studies of Tekeze Reservoir

Dereje Tewabe *et al*. (2009)			Tsegay Teame *et al*. (2016b)		
Species	**Genera**	**Family**	**Species**	**Genera**	**Families**
O. niloticus	*Oreochromis*	Cichlidae	*O. niloticus*	*Oreochromis*	Cichlidae
B. docmak	*Bagrus*	Bagridae	*B. docmak*	*Bagrus*	Bagridae
B. bajad	*Bagrus*	Bagridae	*B. bajad*	*Bajad*	Bagridae
C. gariepinus	*Clarias*	Claridae	*C. gariepinus*	*Clarias*	Claridae
H. longifilis	*Hetrobranchus*	Claridae	*H. longifilis*	*Hetrobranchus*	Claridae
H. electricus	*Malapterurus*	Malapteruridae	*L. intermedius*	*Labeobarbus*	Cyprinidae
M. kannume	*Mormyrus*	Mormyridae	*L nedgia*	*Labeobarbus*	Cyprinidae
H. forskahlii	*Hydrocynus*	Characidae	*R. senegalensis*	*Raiamas*	Cyprinidae
L. beso	*Labeobarbus*	Cyprinidae	*L. forskalii*	*Labeo*	Cyprinidae
R. senegalensis	*Raiamas*	Cyprinidae	*L. beso*	*Labeobarbus*	Cyprinidae
L. niloticus	*Labeo*	Cyprinidae	*G. dembeensis*	*Garra*	Cyprinidae
L. forskalii	*Labeo*	Cyprinidae			
L. bynni	*Labeobarbus*	Cyprinidae			
L nedgia	*Labeobarbus*	Cyprinidae			
L. crassibarbis	*Labeobarbus*	Cyprinidae			
L. intermedius	*Labeobarbus*	Cyprinidae			
G. dembeensis	*Garra*	Cyprinidae			
Brabus species	*Barbus*	Cyprinidae			

1.4. Statement of the problem

The human population is highly increasing in Ethiopia and it is difficult to support the population with only cereals and livestock production as a source of protein. Therefore, the sustainable utilization of aquatic resources, particularly the fishery resource, as a cheap source of animal protein is crucial (Shibru Tedla, 1973; Tesfaye Wudneh, 1998). Sustainable utilization of aquatic resources requires scientific information about the diversity, biology, catch status, level of exploitation and managemental problems of the fisheries. Therefore, conducting a well-designed study on fishery areas that lack such information is mandatory for the sustainability of the stock.

Ethiopia has several freshwater bodies from where plenty of aquatic food resources could be produced from the fisheries sector. However, due to poor management, the contribution of the fishery to the economy is by far limited. Capturing of small-sized fish, overexploitation, problem of fishing gears, fishing season, etc. are the major problems in Ethiopia (Mathewos Temesgen and Abebe Getahun, 2016). Urbanization and human settlement close to some Ethiopian lakes are also the other potential causes of changes in water quality and quantity, which directly affect the ecology of fishes (Habiba Gashaw and Seyoum Mengistu, 2012).

Tekeze Reservoir is one of the newly constructed reservoirs mainly for hydropower generation. It has huge potential resources in fish production and other aquatic life (Dereje *et al*., 2009). However, little or no scientific research has been conducted on the diversity, biology and actual production potential of the fishes of the reservoir. *Oreochromis niloticus, L. intermedius* and *B. docmak* are the major commercial fish species commonly caught in the reservoir. They are the most desirable fish species for food and commercial purposes by the fisher in the reservoir.

Fish catches have over time declined and currently, the catch per unit effort is relatively low to be of significant economic importance to the fishing communities. The reservoir fishery is faced with the challenge of lack of proper management practices, which is partly attributed to a lack of basic biological and ecological information on fish species needed to guide the proper management of the fishery. Basic knowledge of critical seasons and habitats for fish breeding and nursery grounds is lacking for fish species in Tekeze Reservoir, which has led to the destruction of breeding sites, nursery grounds and catching of immature fish by fishers, which greatly affects the fisheries productivity.

Little or no documented information can be found on the ecology and reproductive biology of any of the commercial fish species in the reservoir. Basic knowledge on fish species distribution, abundance, biology, actual yield, the extent of immature fish harvesting and management options is therefore deficient, consequently, the fishery of Tekeze Reservoir is poorly understood and its future of sustainability is unpredictable. Therefore, the following questions were raised to fill the gap:

i. What is the status of physico-chemical parameters of the aquatic environment in the Tekeze Reservoir?
ii. What are the species composition and relative abundance of fishes in the Tekeze Reservoir?
iii. Do species composition of fishes of Tekeze Reservoir vary among sampling seasons?
iv. Do fishes of Tekeze Reservoir vary in their relative abundance between sampling sites?
v. What are the biological aspects of the commercially important fish species of the Tekeze Reservoir?
vi. What was the production potential of the Tekeze reservoir?
vii. What is the current catch status of the reservoir fishery?
viii. What is the exploitation level of the three major commercial fish species such as *O. niloticus*, *L. intermedius* and *B. docmak* in the reservoir?

ix. What was the socio-economic importance of the Tekeze Reservoir fishery?

x. What were the existing threats to the production of Tekeze Reservoir fisheries?

xi. What management options should be implemented to create sustainability on the fisheries of the Tekeze Reservoir?

1.5. Significance of the study

This study aimed at contributing to the management of the reservoir fishery by providing critical baseline information on physicochemical parameters, distribution, abundance, size-frequency distribution, condition factor and length-weight relationship, food and feeding habits (diet composition, relative importance, fish size and feeding habit relationship and feeding periodicity) of fishes of the Tekeze Reservoir. It also provides important information on reproductive biology (sex ratio, length at first maturity, fecundity and breeding), yield, the extent of immature fish harvesting, socioeconomic importance and management options that are required for future monitoring and guidance on the conservation and management of the fisheries resources in Tekeze reservoir.

Understanding the updated fish diversity and abundance, biological aspects of some selected commercial fishes, current production potential (yield) and management options will help fisheries managers to design strategies in establishing nursery or breeding grounds to protect the young and the brood stocks. Proper assessment of habitat and specific life history data, therefore, will help managers to design appropriate management measures like closed fishing areas and seasons aimed at sustainable utilization of the fisheries resources. The knowledge of the interaction between habitat or season and fish biology is also required for the development of specific management plans for the reservoir and other similar systems. The information generated in this study will also provide a basis for future research work in the Tekeze Reservoir.

1.6. Dissertation outline

The dissertation contains seven chapters. The first chapter is the background of the study. It highlights about Ethiopian surface water resources and Ichthyofaunal diversity. General description of the study area (Tekeze River Basin), statement of the problem, research questions, objectives and significance of the study are also included in this chapter.

The second chapter deals with the diversity and abundance of fish species in the reservoir. It contains the fish species composition, diversity indices in different sampling sites and seasons, temporal and spatial distributions with some environmental variables. The third and fourth chapters provide some biological aspects of the major commercial fish species in the Tekeze Reservoir. The third chapter focused on size-frequency distribution, length-weight relationship, condition factor and reproductive biology of *O. niloticus*, *L. intermedius* and *B. docmak* in the area. However, chapter four assessed the diet composition, relative contribution and dietary shifts of those fish species in the reservoir.

The fifth chapter discusses production potential, catch and extent of immature fish harvesting by the fishers in the reservoir fisheries. It indicates the current catch and exploitation level of the fishery. The sixth chapter investigates the socio-economic importance of the fishes and fisheries, challenges and problems of the small-scale fisheries and management options of the reservoir fisheries. The seventh chapter contains general conclusions and recommendations. It concludes the overall results obtained in this study and recommends important critical attention needed points for sustainability of the fishery resources in the reservoir.

CHAPTER TWO

2. DIVERSITY AND ABUNDANCE OF FISHES IN TEKEZE RESERVOIR

Abstract

The diversity and relative abundance of fishes were studied from Tekeze Reservoir, Ethiopia from January 2016 to December 2017. Samples were collected from six sites using gill nets with different stretched mesh sizes (0.5 – 5.5, 6, 8, 10, 12 and 14 cm). The size of each net was 50 m (length) X 3 m (width). The fishes were counted and identified to the family and species levels. Ecological indices such as the Shannon-Weaver diversity index, Simpson's diversity index, species evenness and richness were used to analyze the data. The values of the environmental variables were found to be optimum for fish production. Specimens from the reservoir belonged to 15 species within four families: Cyprinidae, Bagridae, Claridae and Cichlidae. Shannon-Weaver and Simpson's diversity indices ranged from 1.447 to 1.697 and 0.7333 to 0.7925, respectively. The species equitability range was 0.6957–0.8718. The estimations of fish species diversity and equitability were higher (H' = 1.715; J' = 0.746) during the wet and dry-cold seasons, respectively. The index of relative importance (%IRI) of the key species in the gill net landings includes Oreochromis niloticus, (35.5%), Bagrus docmak (22.6%), Labeobarbus intermedius (20.5%), Labeo niloticus (10.6%) and Labeo forskalii (10.2%). The species that were in low relative importance were Clarias gariepinus, Labeobarbus nedgia, Raiamas senegalensis, Labeobarbus crassibarbis, Hetrobranchus longifilis, Garra dembeensis, Bagrus bajad, Labeobarbus bynni, Labeo cylindricus and Labeobarbus beso, which constitute below 1% of the total catch. The river mouth habitats contributed the most catch composition while the pelagic habitats contributed the least. The physicochemical parameters played a key role in the spatial variation of the species diversity and abundance. The study demonstrates that fish abundance has declined in the reservoir. Therefore, a management plan and strategy should be in place to maintain the fish species and enhance their sustainable utilization.

Keywords/ phrases: *Abundance, Diversity, Physico-chemical parameters, Species and Tekeze Reservoir*

2.1. Introduction

Reservoirs play a very important role in the geochemical cycling of elements and influence the chemical composition and material transfer of river systems (Singh *et al.*, 2005). They have high ecological, economic and recreational importance (Carol *et al.*, 2006). They contribute significantly to fulfilling basic human needs such as water for drinking and industrial use, irrigation, flood control, hydropower generation, fishing and recreation. However, unwise use of reservoirs can cause decline of the aquatic fauna and flora (Basavaraja *et al.*, 2014).

Fish diversity and abundance reflect the quantity and quality of the available habitat. The decline in the abundance of freshwater fish in the world has been a concern for over one hundred years. Since the twentieth century, many fish species have suffered continuing declines in abundance and distribution. Inland commercial fisheries target many smaller species. The decline of the species is commonly attributed to general habitat degradation, reduced water quality and pollution, illegal fishing and commercial overfishing and altered biotic interactions (Gehrke *et al.*, 1995; Mallen-Cooper *et al.*, 1995). Nevertheless, the impact of the anthropogenic activities, habitat degradation, exotic species introduction, water diversions, pollution and global climate change are the main causative agents for the rapid decline of aquatic species (Barbour *et al.*, 1999).

Due to their easy identification and economic value, fish have been identified as suitable for biological assessment (Siligato and Böhmer, 2001). Fish assemblages have widely been used as ecological indicators to assess and evaluate the level of degradation and health of water bodies at various spatial scales (Vijaylaxmi *et al.*, 2010). As habitat degradation continues on a global scale, maintenance of fish species habitat has become a central issue of conservation biology. This is particularly the case with the fish fauna of inland waters (Pegg and Taylor, 2007).

Management of fishery require scientific information of resources where knowledge of fish stocks is one of the most important parameters (Ricker, 1975). Besides, assessing fish biodiversity and their interaction with biotic and abiotic factors would give a broader understanding of the functions and ecological value of ecosystems (Okyere *et al.*, 2012).

Tekeze Reservoir is one of the newly constructed reservoirs in Ethiopia mainly for hydroelectric power generation (Mebrahtom Gebrmariam, 2012). It has huge potential fishery resources and other aquatic life (Dereje Tewabe *et al.*, 2009; Tsegay Teame *et al.*, 2016b). Dereje *et al* (2009) reported eighteen fish species, but Tsegay Teame *et al*. (2016b) documented eleven fish species and the fishery activities in the reservoir play a significant role in providing income and food supply for the rural families found near the water body (Tsegay Teame *et al.*, 2016b). However, no detailed temporal and spatial studies have been conducted on the diversity and abundance of fishes and the interaction with their environment. Therefore, the objective of this study was stated below.

2.1.1. General objectives

The overall objective of the present investigation was to provide recent data regarding fish diversity status and relative abundance, aiming to contribute to a better knowledge of the fish diversity profile and a tool for conservation planning of the aquatic environment in Tekeze Reservoir.

2.1.2. Specific objectives

i. To identify species diversity and relative abundance of the fishes in Tekeze Reservoir

ii. To study the spatial and temporal variation of the fishes in the reservoir

iii. To determine the role of the environmental variables on distribution of the fish species in the reservoir

2.2. Materials and Methods

2.2.1. Site selection

Regular sampling of the study started in January (2016) but, a four days' reconnaissance survey was carried out in May, September and November (2015) with the fisheries and aquatic ecology research team of Mekelle University. This survey was important to see and observe the different habitats and fishing activities of the Tekeze Reservoir. Therefore, by considering suitability in setting gill nets, the experience of the commercial fishing, depth, flowing velocity, fishing exposure and suitability of habitats, six sampling sites were selected to include various habitats of the reservoir (Fig. 2). The representative sampling sites were Gfrtsatsa, Lmlmo, Tsilare, Kanizu, Seletsa and Ariqua.

The selected sites represent the different habitats present in the reservoir such as river mouths, pelagic and shallow water body or littoral. Tsilare and Kanizu sites were representatives of river mouth habitats. Seletsa and Gfrtsatsa represent shallow water habitats, but Ariqua and Lmlmo represent open water habitats (Table 5).

Gfrtsatsa and Lmlmo were littoral and pelagic habitats, respectively, located near to the main entrance and exit of Tekeze Reservoir. In these areas, fishing exposure was high and more people were settled near to these sites. Because of their proximity, the areas serve as the main fishing center for the fishers with motorized and non-motorized boats. Particularly in the shallow area of Gfrtsatsa, people were spending their leisure time by swimming and more boats spent overnight and daybreak time. Gfrtsatsa was used as a market place and exchange of goods and service were mainly conducted in this area.

Tsilare and Kanizu sites were representatives of riverine habitats, which flow perennially and located far away in the main entrance and exit of the reservoir. They were found in the way of

Tsilare and Tekeze Main Rivers, respectively. Relative to Gfrtsatsa and Lmlmo, there was low fishing exposure and low human disturbance. Similarly, Seletsa was also found far away from the port and was a representative of shallow habitats of the reservoir. It was located near to the seasonal Seletsa River, one of the tributaries of the reservoir.

Arriqu**a** site was located near to the hydropower station or the outlet of the reservoir and was representative of an open water body of the reservoir. It was too gorgy and named so due to the seasonal Ariqua River flowing into the reservoir. Fishing activity in Tekeze Reservoir first started in this area. Fishing exposure and human disturbances were high. It provides alternative entrance and exit services to the fishers and other passengers. In addition to Gfrtsatsa, some fishers and traders have also used this area to sell and buy fish products and other goods and services.

Table 5. Summary of the sampling sites with corresponding characters of Tekeze Reservoir

	Geographic coordination				
Site	**Latitude**	**Longitude**	**Depth (m)**	**Altitude (m)**	**Habitat type**
Gfrtsatsa	13°18'4"N	38°44'5"E	9.50±0.76	1113	Littoral
Lmlmo	13°16'3"N	38°44'2"'E	38.17±4.39	1118	Pelagic
Tsilare	13°07'7"N	38°43'4"'E	15.00±6.64	1115	River mouth
Kanizu	13°07'6"N	38°40'7"E	7.75±1.00	1121	River mouth
Seletsa	13°13'4"N	38°41'9"E	7.42±0.90	1110	Littoral
Ariqua	13°20'2"N	38°45'40"E	49.50±3.27	1119	Pelagic

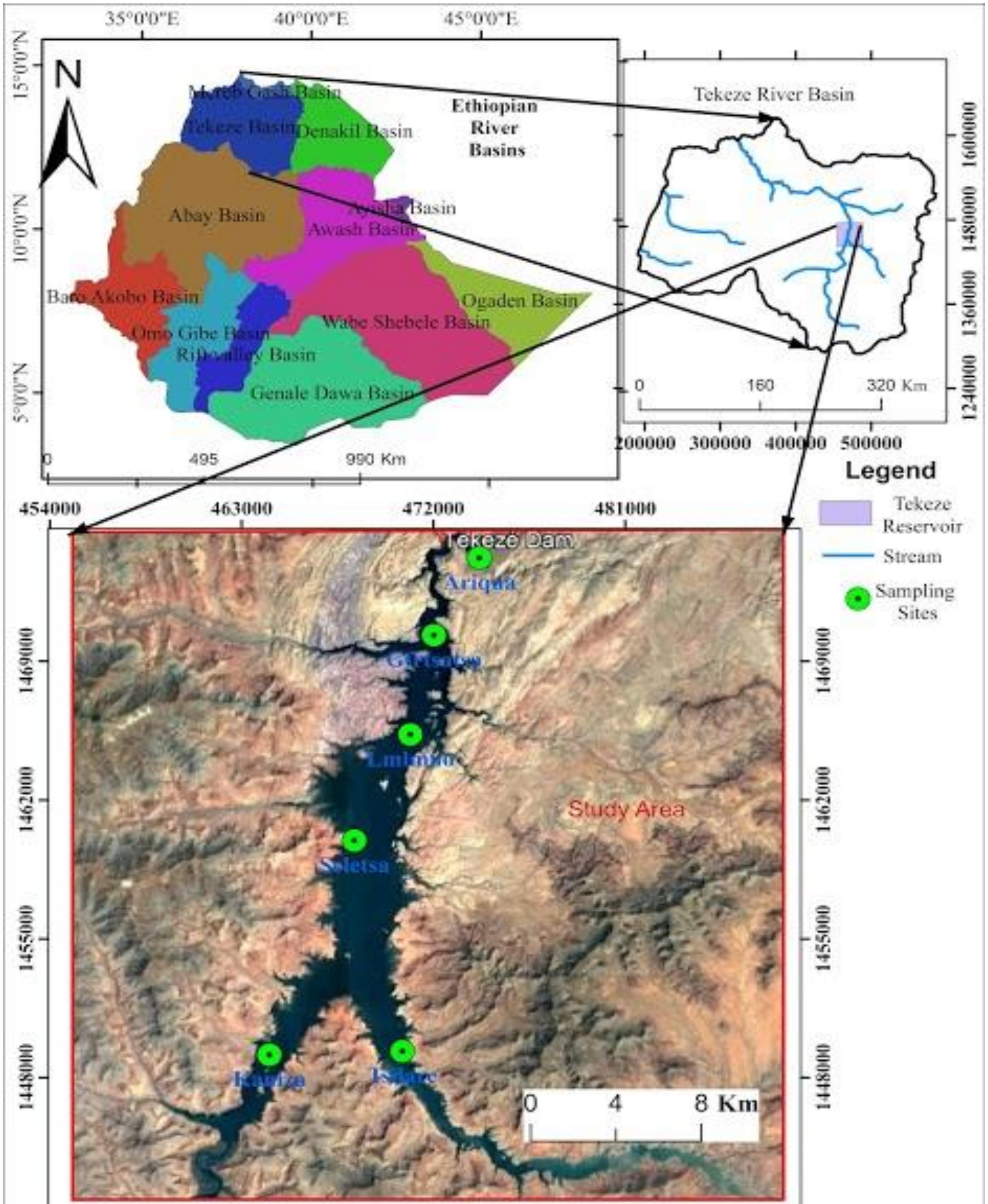

Figure 2. The Ethiopian main basins and sampling sites of Tekeze Reservoir

2.2.2. Physico-chemical variables

The environmental variables of the Tekeze Reservoir were recorded in late morning between 9:00 and 11:00 a. m (Shukla and Singh, 2013). Chlorophyll a and turbidity were measured *in situ* by aqua-flour or fluorometer /turbidity meter (Model 8000 – 001) and dissolved oxygen was measured with a portable oxygen meter probe (Model HQ40d), whereas pH and temperature were measured with coupled pH/MV/meter (Model CE 370 pH meter 01186, EU). Total dissolved solids and electrical conductivity were measured simultaneously with conductivity/TDS meter (Model CE 470 conductivity meter 01189). Water transparency of the reservoir was measured with a standard Secchi-disc of 20 cm diameter.

2.2.3. Fish sampling

Fish specimens were collected from January (2016) to December (2017) using multifilament gill nets with a stretched mesh size of 6, 8, 10, 12 and 14 cm and monofilament gill nets with a stretched mesh size of 0.5 to 5.5 cm from six sampling sites in Tekeze Reservoir. All the panels were combined to form one multi-mesh gill net. The various mesh sizes of the gill nets were chosen to be able to catch the whole range of size classes and species. The size of a single mesh panel was 3 m X 50 m. The nets were deployed in the late afternoon (3:00 p. m) and removed in the following morning (9:00 a. m).

Fish specimens were collected for two consecutive years, two times each during the dry-cold (November - February), dry-hot (March - June) and wet (July - October) seasons. The sampling seasons were classified based on the Ethiopian methodological data obtained from Mekelle Office. The dry cold season was characterized by cold environmental conditions with low temperatures and no rainfall. Relatively to the dry hot season, the high-water level of the reservoir was recorded in this season (Office of Tekeze power station).

The dry hot season of the study period was characterized by high temperature, a little or an insignificant amount of water. However, the wet season was characterized by a high level of water with a high amount of rainfall and a high-water level of the reservoir. Immediately after capture, identification of the fish specimen was made to species level using relevant taxonomic literature (Shibru Tedla, 1973; Nelson, 2006; Redeat Habteselassie, 2012). The total length (TL) and standard length (SL) of each fish specimen were measured to the nearest 0.1cm. The total weight of each specimen was also taken using a digital balance and measured to the nearest 0.1g. Diversity, abundance and temporal and spatial distributions of the fish species in the reservoir were analyzed.

2.2.4. Data analysis

The collected data were analyzed using statistical software and simple descriptive statistics. SPSS version 24, PAST version 3.25, Canoco for windows 4.5 and Pasgear II were used to analyze the data. The environmental variables of the reservoir were analyzed and tested using Post Hoc multiple comparison LSD model and the comparisons between the sampling habitats and seasons were taken using one-way ANOVA (tested at $P = 0.05$).

The species diversity was calculated using different indices. The commonly used indices such as Shannon diversity index (H') (Shannon and Weaver, 1963) and Simpson's dominance or diversity index (Simpson, 1959) were used to evaluate the species diversity. The calculation of fish diversity using the Shannon-Weaver index depends on both the number of species present and the abundance of each species. Simpson's index measures the diversity of species. The value of Simpson's dominance index (D**)** ranges between zero and one. With this index, zero represents infinite diversity and one, no diversity. That is, the bigger the value of D, the lower the diversity. It measures the probability that two individuals randomly selected from a sample will belong to the same species. The value of Simpson's index of diversity (B) also ranges between zero and one, but the greater the value, the greater the sample diversity. In this case, the index represents the probability that two individuals randomly selected from a sample will belong to different species (Simpson, 1959).

Shannon-Weaver Index:

$$H' = -\sum \text{Pi} \times \ln(\text{Pi})$$ Where $\text{Pi} = \frac{\text{ni}}{\text{N}}$, H' = diversity index and ni = number of individuals within species and N= total number of individuals

Simpson's Index of Dominance:

$$D = \frac{\Sigma n(n-1)}{N(N-1)}$$ Where D = Simpson's index of dominance

Simpson's Index of Diversity

$$B = 1 - \frac{\Sigma n(n-1)}{N(N-1)}$$ Where B = Simpson's index of diversity

The species evenness (J') and richness (R) of the reservoir were calculated using Pielou's Evenness Index (Pielou, 1969) and Margalef's Index (Margalef, 1958). Evenness is a measure of the relative abundance of the different species making up the richness of an area. The number of species per sample is a measure of richness. The more species present in a sample, the 'richer' the sample.

Pielou's evenness index:

$$J' = \frac{H'}{\mathbf{H'\,max}}$$ Where $H'max = lnS$, H′ is the value derived from the Shannon-Weaver index.

Margalef's richness index:

$$R = \frac{S-1}{\ln N}$$ Where S = number of species and N is the total number of individuals

Index of Relative Importance (IRI) was used to measure the relative abundance based on number and weight of individuals in catches and their frequency of occurrence (Kolding, 1989). This was calculated as:

$$\text{IRIi} = \frac{(\%Wi + \%Ni)\%Fi}{\sum_{j=1}^{i=1}(\%Wj + \%Nj)\%Fj} X100$$

Where $\%Wi$ = percentage weight of each fish species in total catch

$\%Ni$ = percentage number of each fish species in total catch

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

$\%Wj$ = percentage weight of total species of the total catch

$\%Nj$ = percentage number of total species of the total catch

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

The percentage composition by number and weight of every fish taxa during dry-cold, dry-hot and wet seasons as well as for each sampling habitat were computed. The significance of differences in species relative abundance during the sampling seasons was analyzed using the T-test. One-way ANOVA was used to determine the significance of differences in species diversity between habitats and sampling seasons.

The association between fish species distribution and Physico-chemical variables was evaluated by canonical multivariate analysis using Canoco for windows 4.5-version software (Lepš and Šmilauer, 2003). Detrended correspondence analysis (DCA) was employed to check the response of the data and it was found that the length of the longest gradient was 0.316. According to Leps and Smilauer (2003), redundancy analysis (RDA) should be used only if the length of the longest gradient is shorter than 3. Redundancy analysis was performed to observe the relation of species abundance data to environmental factors. Therefore, the RDA was used as the fish species data showed a linear response to the environmental variables.

2.3. Results

2.3.1. Physico-chemical parameters

The spatial variation of the environmental variables of the Tekeze Reservoir is given in Table 6. There was no statistically significant variation ($p > 0.05$) in all parameters between all sampling habitats of the reservoir.

Table 6. Spatial variation of abiotic parameters (mean ± SE) of Tekeze Reservoir

	Sampling habitats		
Variables	**Littoral**	**Pelagic**	**River mouth**
Chl. (mg/l)	45.75±5.88	46.71±4.98	57.55±8.8
TRB (NTU)	6.81±1.01	7.89±1.17	6.81±0.99
DO (mg/l)	4.98±0.53	5.13±0.62	6.29±0.29
Temp. (^{o}C)	27.88±0.61	27.58±0.4	27.73±0.41
pH	7.83±0.17	8.1±0.14	8.09±0.11
TDS (ppm)	132.92±9.34	129.03±8.29	141.38±13.08
EC (µS/cm)	204.5±14.37	198.5±12.75	217.5±20.12
WT (cm)	207.08±11.93	203.33±14.28	206.25±11.4

Note: *Chl. - chlorophyll, TRB – turbidity, DO - dissolved Oxygen, Temp. - temperature, TDS - total dissolved solids, EC – electrical conductivity and WT - water transparency (Secchi disk).*

Seasonal variations of all Physico-chemical parameters in the Tekeze Reservoir were given in Table 7. The chlorophyll of the reservoir varied from 32.20±1.2 to 61.58±7.72 mg/l and the overall mean was 50.00±3.86 mg/l. The maximum value was recorded during the dry-cold season and the minimum in the dry-hot season. The results indicated a significant difference in the chlorophyll between dry-cold and dry-hot seasons, as well as between wet and dry-hot seasons. However, there was no significant difference between the dry-cold and wet seasons of the investigation period (Table 7). Similarly, the results of this study showed a high mean value (10.64±1.21 NTU) of turbidity during the dry-cold season and low mean value (4.32±0.31 NTU), in the dry-hot season of the study period (Table 7). The results also showed marked seasonal variation between all sampling seasons. Dissolved oxygen values ranged from 4.44±0.41 mg/l to 6.90±0.14 mg/l. The overall mean was 5.47 mg/l (Table 7). The highest value was measured during the dry-hot season while the lowest was in the dry-cold season. There was a statistical variation between dry-cold and dry-hot seasons, as well as between wet and dry-hot seasons, but not between the dry-cold and wet seasons (Table 7).

The minimum values, i.e. 26.85±0.03^{o}C of the surface water temperature were observed during the dry-cold season, but its maximum, i.e. 28.24±0.38 was measured in the wet season. However, almost similar values were recorded in the dry-hot and wet seasons (Table 7). As a result, significant seasonal variation between dry-cold and wet seasons of the sampling period was observed (Table 7). The overall mean temperature of the surface water was 27.73±0.27^{o}C (Table 7). The pH value of the surface water of the Tekeze Reservoir ranged from the lowest value of the dry-cold season (7.64±0.08) to the highest value of dry-hot season (8.60±0.06). The overall mean pH was 8.01±0.08 (Table 7). The value of the dry-cold season showed significant variation from the result obtained in the dry-hot season. The pH value of the dry-hot season was significantly different from the results recorded during the dry-cold and wet seasons and the value of the wet season was different from the value of the dry-hot season, but not from the value of dry-cold season (Table 7). Total dissolved solids were found between 112.62±1.69 ppm and 158.55±8.93 ppm and the overall mean was 134.44±5.92 ppm (Table 7). As indicated in Table 3, the mean value of total dissolved solids was higher during the dry-cold season, but low in the dry-hot season. Therefore, this showed a significant difference between the dry-cold and dry-hot seasons and dry-cold and wet seasons (Table 7). Similar to total dissolved solids, the minimum (173.25±2.6 µS/cm) and maximum (243.92±13.73 µS/cm) value of electronic conductivity were recorded during the dry-hot and dry-cold seasons, respectively. The measured conductivity was not a significant difference between wet and dry-hot seasons, but a significant difference between the dry-cold and dry-hot seasons and dry-cold and wet seasons (Table 7). Water transparency of the Tekeze Reservoir was significantly different in different sampling seasons. The highest transparency was recorded in the dry-cold season (237.08±9.89 cm), while the lowest was recorded in the wet season (171.25±12.65 cm) (Table 7). The overall mean water transparency was 205.56±7.07 cm. Water transparency was significantly different among all sampling seasons.

Table 7. Seasonal variation (mean ±SE) of abiotic parameters in Tekeze Reservoir

Parameters	**Sampling seasons**			**Overall mean± SE**
	Dry-cold	**Dry-hot**	**Wet**	
Chlorophyll (mg/l)	61.58±7.72^{a}	32.2±1.2^{b}	56.24±6.07^{a}	50.00±3.86
Turbidity (NTU)	10.64±1.21^{a}	4.32±0.31^{b}	6.55±0.11^{c}	7.17±0.60
Dissolved Oxygen (mg/l)	4.44±0.41^{a}	6.9±0.14^{b}	5.05±0.59^{a}	5.47±0.30
Temperature (^{o}C)	26.85±0.57^{a}	28.1±0.37^{ab}	28.24±0.38^{b}	27.73±0.27
pH	7.64±0.08^{a}	8.6±0.06^{b}	7.79±0.09^{a}	8.01±0.08
Total dissolved solids (ppm)	158.55±8.93^{a}	112.62±1.69^{b}	132.17±12.46^{b}	134.44±5.92
Conductivity (µS/cm)	243.92±13.73^{a}	173.25±2.6^{b}	203.33±19.16^{b}	206.83±9.10
Water Transparency (cm)	237.08±9.89^{a}	208.33±4.58^{b}	171.25±12.65^{c}	205.56±7.07

***Note**: different superscript letters in the column indicate for statistically significant different but similar letter represented for not significant different at 0.05 level.*

2.3.2. Fish species composition

A total of 2,110 fish specimens, belonging to 3 orders, 4 families, 8 genera and 15 species (Table 8; Appendix 1) were collected from six sampling sites, which represent river mouth, open water and littoral habitats. Three Orders: Cypriniforms, Siluriforms and Perciforms were represented in the reservoir.

Order Cypriniformes was the most diverse taxa represented by 1 family, 4 genera and 10 species. The fish species found under this order were *Labeo niloticus* (Linnaeus, 1758), *Labeo forskalii* (Rüppell, 1835), *Labeo cylindricus* (Peters, 1852), *Labeobarbus beso* (Rüppell, 1835), *Labeobarbus intermedius* (Rüppell, 1835), *Labeobarbus bynni* (Forsskål, 1775), *Labeobarbus nedgia* (Rüppell, 1835), *Labeobarbus crassibarbis* (Nagelkerke and Sibbing, 1997), *Raiamas senegalensis* (Steindachner, 1870) and *Garra dembeensis* (Rüppell, 1835).

Order Siluriformes was also represented by 2 families, 3 genera and 4 species. *Bagrus bajad* (Forsskål, 1775) and *Bagrus docmak* (Forsskål, 1775) were from the family Bagridae and *Clarias gariepinus* (Burchell, 1822) and *Hetrobranchus longifilis* (Valenciennes, 1840) were from the family Claridae. However, only 1 family, 1 genus and 1 species (*Oreochromis niloticus* (Linnaeus, 1758)) represented the order Perciforms. *Labeo cylindricus* was a new record for the reservoir. Generally, the taxonomic classification, common and local (Amharic) names of the identified fish species from the Tekeze Reservoir are given in table 8.

Table 8. Fish species composition and their local names (Amharic) from Tekeze Reservoir

Order	Family	Genus	Species name	Local name	Common name
Cypriniformes	Cyprinidae	*Labeo*	*L. niloticus*	Gebsma	Nile labeo
			L. forskalii	Tiqurie	Not available
			L. cylindricus	Not available	Redeye labeo
		Labeobarbus	*L. beso*	Not available	African scraping feeder
			L. intermedius	Nech asa	Ethiopia barb
			L. bynni	Nech asa	Nile/Niger barb
			L. nedgia	Nech asa	Not available
			L. crassibarbis	Nech asa	Not available
		Raiamas	*R. senegalensis*	Shilm	Senegal minnow
		Garra	*G. dembeensis*	Not available	Dembea stone lapper
Siluriformes	Bagridae	*Bagrus*	*B. bajad*	Qey ambaza	Bayad
			B. docmak	Nech ambaza	Semutundu
	Claridae	*Clarias*	*C. gariepinus*	Qey mbaza	African catfish
		Hetrobranchus	*H. longifilis*	Qey ambaza	Sampa
Perciformes	Cichlidae	*Oreochromis*	*O. niloticus*	Qereso	Nile tilapia

The study revealed that there was a dominance of fish species belonging to the family Cyprinidae. This family had contributed the highest percentage of the total species (66.67%), which is followed by Bagridae and Claridae (13.33%, each) and the family Cichlidae contributed the lowest with 6.67% of the total species sampled in the study period (Fig. 3).

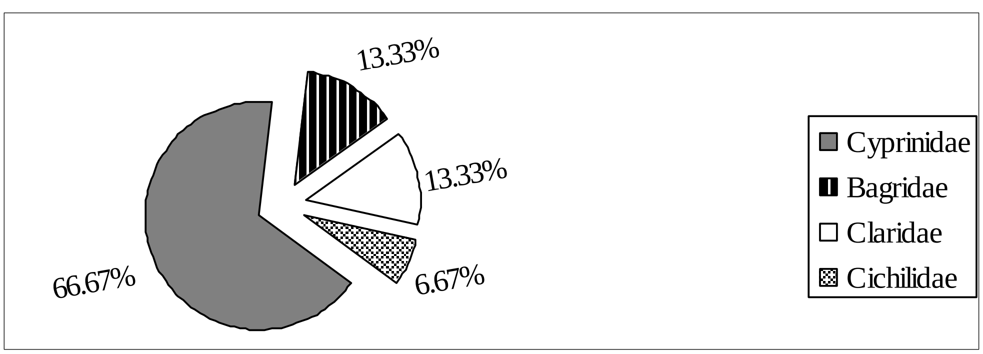

Figure 3. Percentage occurrence of fish families in Tekeze Reservoir

2.3.3. Fish diversity indices

The diversity indices of fishes in different habitats of the Tekeze Reservoir are given in table 9. Simpson's dominance index (D) shows the higher value at the pelagic area (0.2371), but low at littoral habitat (0.2085). That is, the bigger the value of D, the lower the diversity. However, the value of Simpson's index of diversity (B) for the sampling habitat of the littoral area (0.7915) was high. The lowest value (1.555) of the Shannon–Weaver species diversity index (H′) was recorded at the pelagic zones of the reservoir. Conversely, high values were recorded at the littoral and river mouth habitats. The value of species richness index ranged from 1.294 to 1.843 at the littoral and pelagic habitats, where the lowest and highest numbers of species were obtained, respectively.

Table 9. Fish diversity indices from different sampling habitats of the Tekeze Reservoir

Parameters	Sampling habitats		
	Littoral	**Pelagic**	**River mouth**
Number of species (S)	13	9	10
Number of individuals (N)	672	484	954
Simpson's dominance index (D)	0.2085	0.2371	0.2111
Simpson's diversity index (B)	0.7915	0.7629	0.7889
Shannon-Weaver index (H')	1.726	1.555	1.663
Margalef's richness index (R)	1.843	1.294	1.312
Pielou's evenness (J')	0.6728	0.7078	0.7224

The diversity indices of fishes in different sampling seasons are also given in table 10. The value of B was high in the wet season (0.7978), but low in the dry-hot season (0.7661). Similarly, the lowest value of H´ was recorded in the dry-hot season (1.592), but the high value was recorded in the wet season (1.715). The value of R ranged from 1.285 to 1.596 in the dry-cold and wet seasons, respectively. The overall value of the diversity indices in the reservoir was 0.7901 (B), 1.688 (H´), 1.826 (R) and 0.6232 (J). The overall value of the diversity indices in the reservoir was 0.7901 (d), 1.688 (H´), 1.826 (R) and 0.6232 (J).

Table 10. Fish diversity indices in different sampling seasons of the Tekeze Reservoir

Parameters	Sampling seasons			Overall values
	Dry-cold	**Dry-hot**	**Wet**	
Number of species (S)	9	10	12	15
Number of individuals (N)	506	621	983	2110
Simpson’s dominance index (D)	0.216	0.2339	0.2022	0.2099
Simpson’s diversity index (B)	0.784	0.7661	0.7978	0.7901
Shannon-Weaver index (H’)	1.639	1.592	1.715	1.688
Margalef’s richness index (R)	1.285	1.399	1.596	1.829
Pielou’s evenness index (J’)	0.746	0.6916	0.69	0.6232

2.3.4. The relative abundance of fishes

The catch composition and index of relative importance are described in table 11. Five fish species; such as *O. niloticus*, *L. intermedius*, *L. forskalii*, *B. docmak* and *L. niloticus* were dominant in number, weight, frequency and index of the relative importance of the total catch. In the case of numerical percentage (%No), *O. niloticus* (26.9%) was the most dominant in the catch and followed by *L. forskalii* (24.8%), *L. intermedius* (21.5%), *B. docmak* (14%) and *L. niloticus* (10.1%). However, *B. docmak* (28.1%) dominated the catch by weight (%W) followed by *O. niloticus* (27.1%, *L. intermedius* (14%), *L. niloticus* (13%) and *L. forskalii* (11.7%). *Oreochromis niloticus* (91.7%), *L. intermedius* (80.6%), *B. docmak* (75%), *L. niloticus* (63.9%) and *L. forskalii* (38.9%) were the most frequently occurring fish species in the total setting. According to the index of relative importance (%IRI), *O. niloticus* (35.5%) was the most dominant species, followed by *B. docmak* (22.6%), *L. intermedius* (20.5%), *L. niloticus* (10.6%) and *L. forskalii* (10.2%) in the descending order of their importance.

Table 11. Catch composition and index of relative importance (IRI) of fish species in Tekeze Reservoir

Spp.	No	%No	W (kg)	%W	FRQ	%FRQ	IRI	%IRI
O. niloticus	567	26.9	132.103	27.1	33	91.7	4945	35.5
B. docmak	295	14.0	137.115	28.1	27	75.0	3156	22.6
L. intermedius	454	21.5	68.516	14.0	29	80.6	2865	20.5
L. niloticus	214	10.1	63.626	13.0	23	63.9	1481	10.6
L. forskalii	523	24.8	57.218	11.7	14	38.9	1420	10.2
C. gariepinus	7	0.3	19.077	3.9	3	8.3	35	0.3
L. nedgia	12	0.6	0.953	0.2	7	19.4	15	0.1
R. senegalensis	13	0.6	0.259	0.1	4	11.1	7	0.1
L. crassibarbis	7	0.3	0.945	0.2	5	13.9	7	0.1
H. longifilis	2	0.1	5.206	1.1	2	5.6	6	0.0
G. dembeensis	10	0.5	0.046	0.0	4	11.1	5	0.0
B. bajad	1	0.0	2.145	0.4	1	2.8	1	0.0
L. bynni	2	0.1	0.392	0.1	2	5.6	1	0.0
L. cylindricus	2	0.1	0.077	0.0	1	2.8	0	0.0
L. beso	1	0.0	0.204	0.0	1	2.8	0	0.0
Total	**2110**	**100.0**	**487.882**	**100.0**	**-**	**-**	**13947**	**100.0**

Note*: Spp. – species, No. – catch number, %No – numerical percentage, W – catch weight, %W – the percentage of catch-weight, FRQ - frequency of occurrence, %FRQ – the percentage of frequency of occurrence, IRI – index of relative importance and %IRI – the percentage of the index of relative importance.*

2.3.5. Spatial and temporal distribution of fishes

There were significant spatial differences in the numbers and weight of the fishes among the habitats of the Tekeze Reservoir. The river mouth habitats (Kanizu and Tsilare) had significantly higher catch numbers of fish (45.21%) and fish weights (45.31%), followed by the offshore habitats (Seletsa and Gfrtsatsa), but the pelagic (Ariqua and Lmlmo) area had relatively the lowest catch. Numerically, *O. niloticus, L. intermedius* and *L. forskalii* have dominated the catch of the littoral, pelagic and the river mouth habitats, respectively. However, *B. docmak* dominated the catch by weight of the pelagic and river mouth habitats (Table 12).

Table 12. Catch distribution of the fish species in the littoral, pelagic and river mouth habitats of Tekeze Reservoir

	Littoral		**Pelagic**		**River mouth**	
Species	**%No**	**%W**	**%No**	**% W**	**%No**	**%W**
Oreochromis niloticus	26.5	27.5	27.5	28.0	26.8	26.3
Bagrus docmak	12.5	17.6	13.8	33.8	15.1	31.1
Labeobarbus intermedius	24.7	17.1	30.6	18.2	14.7	9.7
Labeo niloticus	9.1	15.5	5.2	4.4	13.4	16.7
Labeo forskalii	23.1	9.2	21.5	8.9	27.7	15.0
Clarias gariepinus	0.7	10.6	0.4	3.6	-	-
Labeobarbus nedgia	0.7	0.2	0.4	0.3	0.5	0.1
Raiamas senegalensis	0.4	0.1	-	-	1.0	0.1
Labeobarbus crassibarbis	0.7	0.5	-	-	0.2	0.1
Hetrobranchus longifilis	0.1	1.5	0.2	2.4	-	-
Garra dembeensis	0.9	0.0	-	-	0.4	0.0
Bagrus bajad	-	-	-	-	0.1	1.0
Labeobarbus bynni	-	-	0.4	0.3	-	-
Labeo cylindricus	0.3	0.1	-	-	-	-
Labeobarbus beso	0.1	0.2	-	-	-	-
Total	**31.85**	**27.57**	**22.94**	**27.1**	**45.21**	**45.31**

Note: *No – catch number, %No – numerical percentage, W – catch weight, %W – the percentage of catch weight and x - absent.*

The total percentage distribution of fish caught by the number and weight in each sampling habitat during the research period is given in figure 4. The highest percentages of the catch were observed at the river mouth habitats. However, the lowest catch was recorded at the pelagic habitats of the reservoir. The result shows spatial differences in the catch among the habitats of the reservoir. As indicated in figure 4, the river mouth contributed 4s.21% (catch by number) and 45.32% (catch by weight) followed by the littoral area that contributed 31.85% (catch by number) and 27.59% (catch by weight). However, the pelagic habitats had low catch composition. This might be due to the high fishing pressure in the areas (personal observation).

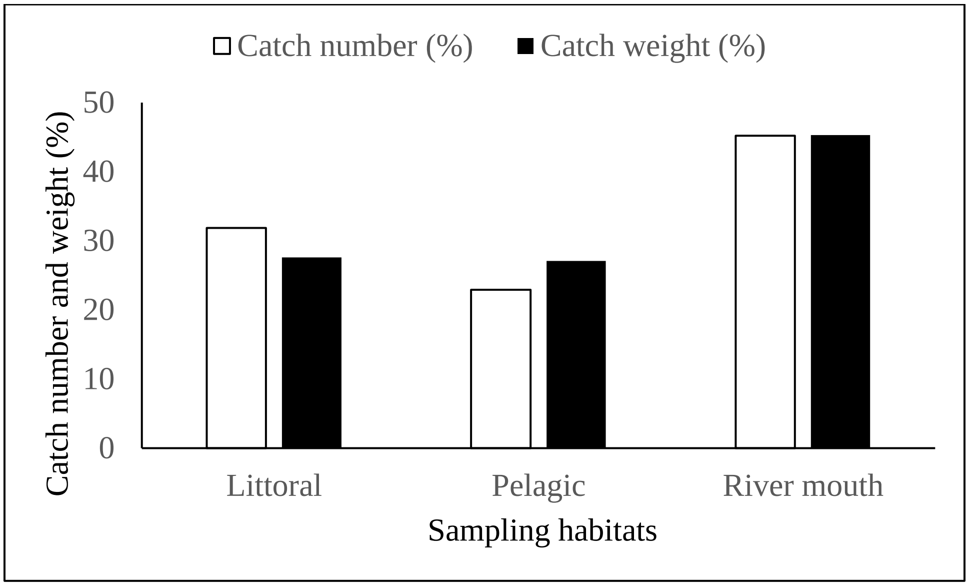

Figure 4. Percentage of catch by number and weight of fish species in each sampling site of Tekeze Reservoir

The study shows that *L. forskalii*, *L. intermedius*, *L. nedgia*, *B. docmak* and O. *niloticus* were collected from all habitats of the reservoir. Conversely, *L. cylindricus* and *L. beso* in the littoral as well as *L. bynni* and *B. bajad* were found only pelagic and river mouth habitats, respectively (Table 13).

Table 13. Fish species composition identified from different sampling habitats of Tekeze Reservoir (present (√) and absent (x))

Species	Sampling habitats		
	Littoral	**Pelagic**	**River mouth**
Labeo niloticus	√	√	√
Labeo forskalii	√	√	√
Labeo cylindricus	√	x	x
Labeobarbus beso	√	x	x
Labeobarbus intermedius	√	√	√
Labeobarbus bynni	X	√	x
Labeobarbus nedgia	√	√	√
Labeobarbus crassibarbis	√	x	√
Raiamas senegalensis	√	x	√
Garra dembeensis	√	x	√
Bagrus bajad	x	x	√
Bagrus docmak	√	√	√
Clarias gariepinus	√	√	x
Hetrobranchus longifilis	√	√	x
Oreochromis niloticus	√	√	√

Of the total specimens, 983 (46.59%) were caught during the wet, 621 (29.43%) in the dry-hot and 506 (23.98%) in the dry-cold seasons. Similar to catch number, a high proportion of catch by weight (51.72%) was recorded in the wet season. The remaining 26.56% and 21.72% were caught in the dry-hot and dry-cold seasons, respectively. The result showed significant temporal variation in number and weight between seasons. *Oreochromis niloticus*, *L. forskalii*, *L. intermedius*, *B. docmak* and *L. niloticus* were the dominant fish species in all seasons. *Oreochromis niloticus* was the most abundant species in number in the dry-cold and wet seasons, but *L. forskalii* dominated the dry-hot season of the sampling period (Table 14). *Oreochromis niloticus*, *L. intermedius*, *B.*

docmak, *L. niloticus*, *L. forskalii*, *R. senegalensis* and *L. crassibarbis* were caught in all seasons during the study period. *Labeobarbus nedgia* and *G. dembeensis* were obtained in both the dry-hot and wet seasons. *Clarias gariepinus*, *H. longifilis* and *B. bajad* were collected in the wet, *L. cylindricus* in the dry-hot, *L. beso* and *L. bynni* in the dry-cold seasons.

Table 14. Catch distributions of the species in different sampling seasons of the study period in Tekeze Reservoir

Species	**Sampling seasons**					
	Dry-cold		**Dry-hot**		**Wet**	
	%No	**%W**	**%No**	**%W**	**%No**	**%W**
Oreochromis niloticus	25.89	28.4	24.64	28.3	28.79	25.9
Labeobarbus intermedius	25.3	15.4	23.99	16.7	18.02	12.1
Bagrus docmak	12.25	28.6	12.08	25.1	16.07	29.4
Labeo niloticus	9.29	14.4	5.8	7.2	13.33	15.5
Labeo forskalii	24.7	12.5	31.24	22.1	20.75	6.1
Clarias gariepinus	-	-	-	-	0.71	7.6
Labeobarbus nedgia	-	-	0.65	0.2	0.81	0.3
Raiamas senegalensis	1.78	0.1	0.48	0.1	0.1	0.0
Garra dembeensis	-	-	0.48	0.0	0.71	0.0
Labeobarbus crassibarbis	0.2	0.1	0.32	0.2	0.41	0.2
Hetrobranchus longifilis	-	-	-	-	0.2	2.1
Bagrus bajad	-	-	-	-	0.1	0.9
Labeobarbus bynni	0.4	0.4	-	-	-	-
Labeo cylindricus	-	-	0.32	0.1	-	-
Labeobarbus beso	0.2	0.2	-	-	-	-
Total	**23.98**	**21.72**	**29.43**	**26.56**	**46.59**	**51.72**

***Note**: No – catch number, %No – numerical percentage, W – catch weight and %W – percentage of catch weight*

2.3.6. Distribution of the species in relation to environmental variables

The RDA ordination of the species-environment association indicated that chlorophyll, dissolved oxygen, total dissolved solids, electrical conductivity, Water transparency, temperature and pH were positively correlated with the first axis, which contributed 98.9% of the variance. However, the first five environmental variables were strongly correlated with the axis. On the other hand, turbidity was negatively strongly correlated with the second axis. The abundances of *O. niloticus*, *B. docmak*, *L. niloticus and L. forskalii* were positively-strongly related to chlorophyll, TDS, electronic conductivity and dissolved oxygen. *However, L. intermedius* were negatively associated with axis 1 and mainly distributed at the littoral area of the reservoir (Fig. 5; Table 15).

The second axis was strongly correlated with environmental variables such as temperature, water transparency, pH and turbidity. However, Temperature and water transparency showed a strong positive correlation, but turbidity and pH were negatively correlated with this axis. Chlorophyll, electronic conductivity, total dissolved solids and dissolved oxygen were negatively associated with the relatively high abundance of *B. docmak*, *O. niloticus*, *L. forskalii and L. niloticus*. Both axes explained 100% of the cumulative percentage variance of the species-environment relation (Table 15).

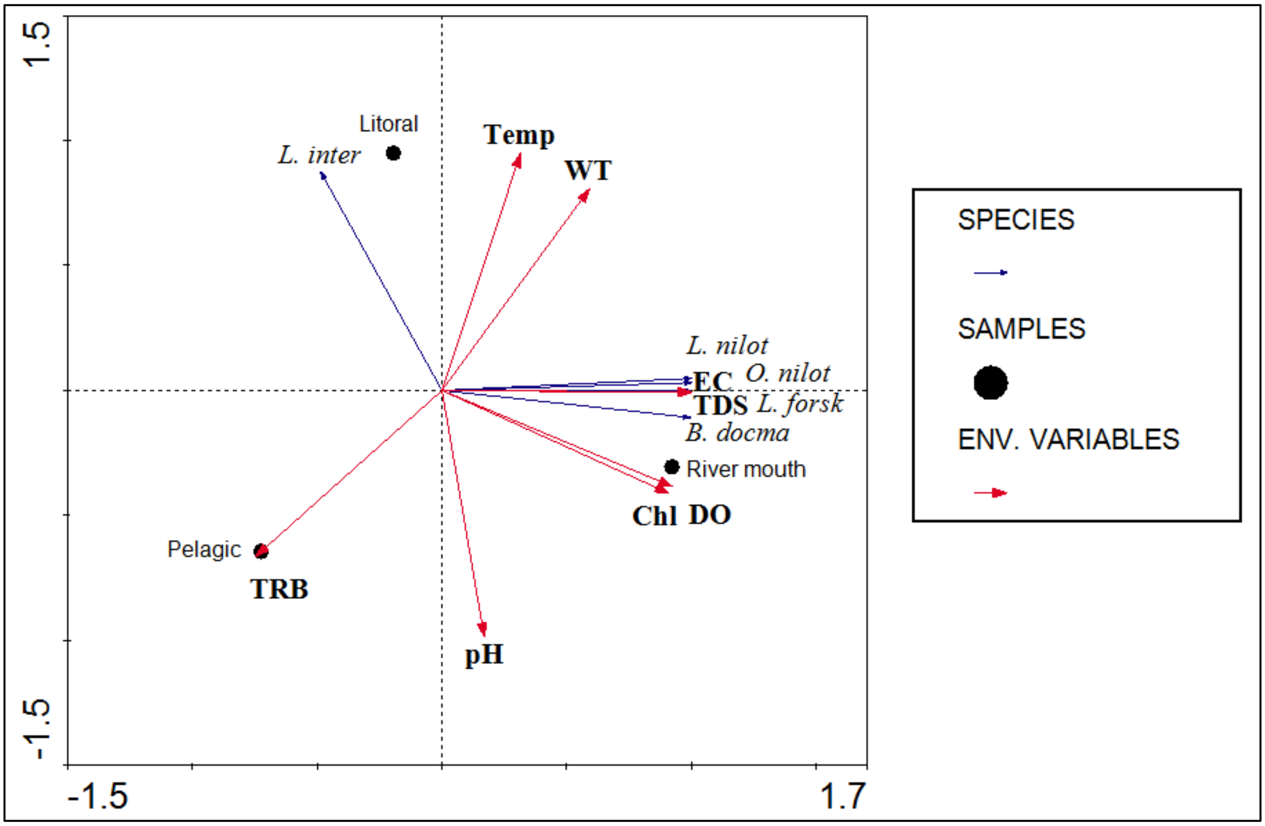

Figure 5. Tri-plots of the first two axes of the redundancy analysis showing the association of samples, fish species and environmental variables in Tekeze Reservoir

Note: *Chl. - chlorophyll, TRB – turbidity, DO - dissolved Oxygen, T. - Temperature, TDS - total dissolve solids, EC – electronic conductivity, WT - water transparency (Secchi disk), L. inter – Labeobarbus intermedius, L. nilot – Labeo niloticus, O. nilot – Oreochromis niloticus, B. docma – Bagrus docmak and L. forsk – Labeo forskalii.*

Table 15. Canonical coefficients of the first two axes showing the correlation of species abundance and environmental variables in Tekeze Reservoir

Variables	Canonical coefficients	
	Axis1	**Axis2**
Eigenvalues	0.989	0.011
Cumulative percentage variance of species-environment relation	98.9	100
Chlorophyll	0.9234	-0.3839
Turbidity	-0.7475	-0.6643
Dissolved oxygen	0.9108	-0.4127
Temperature	0.3152	0.949
pH	0.1694	-0.9855
Total dissolved solids	1	-0.0075
Electric conductivity	1	-0.0066
Water transparency	0.5907	0.8069

2.4. Discussions

2.4.1. Environmental variables

The Physico-chemical parameters of the reservoir in all three sampling seasons were significantly different. Spatially, the values of the parameters varied between sampling sites, while statistically there was no significant difference. The highest and lowest values of chlorophyll, turbidity, total dissolved solids, electronic conductivity and water transparency were recorded during the dry-cold and dry-hot seasons, respectively. However, the lowest values of dissolved oxygen, temperature and pH were recorded during the dry-cold season.

Chlorophyll is a measure of the number of algae growing in a water body. It is used to classify the trophic condition of a water body. Too many algae can cause decreased levels of dissolved oxygen (Boyd and Lichtkoppler, 1979). The chlorophyll concentration in Tekeze Reservoir was found in the range of 32.2 to 61.58 mg/l. However, Dereje Tewabe *et al*. (2009) reported 80 µg/l average concentration of chlorophyll in the reservoir.

Turbidity is a measure of how particles suspended in water affect water clarity. It is an important indicator of suspended sediment and erosion levels. It increases sharply during and after rainfall, which causes sediment to be carried into the water body (Higham *et al.*, 2015). High turbidity also raises the water temperature, lower dissolved oxygen, prevent light from reaching aquatic plants, which reduces their ability to photosynthesize and harm fish gills and eggs (Matveev and Steven, 2014). The turbidity of the present investigation ranged from 4.32 to 10.64 NTUs, which is different from the range of 8 to 11 NTUs reported by Dereje Tewabe *et al*. (2009). The water transparency of the reservoir also recorded an average value of 205.56 cm, which may not harm the production, survival and growth of fishes.

Dissolved oxygen is one of the most important factors in any aquatic ecosystems (Rice *et al.*, 2012). It affects the growth, survival, distribution, behavior and physiology of aquatic organisms (Bhatnagar and Singh, 2010). The mean value of dissolved oxygen in the Tekeze Reservoir was 5.67 mg/l. Greater than 5 mg/l of dissolved oxygen is essential and desirable to support good fish production (Bhatnagar and Singh, 2010; Bhatnagar and Devi, 2013). The minimum dissolved oxygen concentration for fish production should be 3 mg/l. Values below this threshold are very critical and immediate management options should be taken (Rice *et al.*, 2012). The dissolved oxygen value of the Tekeze Reservoir was in optimum condition.

Freshwater pH is considered as an indicator of overall productivity that causes habitat diversity. A desired and safe pH for freshwater fish species is a range from 6.5 to 8.5 (Roberts, 1975). The pH level of the surface water of the Tekeze Reservoir did not deviate from the desired range for the reproductive performance and condition of the freshwater fishes throughout the sampling period.

Therefore, the pH of the surface water of the reservoir is suitable and reasonably good for the fish population.

Warm water fishes grow best at a temperature between 25 and 32°C (Bhatnagar and Devi, 2013). The temperature of the Tekeze Reservoir was not different from this range. Water temperature was almost uniform in the six sampling sites, but fluctuated between dry-cold and wet sampling seasons of the reservoir. The uniformity of temperature in the reservoir reflects the prevailing weather conditions and favors the performance of its function as a regulator of the physiological and ecological parameters of the fish (Boyd and Lichtkoppler, 1979). It enhances both the production of food for fish as well as influences the spawning time (Mills and Mann, 1985).

Water is a universal solvent and has a large amount of salts dissolved in it, which largely governs the Physico-chemical properties (Singh *et al.*, 2005). The value of total dissolved solids and electronic conductivity was significantly high during the dry-cold season. This degree of variation may be related to the color of the water due to stratification. During this season, the water of the reservoir was dark-brown in color and smells like a rotten egg. Although further investigation is required, the rotten egg smell is likely to be a result of the activity of sulfate-reducing microorganisms that can oxidize inorganic sulfur compounds such as sulfite (SO_3^{-2}), dithionite ($S_2O_4^{-2}$), thiosulfate ($S_2O_3^{-2}$), trithionate ($S_3O_6^{-2}$) tetrathionate ($S_4O_6^{-2}$), elemental sulfur (S_8) and polysulfide (S_n^{-2}).

Conductivity was also related to the concentration of total dissolved solids and major ions. However, the values obtained were not dangerous for the fish species of the reservoir. The pattern of variation in conductivity for the six sampling sites represented for three habitats showed some uniformity throughout the study period.

Dereje Tewabe *et al*. (2009) have also reported similar findings in the same water body. They reported that most water quality parameters at the time of their survey in the reservoir area were in the optimum condition for fish production except for the very much-elevated values of sulfate and chloride, which is associated with the dam construction work (Dereje Tewabe *et al.*, 2009).

The optimum fish production is very dependent on the physical, chemical and biological qualities of water. Fish do not like changes in their environment beyond their limit. Any change can cause stress to the fish. The larger the changes the greater the stress could be on fishes (Bhatnagar and Devi, 2013). Although the values were different between seasons and sampling sites, the mean values of all the parameters were not much deviated from the desired ranges. Therefore, all of the values in the reservoir were found in the optimum condition for fish production.

2.4.2. Composition and diversity of fishes

The family Cyprinidae dominated the catch composition of the species and contributed more than 66% (10 species) of the total (15 species) species. Tsegay Teame *et al*. (2016b) have also reported a similar number of families and orders, but listed 11 fish species from the reservoir. The authors also confirmed that family Cyprinidae was the highest contributor to the composition of the fish diversity.

The fish species that were recorded in the present study, but not in the list of Tsegay Teame *et al*. (2016b) were *L. niloticus*, *L. cylindricus*, *L. bynni* and *L. crassibarbis.* Relatively, a wider range of habitats and seasons were sampled for two consecutive years during this study. Therefore, this might be the reason for more species to be caught in the present study that was not reported in previous study. However, a previous fish survey by Dereje Tewabe *et al.* (2009) reported 18 fish species, five orders, seven families and thirteen genera to be found in the Tekeze Reservoir.

The family Malapteruridae, Mormyridae and Characidae, represented by the fish species of *Malapterurus electricus*, *Mormyrus kannume* and *Hydrocynus forskahlii*, respectively and reported by Dereje Tewabe *et al*. (2009) were not collected during this study. Conversely, *L. cylindricus* was a new record for the present study, which was not reported by the previous authors. Fishing pressure and other anthropogenic activities have negatively affected the fishery activities (Solomon Tesfay and Mekonen Teferi, 2017; Ayalew Assefa *et al.*, 2018). Therefore, this might be the cause for the decline of fish species and abundance in the reservoir.

During the survey of Dereje Tewabe *et al*., (2009), the reservoir was new and full-time fishing activity has not yet started. Therefore, the fish species that entered into the reservoir through the tributaries may have contributed to the higher diversity of the species at the time. Currently, legal and illegal fishing activities are high in the reservoir (Tsegay Teame *et al.*, 2016b; Ayalew Assefa *et al.*, 2018). These activities could have caused a decline in the number and type of species. As in many parts of the world, population growth, agricultural development and industrialization contribute to the loss of species diversity of freshwater fishes in Ethiopia (Abebe Getahun and Stiassny, 1998; Gashaw Tesfaye and Wolff, 2014). The diversity of the fishes mainly depends upon the biotic and abiotic factors and type of the ecosystem, age of the water body, mean depth, water level fluctuations, morphometric features and bottom types (Thirumala *et al.*, 2011).

Based on the result of diversity indices, the fish species diversity in the Tekeze Reservoir was low. The reservoir has an outlet, so low diversity is common in reservoirs that have such kinds of outflow (Wandera and Balirwa, 2010). Flushing out accumulated nutrients in water bodies could result in low nutrients (Burlakoti and Karmacharya, 2004). Besides, all parts and sampling sites of the reservoir are rocky with no vegetation and almost uniform morphometric features (personal observation). The difference in fish diversity between the sampling sites was due to the depth and anthropogenic activity (fishing pressure) in the reservoir. Therefore, the absence of more significant heterogeneity among the sampling habitats can induce a low diversity of fishes. Homogeneity of habitats favors a lower diversity of fishes (Wandera and Balirwa, 2010). According to the review of Golubstov and Mina (2003), Tekeze- Atbara system has lower fish species diversity compared to the Nile River Basin within the limits of Ethiopia. This could be because of the remarkable seasonal variation of water discharge in the system (Golubtsov and Mina, 2003). Therefore, the seasonal tributaries of the Tekeze Reservoir may have contributed to the low species diversity of the reservoir.

2.4.3. Relative importance and distribution

Only five fish species such as *O. niloticus*, *B. docmak*, *L. intermedius*, *L. niloticus* and *L. forskalii* comprised 99.4% IRI of the reservoir's fish composition. The remaining fish species contributed below 1% IRI of the total catch composition of the fishes. Although the highest contributions of *O. niloticus* and *L. intermedius* were previously reported, *B. docmak* and *L. forskalii* were listed under the least dominant of the catch composition in the reservoir (Dereje Tewabe *et al.*, 2009; Tsegay Teame *et al.*, 2016b). *Labeobarbus nedgia* which was the lowest in the present study is the third dominant species in the reservoir (Tsegay Teame *et al.*, 2016b). Besides, it was reported that *G. dembeensis* was one of the dominant fish species in the reservoir (Dereje Tewabe *et al.*, 2009). Environmental variables play a key role in the abundance and composition of aquatic flora and fauna in freshwater ecosystems (Matveev and Steven, 2014; Manish *et al.*, 2018).

Spatial distributions of the fish species varied considerably according to habitat in the reservoir. In the present study, the river mouth habitats such as Kanizu and Tsilare sampling sites contributed to most of the total fish catch. The inshore (Gfrtsatsa and Seletsa) sampling habitats ranked second and the offshore (Lmlmo and Ariqua) habitats third. This variation might be due to the difference in the preference of the species for spawning grounds. During the spawning period, different fish species move towards the river mouth and littoral area of the reservoir. Other authors had similar findings that various fish communities exhibit some patterns in migration and hence show defined variation in the space they occupy over time and space (Gehrke *et al.*, 1995; Jackson and Harvey, 1997).

Seasonal variations in the relative abundance of fish species were observed in this study. Higher numbers of fish specimens were caught during the wet season as compared to the other sampling seasons. This could be related to the breeding time of the species that have a high chance of vulnerability to fishing gears (Assefa Tessema *et al.*, 2011). Variation in available nutrients, water level, turbidity, fish behavior, size and life stages of fishes might also contribute to variations in the catches (Kolding *et al.*, 2003).

The present investigation revealed that the environmental variables play a key role in the distribution of fishes in the reservoir. Habitat alteration brought about a threat to freshwater fish fauna (Manish *et al.*, 2018). Among the Physico-chemical attributes, chlorophyll a, total dissolved solids, dissolved oxygen, electrical conductivity, temperature and water transparency were strongly correlated with fish assemblages and influenced the fish distribution. Similarly, Manish *et al*. (2018) reported a similar finding in Haro Reservoir (India).

2.5. Conclusions

Based on the results obtained in this study, the following conclusions could be drawn on the Physico-chemical variables, Ichthyofaunal diversity, abundance and contribution of the environmental variables to the distribution of fish species in Tekeze Reservoir: The Physico-chemical parameters of the reservoir are found in the optimum condition for survival, growth and production of freshwater fishes. Only five species (*O. niloticus*, *L. forskalii*, *L. intermedius*, *B. docmak* and *L. niloticus)* have dominated the catch composition of the reservoir. The highest catch composition of the fishes is recorded in the river mouth habitats of the reservoir and wet season of the sampling period. The environmental variables play a key role in the distribution of fishes in the reservoir.

2.6. Recommendations

A more detailed assessment of water quality including nitrate, phosphate, silicate, CO_2, biological and chemical oxygen demand, etc. and their potential impacts on the aquatic resources should be investigated. Further investigation on diversity and abundance of fish species using electrofishing or other methods in the reservoir and in the down streams of the reservoir is required. A detailed study on the composition, relative abundance and distribution of planktons, and micro and macroinvertebrates is needed.

CHAPTER THREE

3. LENGTH-WEIGHT RELATIONSHIP AND REPRODUCTIVE BIOLOGY OF THE MAJOR COMMERCIAL FISH SPECIES IN TEKEZE RESERVOIR

Abstract

Length-weight relationship, condition factor and reproductive biology of O. niloticus, L. intermedius and B. docmak in Tekeze Reservoir were studied from samples taken between January 2016 and December 2017. The objective of this study was to contribute to the management of the reservoir fishery by generating baseline information about the body condition and reproductive biology of the major commercial fish species. Length-weight relationship of O. niloticus, L. intermedius and B. docmak were best expressed by the equations $TW = 0.014TL^{3.054}$ *(*$r^2 = 0.9743$*,* $P = 0.0001$*),* $TW = 0.0196SL^{2.9493}$ *(*$r^2 = 0.9609$*,* $P < 0.0001$*) and* $TW = 0.0098SL^{3.0819}$ *(*$r^2 = 0.9678$*,* $P < 0.0001$*), respectively. The overall mean condition factor was found to be 1.44±0.01 for O. niloticus, 1.88±0.02 for L. intermedius and 0.94±0.01 for B. docmak. The overall sex ratio (female: male) of O. niloticus and B. docmak was significantly different (*$P < 0.001$*) from the hypothetical distribution of 1:1. However, the sex ratio of L. intermedius did not significantly deviate (*$P > 0.05$*) from 1:1. Size (TL) at first maturity of O. niloticus was 24.2 cm for females and 24.87 cm for males. The size at maturity for L. intermedius and B. docmak (SL) were 20.84 and 27.42 cm for females and 22.05 and 26.79 cm for males, respectively. The mean absolute fecundity of the species was 1,513, 4,788 and 9,2321 eggs for O. niloticus, L. intermedius and B. docmak, respectively. There was strongly positively correlated with the body length, weight and gonad weight of the species. The studied species had extended spawning period, from July to October (wet season) with peak spawning in August for O. niloticus and B. docmak, in September for L. intermedius. The main rhythm in breeding activity occurred during the main rainy season. Labeobarbus intermedius preferred riverine habitats while O. niloticus and B. docmak prefer the littoral habitat for breeding. Generally, the fish species breed intensively during the main rainy season. Therefore, managing the fishing practice during the peak spawning time and spawning areas will be important to create sustainability in the reservoir fisheries.*

Keywords /phrases: *Body condition, Spawning, Sex ratio and Size at first maturity*

3.1. Introduction

Utilization of aquatic resources sustainably, especially the fishery resources as a cheap source of animal protein, is mandatory to alleviate the severe suffering of people due to recurring drought and increasing human population in Ethiopia (Tesfaye Wudneh, 1998). Although Ethiopia is a land-locked country, there are several lakes, rivers and reservoirs with important fish resources. Tekeze Reservoir is one of the newly constructed dams for hydropower generation. It has about 15 fish species. Of these, *Oreochromis niloticus*, *Labeobarbus intermedius*, *Bagrus docmak, Labeo niloticus and Labeo forskalii* are dominating the stock. However, the first three are commercially important fish species in the reservoir (chapter two of this study).

Nile tilapia (*Oreochromis niloticus)* is the most important fish species in tropical and subtropical freshwater bodies (Mohammed and Zenebe Bashaw, 2013). Its high tolerance to environmental conditions and the ability to accept formulated and natural feeds makes it economically viable (Adeyemi *et al.*, 2009). It is also one of the most commercially important fish species in Ethiopia (Assefa Mitike, 2014) and contributes about 50% of total landings of fish caught per year (Gashaw Tesfaye and Wolff, 2014). *Oreochromis niloticus* is the most widely distributed fish species in Ethiopian water bodies (Golubtsov and Mina, 2003; Tadlo Awoke *et al.*, 2015).

The African big barb *Labeobarbus intermedius* (Ruppel, 1836) is widely distributed in most parts of Ethiopia. It is one of the commercially important fish species in Ethiopian fisheries (Mathewos Temesgen and Abebe Getahun, 2016). The annual yield of *L. intermedius* was about 365 tons per year from the inland water bodies of Ethiopia (Reyntjens and Tesfaye Wudneh, 1998). It is the third most commercially important fish next to *O. niloticus* and *Clarias gariepinus*. However, its production has declined due to overfishing by commercial gillnets (Shewit Gebremedhin *et al.*, 2012; Elias Dadebo *et al.*, 2013).

The bagrid catfishes are widely distributed in African and Asian freshwaters. About 100 species occur in African freshwaters (Lowe-McConnell, 1987) and widely distributed in the basins of the Gambia, the Nile system, Chad, Niger, Senegal, the Volta and most of the East African rift lakes (Golubtsov *et al.*, 1995). In Ethiopia, the catfish; *Bagrus docmak* (Forskål) occurs in lakes of Abaya and Chamo (Shibru Tedla, 1973), in the Segen River (Risch, 1986) and the Nile system (Golubtsov *et al.*, 1995). It is one of the commercially important fish species in Ethiopia. It is highly regarded by local people as food fish because it has few intramuscular bones (Hailu Anja *et al.*, 2009). *Bagrus docmak* is also the third dominant species next to *O. niloticus* and *L. interm*edius and one of the most preferred fish species in the Tekeze Reservoir.

*Oreochromis niloticus, L. interm*edius and *B. docmak* are the most commercially important fish species in Tekeze Reservoir. However, information on the biology of those fish stocks in the reservoir is scarce. Area-specific information on the length frequency distribution, length-weight relationship and condition factor is critical for appropriate management and utilization of the stock. The reproduction biology of the commercially important fish species also provides vital information required in designing fisheries management strategies. It answers important questions as to what size, when and where each species spawns. Determination of length at first maturity, breeding season and area of spawning allow to set the minimum allowable fish size in the catch and to protect the breeding stocks which become vulnerable as they aggregate at the spawning grounds (Ogutu-Ohwayo, 1990; Tesfaye Wudneh, 1998). Although many studies have been carried out on the biological aspects of *O. niloticus, L. interm*edius and *B. docmak* in various Ethiopian and other tropical water bodies, such information is not available for Tekeze Reservoir. Therefore, to fill in the gap and generate baseline data, this chapter focused on wellbeing, feeding habits and reproductive biology of the three important fish species in the reservoir.

3.1.1. General objective

The general objective of this chapter was to provide critical baseline biological information needed to guide the sustainable utilization of the fishery resources or the commercially important fish species in the Tekeze Reservoir.

3.1.2. Specific objectives:

The specific objectives were:

i. To determine the length-frequency distribution of the commercially important fish species in the Tekeze Reservoir.
ii. To assess the length-weight relationship and condition of *O. niloticus*, *L. intermedius* and *B. docmak*
iii. To determine the sex ratio and length at maturity of the three selected fish species.
iv. To estimate the absolute fecundity of the three selected fish species.
v. To assess the relationship between fecundity and body size of these species.
vi. To determine the breeding season and breeding area of *O. niloticus*, *L. intermedius* and *B. docmak*

3.2. Materials and methods

3.2.1. Length-weight relationship and condition factor

Samples of fish species were collected using fishing gears from six sampling sites of the reservoir. The length of the fishes was measured with a measuring board to the nearest 0.1 cm and body weight measured using a digital balance to the nearest 0.1 gram. The length-weight relationship of the commercially important fish species was estimated by using the power function formula and analyzed by the least square regression analysis for both sexes and the population as a whole (Bagenal and Tesch, 1978).

$$W = aL^b$$

Where, W= weight, b = exponent and L = length.

The relative robustness or degree of the well-being of a fish is expressed by the coefficient of the condition also known as condition factor or length-weight factor. Variations in a fish's coefficient of condition primarily reflect the state of sexual maturity and degree of nourishment. Condition values may also vary with fish age and in some species, with sex. Condition factor or the well-being of fishes in the reservoir was calculated using the equation below (Bagenal and Tesch, 1978; Kuriakose, 2017) and analyzed for the significance of differences between sampling seasons and sites by using Mann-Whitney U test.

$$K = \frac{W}{L^b} X100$$

Where, K= condition factor, W= total body weight, L= total length.

3.2.2. Sex ratio and length at maturity

The number of female and male of the commercial fish species caught in the reservoir was recorded for each sampling occasion. The sex ratio was estimated by using the following female to male formula recommended by Pena-Mendoza *et al*. (2005). Chi-square was used to test if the sex ratio varied from the expected (1:1) (Demeke Admassu, 1994; Peña-Mendoza *et al.*, 2005).

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

The average length maturity (L_{50}) has been defined as the length at which 50% of the individuals in a given length class reach maturity (Willoughby and Tweddle, 1978; Rickey, 1995). Thus, after classifying data by length class, the percentages of male and female of the dominant fish species with mature gonads were plotted against length to estimate L_{50} (Willoughby and Tweddle, 1978; Gunderson *et al.*, 1980). This gives gonadal stages by length and sex, as well as the percentage of mature individuals depending on the chosen stage for individuals considered mature. A length at maturity can be estimated by fitting a logistic model (Gunderson *et al.*, 1980).

$$P_m = \frac{1}{1+e^{(-aL+b)}}100$$

Where, P_m is percent mature at length (L) and a and b are fitted constants. The constants are estimated by an iterative numerical search of the minimum sum of square (Hilborn and Walters, 1992). Length at maturity was calculated (Rickey, 1995) from the estimated constant a and b:

$$L_{50\%} = \frac{a}{b}$$

3.2.3. Estimation of fecundity

For the estimation of fecundity, fresh gonads were removed from the fish within a few hours of capture and their sex and stage of reproductive maturity were determined. The ripe ovaries were split longitudinally and turned inside out to ensure the penetration of the preservative before they are stored in labeled vials (Bagenal and Tesch, 1978). Then, ripe ovaries were preserved in Gilson's fluid to estimate fecundity (Simpson, 1959). The fecundity of ripe gonads preserved in Gilson's fluid was estimated gravimetrically.

$$\text{Fecundity} = \frac{\text{Total weight of ovary}}{\text{Weight of subsample}} \text{ X number of matured eggs in the subsample}$$

Least squares regression was used to find the relationship between fecundity and the total length, total weight and gonad weight.

$$AF = aX^b$$

Where: AF = absolute fecundity, X = independent variables (body weight, total length and gonad weight). a = scaling constant representing the intercept, b = allometric coefficient; both of which were estimated by least squares regression analysis.

3.2.4. Determination of breeding season and area

The breeding season of the selected fish species was determined from the frequency of occurrence of ripe gonads and the gonado-somatic index. The gonado-somatic index (GSI) was calculated by using the formula below.

$$\text{GSI} = \frac{\text{Gonad weight (g)}}{\text{Body weight (g)}} \times 100.$$

Monthly observations of ripe ovaries from the catch of the commercial fishery was used to identify the breeding season of the fishes. On the other hand, the percentage of occurrence of ripe ovaries in each habitat was used to determine the breeding area of the studied fish species in the reservoir.

3.3. Results

3.3.1. Size frequency distribution

The length-frequency distribution of the commercially important fish species in the Tekeze Reservoir is presented in figure 6. During the study, 567 *O. niloticus* specimens were caught. Of these, 324 were females and 243 were males. The total length of the fish specimens ranged from 5 to 37 cm for females and from 7.5 to 38.5 cm for males. The corresponding total weight ranged between 3 and 799 g for females and 5 to 802 g for males. The greater proportion of the sampled *O. niloticus* ranged in size between 14 and 34 cm (Fig.6a). These length groups alone were about 74.23% of the total catch.

Throughout the study period, 454 *L. intermedius* were also collected and of those, 243 were females and 211 were males. *Labeo intermedius* had standard length ranging from 5.7 to 45.4 cm for females and from 6 to 39 cm for males, with corresponding total weight ranging from 4 to 1, 311 g for females and 3 to 852 g for males. The length group of 15 to 25 cm was dominated by the catch of both sexes (Fig. 6b) and estimated to about 86.34% of the total sample size of the species.

About 295 *B. docmak* samples were collected in different sampling seasons and different habitats of the reservoir. Of the total samples, 170 were females and 125 were males. The standard length of female *B. docmak* ranged from 16 to 83 cm and the total weight ranged from 51 to 8, 526 grams. The males were found in the range of 19 to 62 cm standard length and 83 to 4, 752 g total weight. As indicated in Figure 1c, the large proportion was found in the range of 21.5 to 35.5 cm, but the peak was found between 19 to 34 cm length intervals (Fig.6c). The dominated length class alone was estimated at 82.03% of the total sample size.

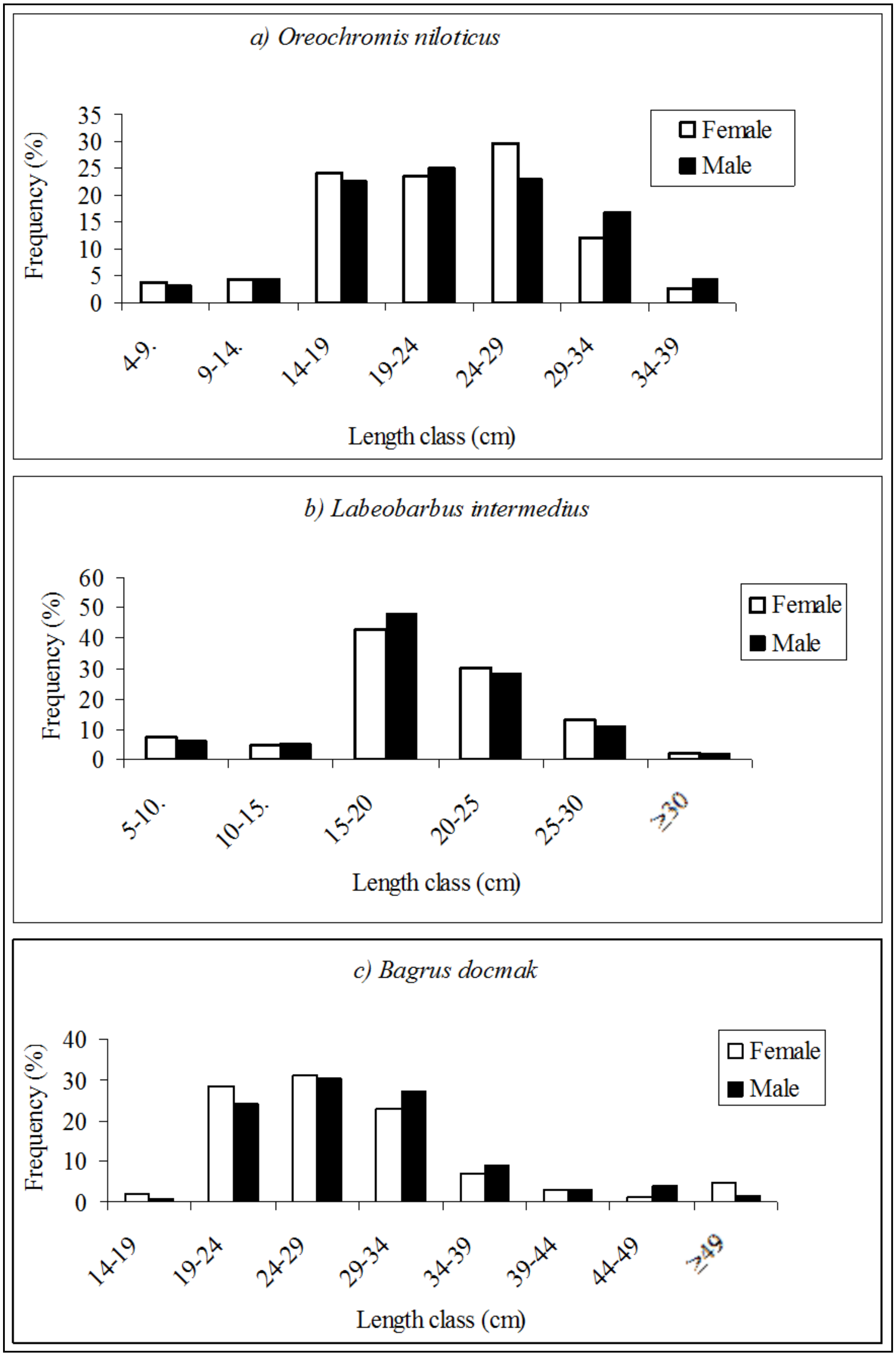

Figure 6. Length frequency distribution of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* from Tekeze Reservoir

3.3.2. Length-weight relationship

The length-weight relationship of *O. niloticus* in Tekeze Reservoir was curvilinear and showed statistically highly significant (P = 0.0001) difference from the expected isometric growth pattern (Fig. 7a). The regression equation for female *O. niloticus* was $TW = 0.0141TL^{3.0535}$ ($r^2 = 0.9784$, n = 324), while for males it was $TW = 0.013TL^{3.0546}$, ($r^2 = 0.9716$, n = 243) and for combined sexes it was $TW = 0.014TL^{3.054}$ ($r^2 = 0.9743$, N = 567). The regression coefficient value (b = 3.054) of *O. niloticus* showed positive allometric growth pattern (> 3).

The relationship between standard length and total weight for *L. intermedius* were also curvilinear and the line fitted to the data was described by the regression equation (Fig. 7b). The regression equation for female was expressed as $TW = 0.0197SL^{2.9473}$ ($r^2 = 0.9622$, n = 243) and for males it was $TW = 0.0194SL^{2.9518}$, ($r^2 = 0.9446$, n = 211) and for overall sexes it was $TW = 0.0196SL^{2.9493}$ ($r^2 = 0.9609$, N = 454). The regression coefficient value (b = 2.9493) of *L. intermedius* was close to the cubic value (b = 3), but statistically different from the expected isometric relationship ($P < 0.0001$) and describes negative allometric growth pattern of the fishes.

The graphical representation of the regression equation for the combined sexes of *B. docmak* was given in figure 2c. The "b" value for female and male *B. docmak* was 3.0562 and 3.133, respectively. The regression equations of female and male *B. docmak* were represented as $TW = 0.0107SL^{3.0562}$ ($r^2 = 0.9491$, n = 170) and $TW = 0.0083SL^{3.133}$ ($r^2 = 0.9351$, n = 125), respectively and the combined sexes was expressed by the regression equation of $TW = 0.0098SL^{3.0819}$ ($r^2 = 0.9678$, N = 295). The result showed significant variation from the isometric growth relationship ($P < 0.0001$) that there was a curvilinear relationship and exhibited positive allometric growth pattern for the fishes.

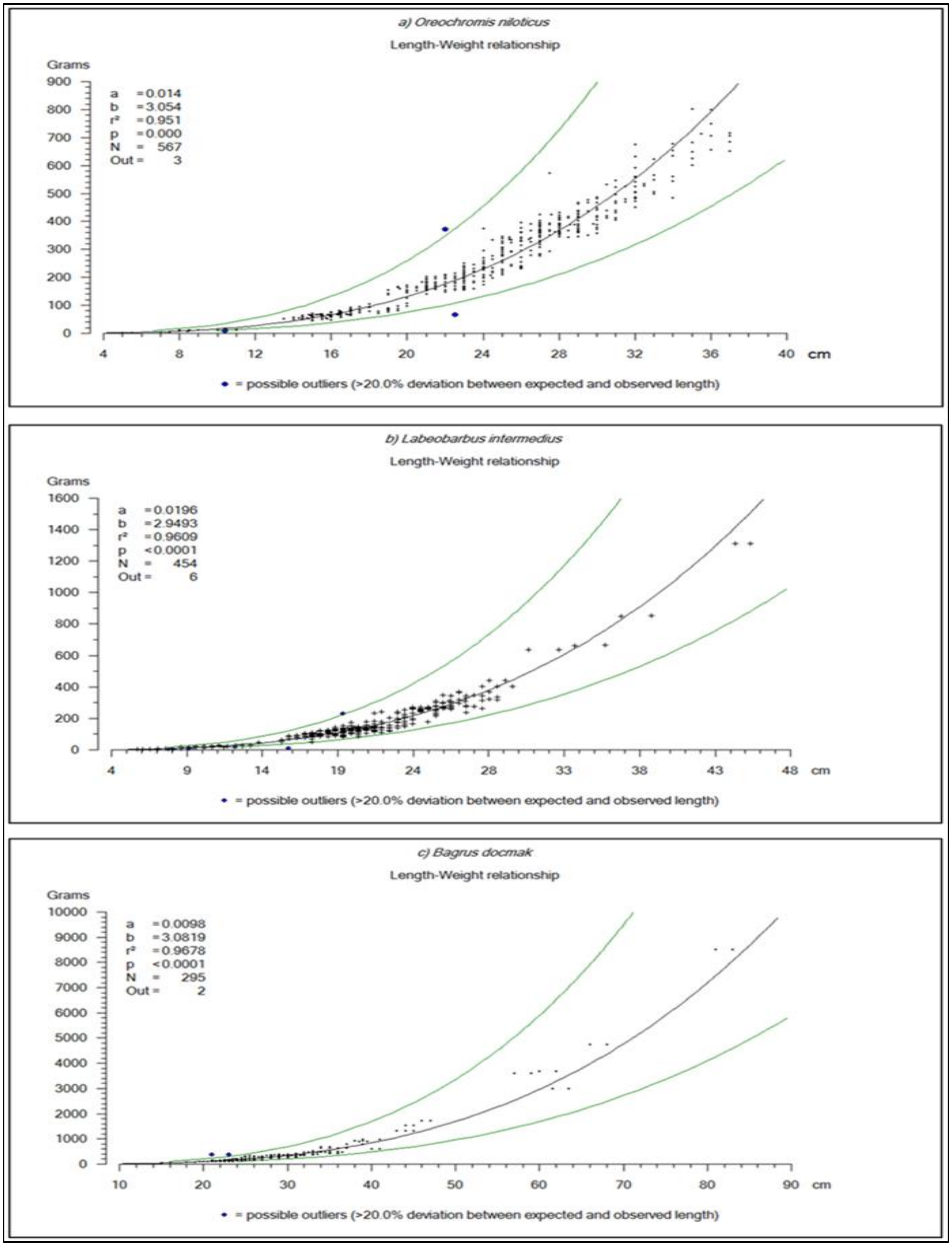

Figure 7. Length-weight relationship of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in Tekeze Reservoir

3.3.3. Condition factor

The condition factor value of female and male *O. niloticus* in the dry cold season of the study area was 1.37±0.03 and 1.41±0.03, respectively with a mean value of 1.39±0.02. During the dry hot season, the value was 1.38±0.02 for females and 1.41±0.04 for males and the average value was 1.40±0.02 for combined sexes. In the wet season, the value was 1.49±0.02 (females) and 1.46±0.02 (males) and the mean value for both sexes was 1.48±0.01. The total mean value of *O. niloticus* was 1.44±0.01 (females) and 1.43±0.02 (males) with a grand mean of 1.44±0.01. However, the results did not show variation among the sexes and seasons (Table 16a).

The condition value of *L. intermedius* was 1.87±0.04 for females and 1.41±0.03 for males with a mean of 1.84±0.03 in the dry cold season. During the dry hot season, the value was found to be 1.88±0.04 for females and 1.89±0.04 for males and the mean was 1.88±0.03. However, in the wet season, it was 1.89±0.02 for females and 1.91±0.03 for males with a mean of 1.90±0.03. The grand mean value of the condition factor of *L. intermedius* was 1.88±0.02 (Table 16b). The values were found to be not significantly different between sexes and sampling seasons of the study period.

Table 16c shows the seasonal variation in the mean condition factor of *B. docmak* in the Tekeze Reservoir. The results indicated that there was no significant difference between both sexes ($P > 0.05$). During the dry cold season, the value of female *B. docmak* was 0.87±0.04, but the male's value was 0.98±0.07 and the mean was 0.91±0.03. In the dry hot season, the condition factor of female *B. docmak* was 0.98±0.06, while the male's value was 0.87±0.02 and the mean in this season was 0.93±0.03. In the wet season, the female's condition factor was 0.96±0.02, the males were 0.97±0.02 and the mean value for both sexes was 0.96±0.01. Although the value varied in magnitude, there was no statistically significant difference between sexes and seasons.

Table 16. Seasonal variation of the condition factor of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in Tekeze Reservoir

a) ***Oreochromis niloticus***				
Season	**Female (mean±SE)**	**Male (mean±SE)**	**Mean (mean±SE)**	**Sig. (0.05)**
DCS	1.37±0.03	1.41±0.03	1.39±0.02	0.432
DHS	1.38±0.02	1.41±0.04	1.40±0.02	0.411
WS	1.49±0.02	1.46±0.02	1.48±0.01	0.173
Overall	**1.44±0.01**	**1.43±0.02**	**1.44±0.01**	**0.811**

b) ***Labeobarbus intermedius***				
Season	**Female (mean±SE)**	**Male (mean±SE)**	**Mean (mean±SE)**	**Sig. (0.05)**
DCS	1.87±0.04	1.80±0.05	1.84±0.03	0.302
DHS	1.88±0.04	1.89±0.04	1.88±0.03	0.885
WS	1.89±0.04	1.91±0.03	1.90±0.03	0.713
Overall	**1.88±0.02**	**1.88±0.02**	**1.88±0.02**	**0.865**

c) ***Bagrus docmak***				
Season	**Female (mean±SE)**	**Male (mean±SE)**	**Mean (mean± SE)**	**Sig. (0.05)**
DCS	0.87±0.02	0.98±0.07	0.91±0.03	0.066
DHS	0.98±0.06	0.87±0.02	0.93±0.03	0.097
WS	0.96±0.02	0.97±0.02	0.96±0.01	0.620
Overall	**0.94±0.02**	**0.94±0.02**	**0.94±0.01**	**0.909**

***Note**: DCS – dry cold season, DHS – dry hot season and WS – wet season*

3.3.4. Sex ratio

Sex ratio results of *O. niloticus* are presented in Tables 17(a) and 18(a). The ratio was not significantly different from1:1 in all sampling seasons, except in the wet season when there was the predominance of females ($\chi^2 = 10.689$, $P < 0.001$) over males (Table 17a). It was also similar to 1:1 for all length classes, but there was a significant difference between the length class of 14-19 ($\chi^2 = 3.977$, $P < 0.05$) and 24-29 ($\chi^2 = 10.526$, $P < 0.001$) cm (Table 18a). However, females have significantly outnumbered ($\chi^2 = 11.571$, $P < 0.001$) males in the total sample of *O. niloticus* (Table 17a).

The sex ratio results of *L. intermedius* were not significantly different ($\chi^2 = 2.256$, $P > 0.05$) from1:1 in all seasons and all length classes of the sample size (Tables 17b and 18b). Although females dominated in number, there have not been significant outnumbering in the total sample of *L. intermedius* (Table 17b). However, a slight difference was observed throughout the sampling time.

The sex ratio results of *B. docmak* are also presented in Tables 17c and 18c. The ratio was not significantly different from1:1 in all seasons, except in the dry cold season when there was the predominance of females ($\chi^2 = 6.252$, $P < 0.05$) over males (Table 17c). It was also similar to 1:1 for all length classes, except in the length class ranging from 19 to 24 (Table 18c). In this length group, females were significantly dominant ($\chi^2 = 4.154$, $P < 0.05$). From the total sample, females significantly outnumbered ($\chi^2 = 6.864$, $P < 0.001$) males in the total sample of *B. docmak* (Table 17c).

Table 17. The sex ratio of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in different sampling seasons of Tekeze Reservoir

a) *Oreochromis niloticus*				
Season	**Female**	**Male**	**Sex ratio**	**Chi-square (χ^2)**
DCS	73	58	1.26:1	1.718
DHS	82	71	1.15:1	0.791
WS	169	114	1.48:1	10.689**
Total	**323**	**244**	**1.32:1**	**11.571****
b) *Labeobarbus intermedius*				
Season	**Female**	**Male**	**Sex ratio**	**Chi-square (χ^2)**
DCS	74	54	1.37:1	3.125
DHS	81	68	1.19:1	1.134
WS	88	89	0.99:1	0.006
Total	**243**	**211**	**1.15:1**	**2.256**
c) *Bagrus docmak*				
Season	**Female**	**Male**	**Sex ratio**	**Chi-square (χ^2)**
DCS	41	21	1.95:1	6.452*
DHS	39	36	1.08:1	0.120
WS	90	68	1.32:1	3.063
Total	**170**	**125**	**1.36:1**	**6.864****

***Note**: ** means significant at 0.001 and * was significant at 0.05 level*

Table 18. The sex ratio of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in different length classes from Tekeze Reservoir

a) *Oreochromis niloticus*				
Size class (cm)	**Female**	**Male**	**Sex ratio**	**Chi-square (χ^2)**
4 – 9	12	8	1.5:1	0.800
9– 14	14	11	1.27:1	0.380
14 – 19	78	55	1.42:1	3.977*
19 – 24	76	61	1.25:1	1.642
24 – 29	96	56	1.71:1	10.526**
29 – 34	39	41	0.95:1	0.050
34 – 39	9	11	0.82:1	0.200

b) *Labeobarbus intermedius*				
Size class (cm)	**Female**	**Male**	**Sex ratio**	**Chi-square (χ^2)**
5 – 10	18	13	1.39:1	0.806
10 – 15	11	11	1:1	0.000
15 – 20	104	101	1.03:1	0.044
20 – 25	73	59	1.38:1	1.485
25 – 30	32	23	1.39:1	1.473
≥ 30	5	4	1.25:1	0.111

c) *Bagrus docmak*				
Size class (cm)	**Female**	**Male**	**Sex ratio**	**Chi-square (χ^2)**
14 – 19	3	1	3:1	1.000
19 – 24	48	30	1.6:1	4.154*
24 – 29	53	38	1.4:1	2.473
29 – 34	39	34	1.15:1	0.342
34 – 39	12	11	1.09:1	0.043
39 - 44	5	4	1.25:1	0.111
44 - 49	2	5	0.4:1	1.286
≥49	8	2	4:1	3.600

Note*: ** means significant at 0.001 and * was significant at 0.05 level*

3.3.5. Length at first maturity

During the sampling period, 260 (45.86%) sexually mature (stage III to V) *O. nilotic*us were collected. Of these, 159 (61.15%) were females and the remaining 101 (38.85) were males. The smallest sexually mature fishes caught were 16.4 cm and 19 cm total length for females and males, respectively. The average length (L_{50}) at which 50% of the *O. niloticus* reached sexual maturity was 24.2 cm for females and 24.89 cm for males (Fig. 8). Although the difference was not large, females show early maturity than males.

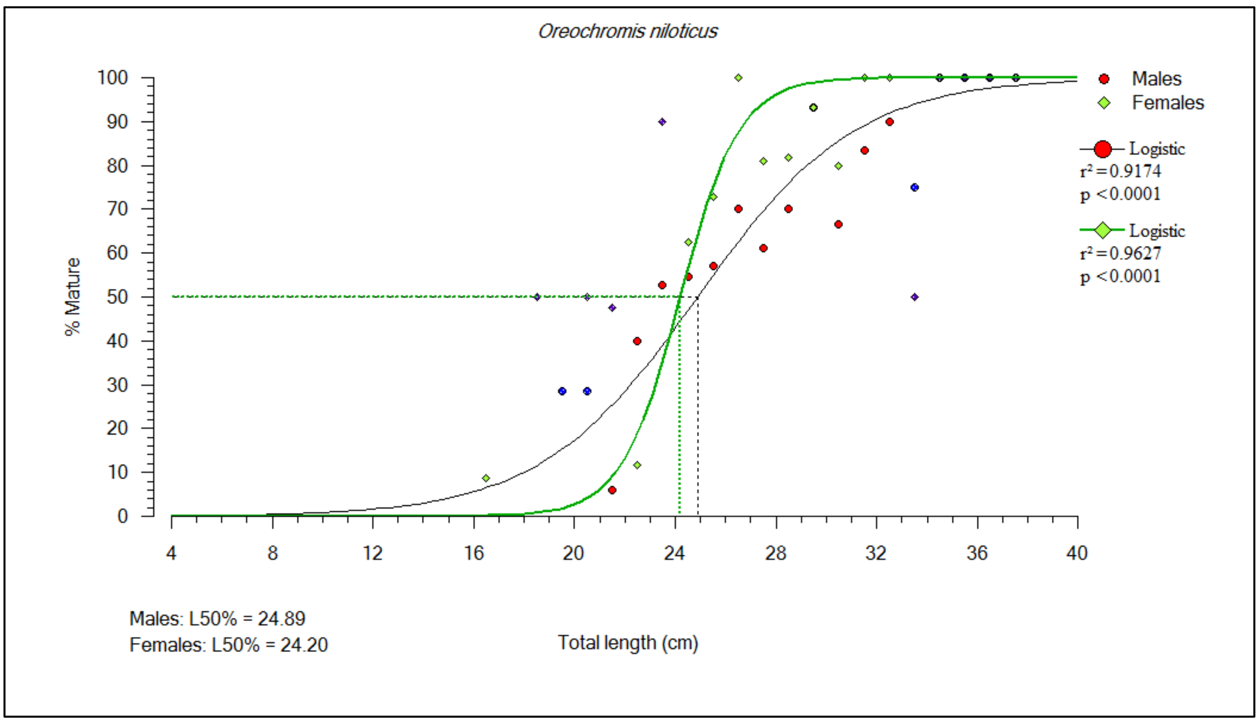

Figure 8. Size at first maturity of *Oreochromis niloticus* from Tekeze Reservoir

From the total sample size of *L. intermedius*, 189 (41.63%) were sexually mature by taking maturity stages of III to V. Of the mature individuals, 102 (53.97%) were females and the remaining 87 (46.03%) were males. The smallest sexually mature fish that was caught was 16.5 cm and 16 cm standard length for females and males, respectively. The average length (L_{50}) at which 50% of the female *L. intermedius* reached sexual maturity was 20.84 cm standard length while the length at which 50% of the males attained sexual maturity was 22.05 cm standard length (Fig. 9).

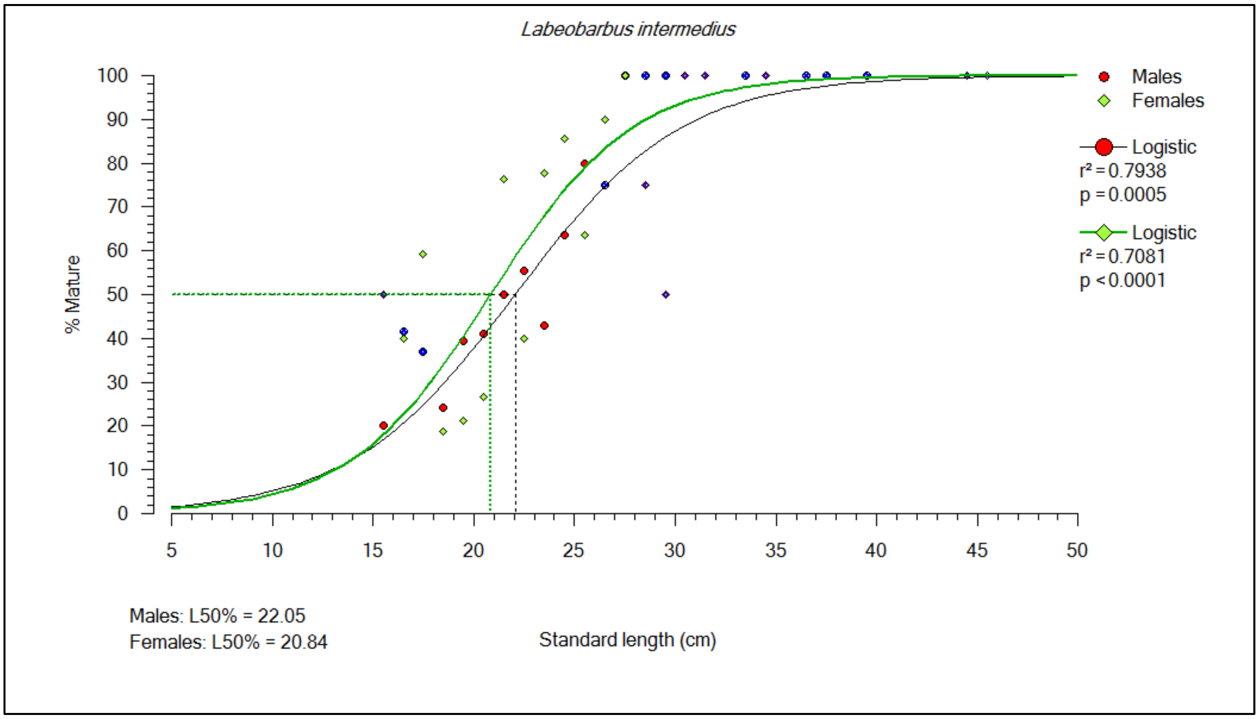

Figure 9. Size at first maturity of *Labeobarbus intermedius* from Tekeze Reservoir

One hundred forty-two (48.14%) sexually mature (stage III to V) *B. docmak* were collected from Tekeze Reservoir. From the collected mature individuals, 77 (54.23%) were females and 65 (45.77%) were males. The smallest sexually mature female *B. docmak* was 21 cm and the male was 22.5 cm standard length. The average length (L_{50}) at which 50% the individuals of *B. docmak* attained sexual maturity was 27.42 cm and 26.79 cm standard length for females and males, respectively (Fig. 10). Although the smallest sexually mature individual was female, males on the average, show early maturity than females.

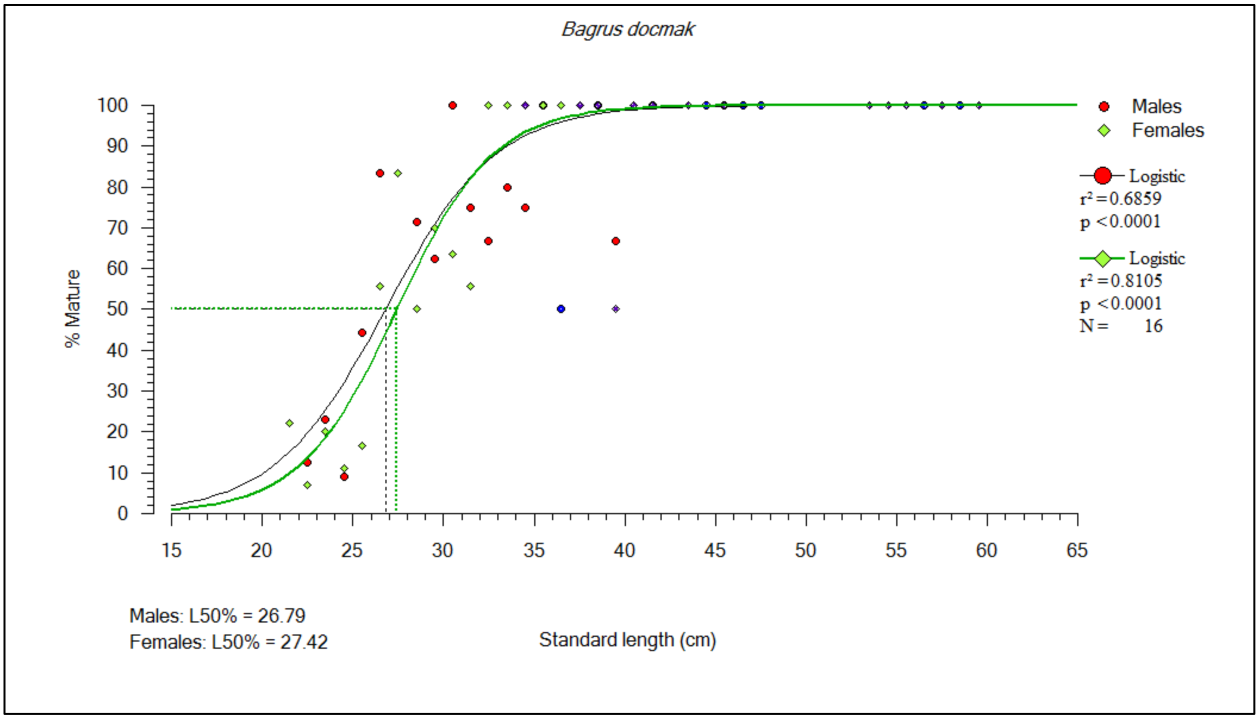

Figure 10. Size at first maturity of *Bagrus docmak* from Tekeze Reservoir

3.3.6. Fecundity

Fecundity of *O. niloticus* was estimated for 59 ripe female individuals. The total length, total weight and gonad weight of these fishes ranged from 17.5 to 37 cm, 98 to 756 g and 1.16 g to 14.02 g, respectively. The fecundity of ripe ovaries ranged from 147 to 325 eggs per gram with a mean of 231 eggs. The estimated absolute fecundity also ranged from 272 to 3,337 with a mean of 1,513. The ovary of the smallest ripe female *O. niloticus* weighed 1.16 g, which was about 1.17% of its body weight and its fecundity was 285 eggs. The highest fecundity of 3,337 eggs was from a fish with a total length of 36.5 cm and a total weight of 756 grams. Its ovary weighed 14.02 g that was about 1.86% of its body weight.

Fifty-four ripe specimens of *L. intermedius* with standard length ranging from 17.3 to 40 cm and total weight ranging from 79 to 664 g were found during the study. The fecundity of the fishes varied from 348 to 577 eggs per gram with a mean of 440 eggs. The estimated absolute fecundity varied from 1,457 to 10,658 eggs with a mean of 4,788 eggs. The ovary of the smallest ripe female weighed 4.86 g, which was about 4.67% of its body weight and its fecundity was 2,051 eggs. The highest fecundity of 10,658 eggs was from a fish with a standard length of 35.5 cm and a total weight of 664 grams. Its ovary weighed 20.98 g that was about 3.2% of its body weight.

Thirty-four ripe *B. docmak* with standard length ranging from 30 to 83 cm and total weight ranging from 398 to 8,526 g were found in the study. The fecundity of the fishes ranged from 3,167 to 6,243 eggs per gram with a mean of 4,474 eggs. The estimated absolute fecundity ranged from 1,7862 to 20,2310 eggs with a mean of 92,321 eggs. The ovary of the smallest ripe female *B. docmak* weighed 10.55 and its fecundity was 53,942 eggs. The highest fecundity of 20,2310 eggs was in a fish with a standard length of 83 cm and a total weight of 8,526 grams. Its ovary weighed 38.55 g, which was about 0.45% of its body weight.

The relationship between absolute fecundity and total length of *O. niloticus* was curvilinear (Fig. 11a), but linear with total weight (Fig. 12a) and gonad weight (Fig. 13a). The absolute fecundity was strongly correlated with total length, total weight and gonad weight of the fishes in the reservoir. There was a significant relation of absolute fecundity (AF) with total length, total weight and gonad weight for *O. niloticus,* ANOVA ($P < 0.05$). The best-fit equation to the data for total length (TL), total weight (TW) and gonad weight (GW) were presented as $AF = 0.068TL^{3.0086}$ ($r^2 = 0.8457$), $AF = 4.0079TW + 26.955$ ($r^2 = 0.8294$) and $AF = 256.27GW - 129.63$ ($r^2 = 0.8689$), respectively.

The relation between absolute fecundity and standard length for *L. intermedius* was curvilinear (Fig. 11b), whereas, the relation with total weight (Fig. 12b) and gonad weight (Fig. 13b) was linear. The absolute fecundity was strongly positively correlated and had a significant relation with standard length, total weight and gonad weight for *L. intermedius,* ANOVA ($P < 0.05$). The relation equations fitted to the data for absolute fecundity (AF) with standard length (SL), total weight (TW) and gonad weight (GW) is described as $AF = 5.563SL^{2.0718}$ ($r^2 = 0.7752$), $AF = 14.005TW + 708.55$ ($r^2 = 0.8088$) and $AF = 427.64GW + 99.009$ ($r^2 = 0.8776$), respectively.

The relations between absolute fecundity with standard length (Fig. 11c), total weight (Fig. 12c) and gonad weight (Fig. 13c) for *B. docmak* were all linear. The absolute fecundity was strongly positively correlated and had a significant relation with standard length, total weight and gonad weight for *B. docmak*, ANOVA ($P < 0.05$). The relation equations fitted to the data for absolute fecundity (AF) with standard length (SL), total weight (TW) and gonad weight (GW) are described as $AF = 2375.3SL - 14877$ ($r^2 = 0.6551$), $AF = 18.809TW + 56747$ ($r^2 = 0.7024$) and $AF = 5048.3GW - 10486$ ($r^2 = 0.8656$), respectively.

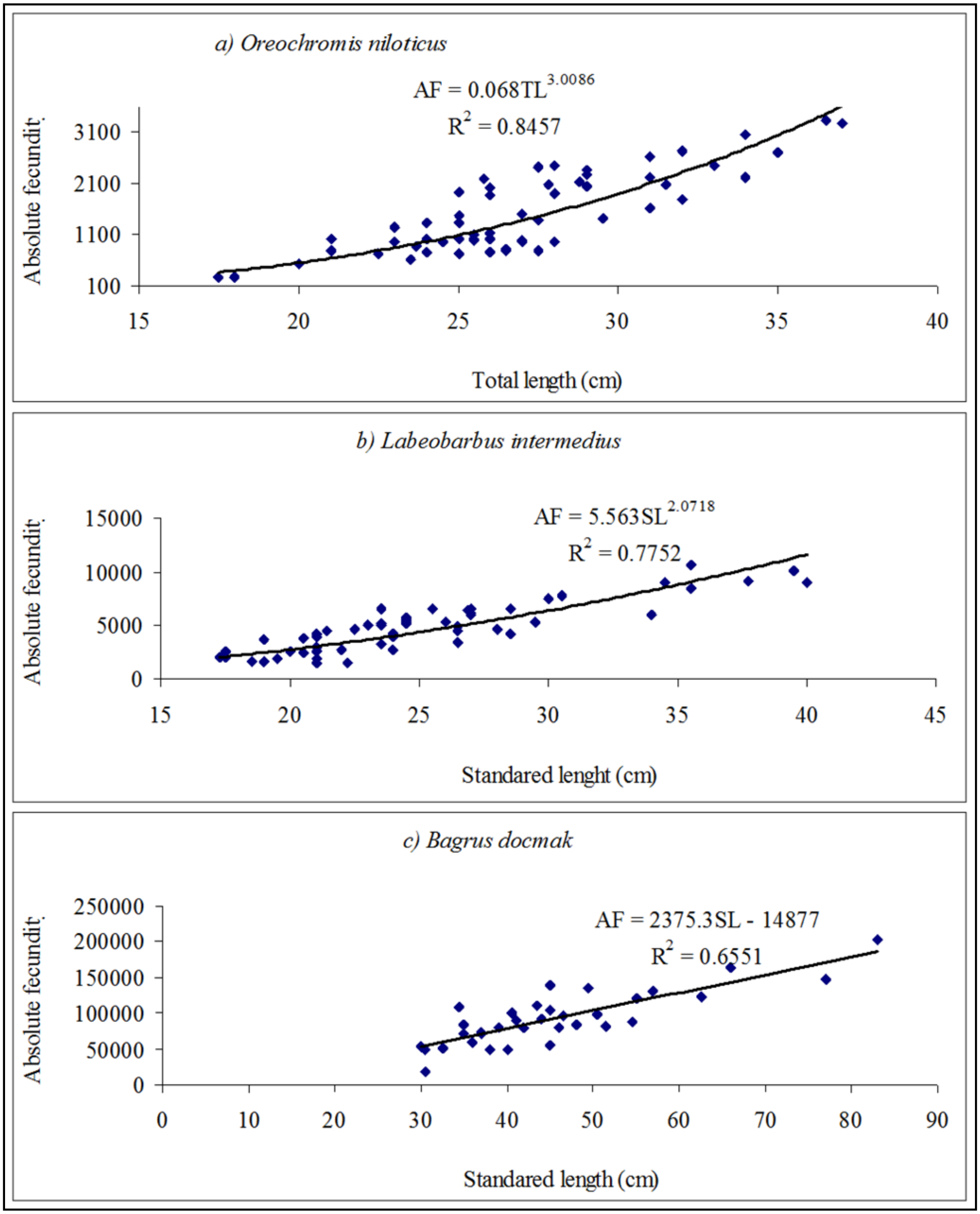

Figure 11. Relationship between length and absolute fecundity of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in Tekeze Reservoir

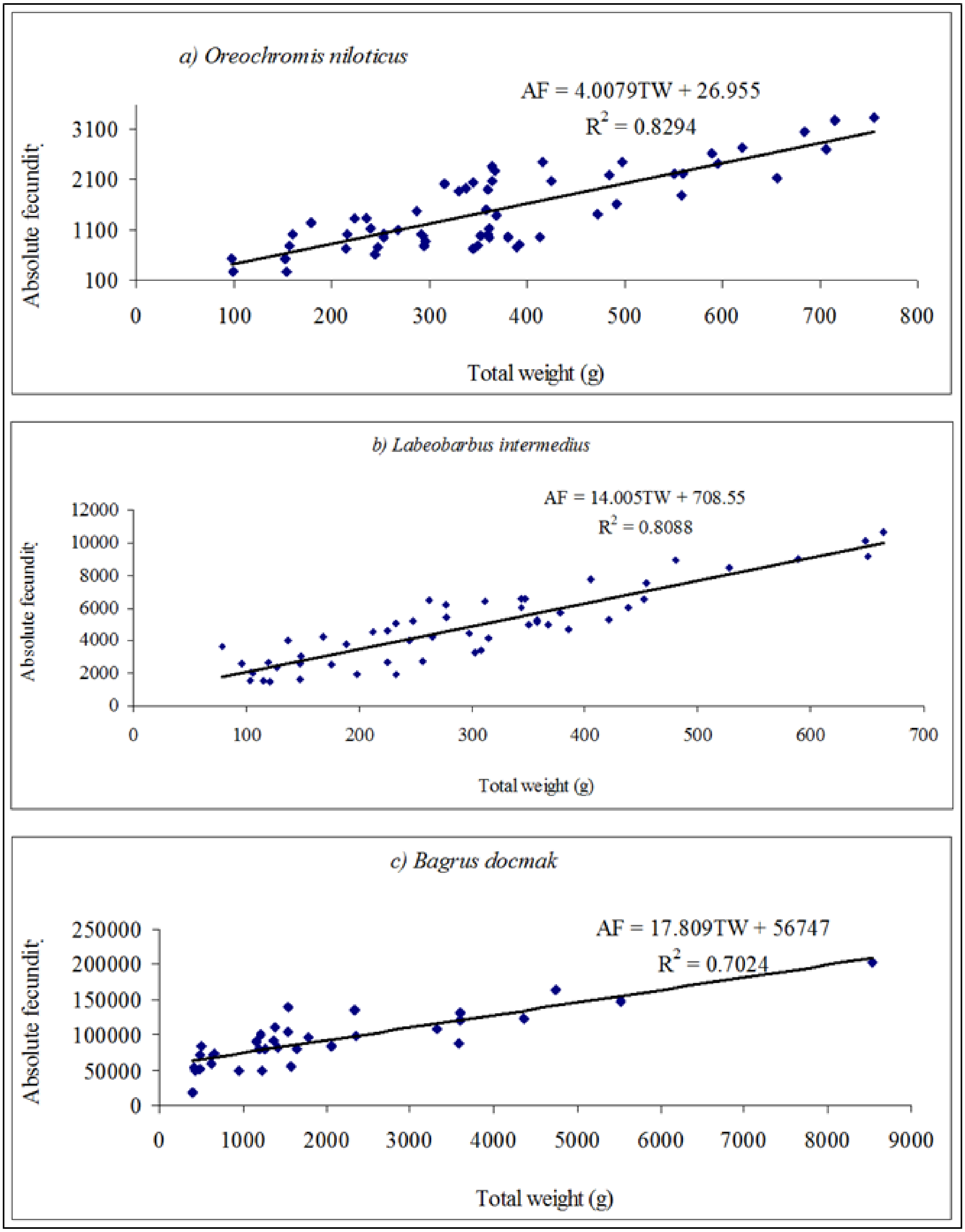

Figure 12. Relationship between total weight and absolute fecundity of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in Tekeze Reservoir

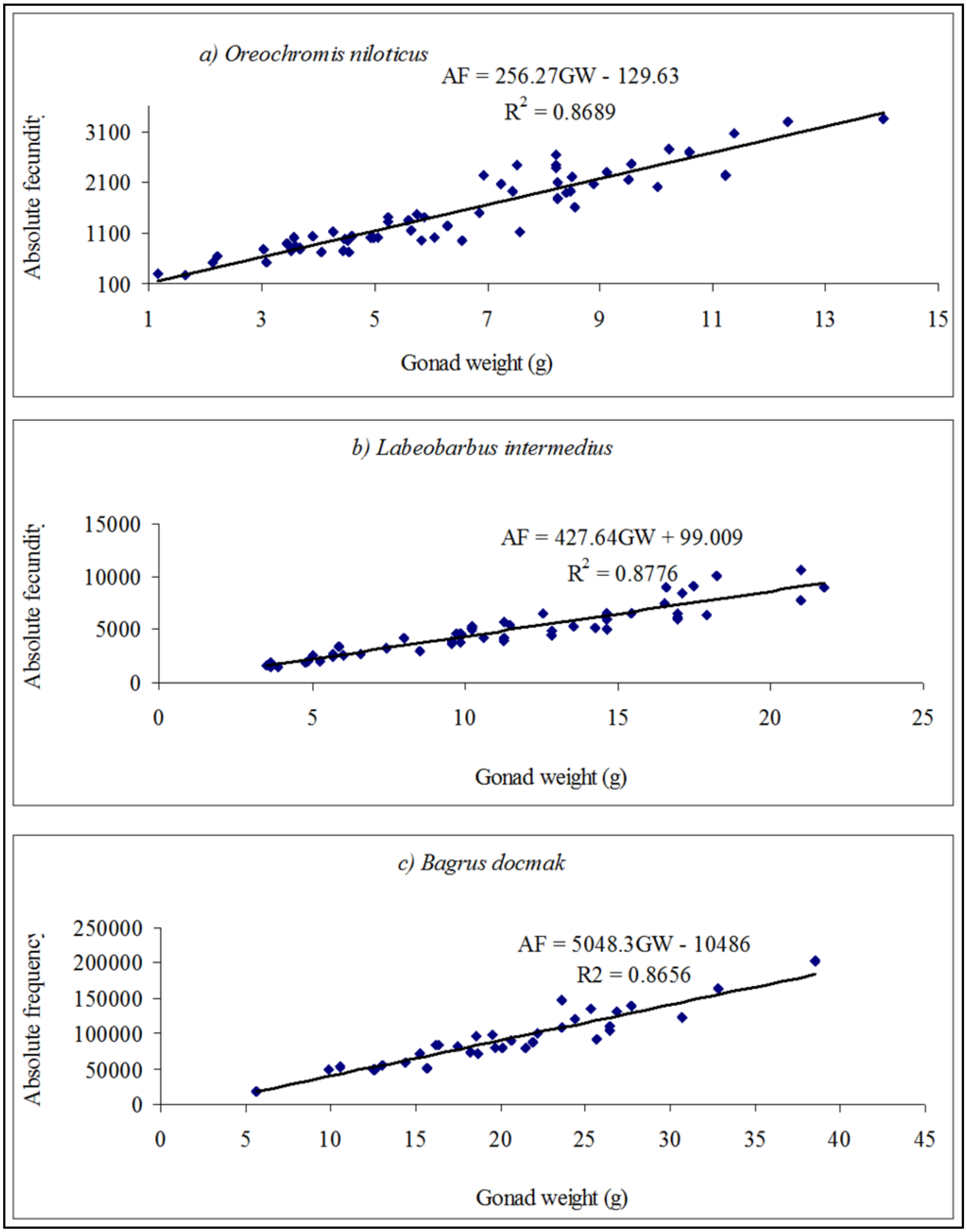

Figure 13. Relationship between gonad weight and absolute fecundity of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in Tekeze Reservoir

3.3.7. Breeding season and area

Seasonal variation in the gonado-somatic index (GSI) of both male and female *O. niloticus* is given below (Table 19a). The GSI values (mean ± SE) of females ranged from 0.79 ± 0.14 in the dry cold season to 1.17 ± 0.10 in the wet season and that of males ranged from 0.32 ± 0.04 in the dry cold season to 0.44 ± 0.05 in the wet season. In the dry hot season, the GSI value for female individuals was 0.94 ± 0.22 and for males, it was 0.34 ± 0.07. The mean value for combined sexes of *O. niloticus* was 0.59 ± 0.09, 0.68 ± 0.13 and 0.92 ± 0.07 for the dry cold, dry hot and wet sampling seasons, respectively. The percentage frequency of ripe *O. niloticus* ranged from 9.33% in the dry cold season to 73.33% in the wet season (Fig. 14a). Relative to the dry cold season, the high frequency of ripe gonads (17.33%) was recorded in the dry hot season.

The seasonal variation in the gonado-somatic index of *L. intermedius* indicated the breeding condition of the fishes in the area. The value of female individuals ranged from 2.43 ± 0.59 in the dry cold season to 3.72 ± 2.34 in the wet season and that of males ranged from 1.20 ± 0.27 in the dry cold season to 2.52 ± 0.35 in the wet season. During the dry hot season, 3.07 ± 1.63 for females and 0.34 ± 0.07 for males were recorded. The mean values of GSI for both sexes were 1.93 ± 1.18, 2.78 ± 1.00 and 2.97 ± 1.15 for the dry cold, dry hot and wet seasons, respectively (Table 19b). The percentage frequency of ripe *L. intermedius* ranged from 12.12% in the dry cold season to 56.06% in the wet season. About 31.82% of ripe gonads were also observed during the dry hot season (Fig. 14b).

The seasonal variation in the gonado-somatic index of *B. docmak* is presented in Table 19c. GSI values of females ranged from 0.48±0.13 in the dry cold season to 0.69 ± 0.21 in the dry hot season, GSI value for males ranged from 0.24±0.02 in the wet season to 0.50±0.15 in the dry hot season. The mean value of GSI for combined sexes of *B. docmak* in Tekeze Reservoir was 0.45±0.08, 0.46±0.09 and 0.60±0.13 for wet, dry cold and dry hot seasons, respectively. Although the relatively low value of GSI for *B. docmak* was recorded in the wet season, a high percentage frequency of ripe gonads was observed during that season. The percentage frequency of ripe *B. docmak* ranged from 7.5% in the dry cold season to 67.5% in the wet season (Fig. 14c). The remaining 25% of the ripe gonads were observed in the dry hot season.

Generally, the wet season (July to October) of the area was the peak-breeding season for the studied fish species. In addition to the proportion of ripe gonads and evaluation of GSI, the large number of eggs and larvae was observed from July to October (wet season) in the shallow and riverine area of the reservoir. Less intensively, the dry hot season (March to June) was also the breeding time of the fish species (Table 19; Fig. 14).

Table 19. Seasonal variation of gonado-somatic index of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in Tekeze Reservoir

a) *Oreochromis niloticus*			
Season	**Female (mean±SE)**	**Male (mean±SE)**	**Mean (mean±SE)**
DCS	0.79±0.14	0.32±0.04	0.59±0.09
DHS	0.94±0.22	0.34±0.07	0.68±0.13
WS	1.17±0.10	0.44±0.05	0.92±0.07
Overall	**1.03±0.05**	**0.38±0.03**	**0.78±0.05**

b) *Labeobarbus intermedius*			
Season	**Female (mean±SE)**	**Male (mean±SE)**	**Mean (mean±SE)**
DCS	2.43±0.59	1.20±0.27	1.93±1.18
DHS	3.07±1.63	2.28±0.57	2.78±1.00
WS	3.72±2.34	2.52±0.35	2.97±1.15
Overall	**2.83±1.04**	**2.44±0.27**	**2.62±0.50**

c) *Bagrus docmak*			
Season	**Female (mean±SE)**	**Male (mean±SE)**	**Mean (mean±SE)**
DCS	0.48±0.13	0.42±0.12	0.46±0.09
DHS	0.69±0.21	0.50±0.15	0.60±0.13
WS	0.64±0.16	0.24±0.02	0.45±0.08
Overall	**0.62±0.11**	**0.32±0.04**	**0.49±0.06**

***Note**: DCS- dry cold season, DHS, dry hot season and WS – wet season*

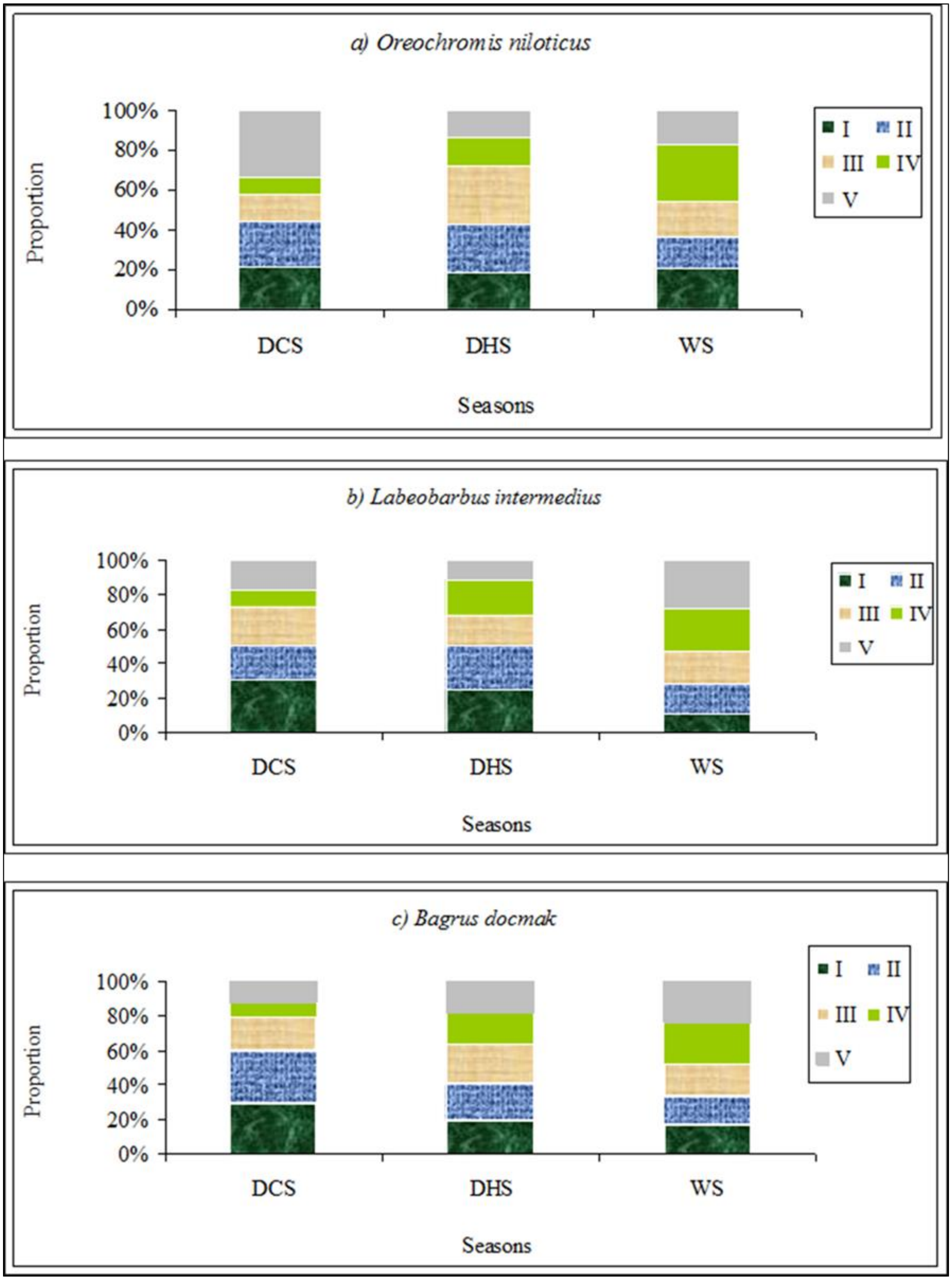

Figure 14. The proportion of the sexual maturity stages of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in different seasons of Tekeze Reservoir

Note*: DCS- dry cold season, DHS, dry hot season and WS – wet season*

During the study period, 436 ripe gonads of *O. niloticus*, *L. intermedius* and *B. docmak* were observed from the catch of fishers in the Tekeze Reservoir. Of these, 172 were *O. niloticus*, 142 were *L. intermedius* and the remaining 122 were *B. docmak.* From the total ripe gonads of *O. niloticus*, 59.3% were from July to October (wet season), 29.05% from March to June (dry hot season) and 11.65% from November to February (dry cold season) (Fig. 15). The highest proportion (66.2%) of ripe *L. intermedius* was also found during July to October (wet season) and the lowest (8.46%) was observed from November to February (dry cold season). The remaining 25.35% of the ripe gonads were obtained from March to June (dry hot season) (Fig. 15). Based on the frequency of ripe gonads from the fisher's catch, July to October (wet season) was the peak breeding months for *B. docmak*. Those months alone comprised 70.49% of the ripe gonads and followed by the months of March to June (dry hot season) that accounted for 19.68% of the ripe gonads. The lowest proportion (9.84%) of ripe gonads for *B. docmak* was observed from November to February (dry cold season) (Fig. 15).

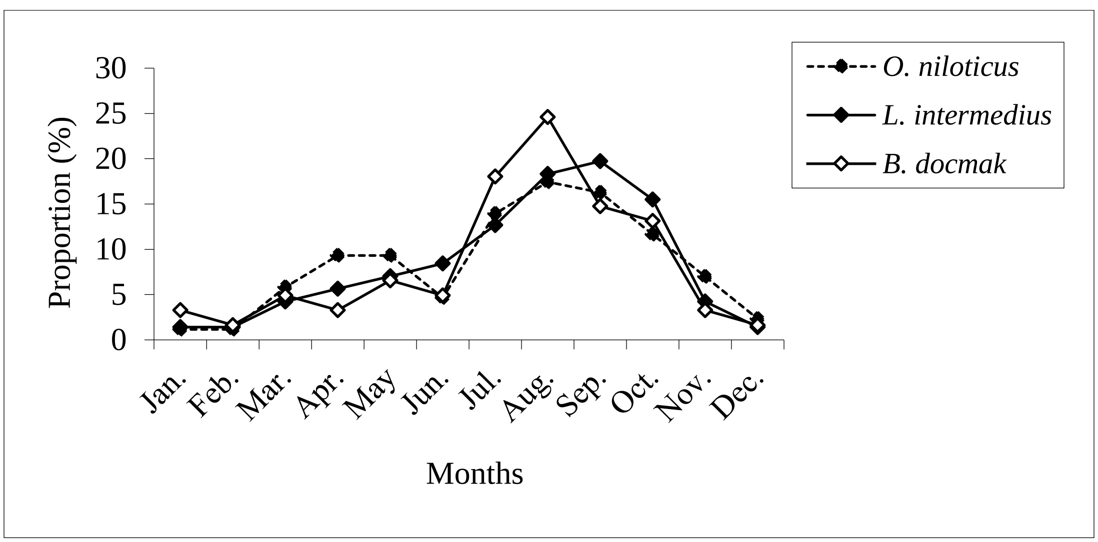

Figure 15. Monthly proportions (%) of ripe gonads from fishers catch data of *Oreochromis niloticus*, *Labeobarbus intermedius* and *Bagrus docmak* in Tekeze Reservoir

Although fishes in breeding condition were found in all habitat types of the reservoir, the riverine for *L. intermedius* and the littoral for *O. niloticus* and *B. docmak* were the main preferred breeding habitats. To some extent, fish species that were in a breeding condition were also found in the pelagic habitats. About 69.33% and 72.5% of the ripe gonads of *O. niloticus* and *B. docmak*, respectively were found in the littoral habitats. The remaining 24% and 6.67% of ripe *O. niloticus and* 20% and 7.5% of *B. docmak* were from the river mouth and pelagic, respectively (Fig. 16). However, a high proportion (63.64%) of ripe *L. intermedius* was found in the riverine habitat and the remaining 25.76% and 10.61% of the ripe gonads were found in the littoral and pelagic habitats, respectively (Fig. 16).

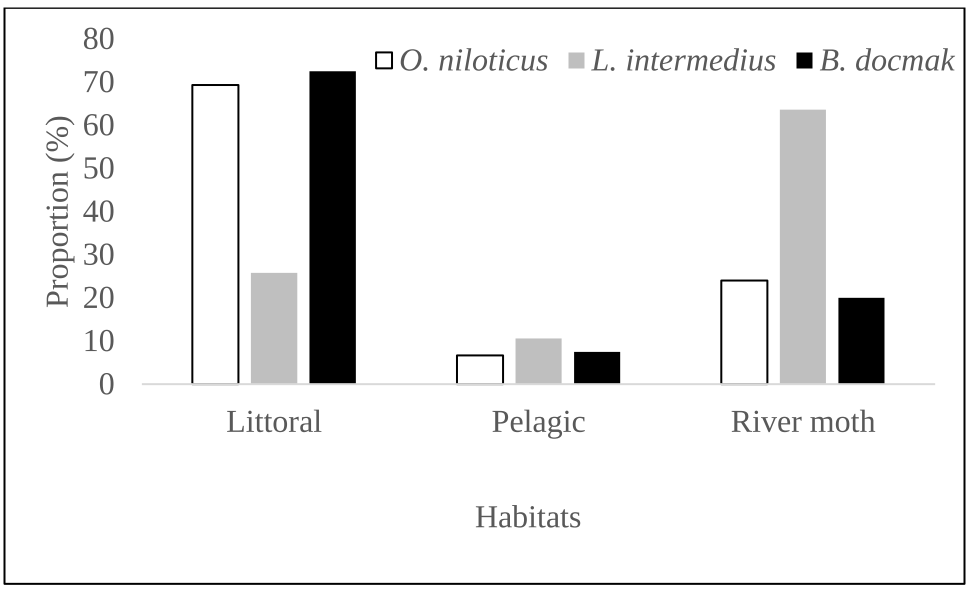

Figure 16. Proportion (%) of ripe gonads of the major commercial fish species in different sampling sites of Tekeze Reservoir

3.4. Discussions

3.4.1. Maximum size and body condition of the commercially important fish species

Maximum size: The maximum size for *O. niloticus* is different in different Ethiopian water bodies. During the present study, 38.5 cm maximum total length was recorded. This was smaller than the records reported in Lake Chamo (61 cm) (Yirgaw Teferi and Demeke Admassu, 2002), Gilgel Gibe Reservoir (50 cm) (Mulugeta Wakjira, 2013) and Lake Hawassa (39 cm) (Tesfaye Muluye *et al.*, 2016). However, it was greater than the records reported in Lake Langeno (Mathewos Temesgen, 2017), Lake Ziway (34 cm), (Lemma Abera, 2016) and Koka Reservoir (35.2 cm) (Flipos Engdaw *et al.*, 2013).

The recorded maximum size for *L. intermedius* (53.5 cm TL) was comparable to the finding reported from Lake Langeno (Mathewos Temesgen, 2017) for the same species. However, it was higher than the findings from Lake Tana (43.8 cm) (Flipos Engdaw, 2014) and Lake Ziway (44 cm) (Lemma Abera, 2016), but slightly less than the findings from Gilgel Gibe Reservoir (54 cm) (Mulugeta Wakjira, 2013).

The maximum length recorded for *B. docmak* was 96.5 cm total length, which was smaller than the fork length reported in Lake Chamo (99 cm) (Hailu Anja and Seyoum Mengistou, 2001). However, it was greater than from the findings in Muess Channel (81 cm) in Egypt (El-Drawany and Elnagar, 2015) and Gelegu and Ayima Rivers (77.4) in Ethiopia (Alamrew Eyayu, 2019).

Therefore, the difference in the size of similar species in different water bodies might be due to the difference in biotic and abiotic factors of the water bodies. Several studies revealed that the interaction of physical and chemical parameters of the water, biological factors and overfishing could determine the size of fishes in the water bodies (Mohammed and Uraguchi, 2013; Deepak and Singh, 2014; Gizachew Teshome *et al.*, 2015).

Length-weight relationship: The relationship between total length and the total weight of *O. niloticus* was curvilinear and highly significant. The slope of the regression line indicated a positive allometric growth pattern (b > 3) of the species. The isometric growth pattern is an indication of the fish growth in which all the body parts grow at nearly the same rate as the fish size increases. Several authors have reported allometric growth patterns of *O. niloticus* from different water bodies. The allometric growth pattern observed in the present study was in agreement with the earlier findings from Lake Tana (Zenebe Tadesse, 1997; Dereje Tewabe, 2014), Lake Chamo (Yirgaw Teferi and Demeke Admassu, 2002), Nkoro River in Nigeria (Abowei *et al.*, 2009), Koka Reservoir (Flipos Engdaw *et al.*, 2013), Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013) and Lake Langeno (Mathewos Temesgen, 2017).

The result obtained for the length-weight relationship of *L. intermedius* showed that the fish has obeyed the cube law of Bagenal and Tesch (1978), which assumes the regression slope (b) to be three or near to three. The coefficient obtained in this study indicated the isometric growth pattern (b = 3), that is, the fish length and weight grow at the same rate. The b value recorded in this study was comparable to the isometric growth reported in some tributaries of Lake Tana (Gizachew Teshome *et al.*, 2015), Lake Tana (Flipos Engdaw, 2014), Blue Nile River (Tadlo Awoke *et al.*, 2015) and Borkena and Mille Rivers (Assefa Tessema *et al.*, 2011). However, negative allometric growth patterns (b < 3) were also reported in Lake Langeno (Mathewos Temesgen, 2017), Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013).

There was no observed variation in the b value of the *B. docmak*. It showed that the rate of increase in body length was proportional to the rate of increase in body weight. The values obtained for the length-weight relationship showed that *B. docmak* exhibited an isometric growth pattern. This agrees with b value recorded for similar fish species in Cross River inland wetlands, Nigeria

(Offem *et al.*, 2009), Lake Chamo (Hailu Anja *et al.*, 2009) and Muess Channel, in Egypt (El-Drawany and Elnagar, 2015). However, the allometric growth pattern is reported from Lake Akata, Nigeria (Ikongbeh *et al.*, 2012) and Gelegu and Ayima Rivers (Alamrew Eyayu, 2019). Sufficient space area and abundant food supply throughout the year were probably some of the main factors contributing to the steady increase in their weight and length.

The variation between habitats, physiological and biological factors of the fish can influence the fish growth pattern of fishes (Zdanowski *et al.*, 2001). The gonad development also affects the fish weight and b values in the length-weight relationship (Wooton, 1986; Zdanowski *et al.*, 2001). Seasonal variations in water quality parameters, food availability, feeding rate, gonad development and spawning period also influence the growth pattern of fishes (Bagenal and Tesch, 1978).

Condition factor: In the present study, the almost similar value was obtained for the female (1.44±0.01) and male (1.43±0.02) *O. niloticus*, which indicated good body condition of the fishes. This means that both female and male individuals of *O. niloticus* were equally adapted to the environmental conditions of the reservoir. Values higher than one was recorded in the Koka Reservoir (Berhan Asmamaw *et al.*, 2019), Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013) and Lake Langeno (Mathewos Temesgen, 2017), which agrees with the result of this study. Values higher than two were also reported for Lake Chamo (Yirgaw Teferi and Demeke Admassu, 2002) and River Baro (Tesfaye Melak, 2009).

Similar to *O. niloticus*, the condition factor of *L. intermedius* was found to be higher than one (1.88±0.02) that was a good indication for the suitability of the ecology of the reservoir for this fish species. The mean value (1.88±0.01) was to some extent higher than from the reports obtained from Geba and Sor Rivers (Simagegnewu Melaku *et al.*, 2017), Infranz River (Shewit Gebremedhin *et al.*, 2013), Lake Tana (Shewit Gebremedhin *et al.*, 2012), Borkena and Mille

Rivers (Assefa Tessema *et al.*, 2011), Belles and Gelgel Belles Rivers (Zeleke Berie, 2007) and Guang, Ayima, Gendawuha and Shinfa Rivers (Dereje Tewabe, 2008) for similar fish species.

The condition factor value (0.94±0.01) of *B. docmak* was found near to one. There were no significant differences between sexes and sampling seasons of the study period. Relative to *O. niloticus* and *L. intermedius*, the condition factor value of *B. docmak* was low. This might be due to differences in the adaptability of the different species to the environmental condition of the reservoir. Less than this value was reported for similar fish species in Lake Chamo (Hailu Anja *et al.*, 2009), Victoria Nile (Aruho *et al.*, 2013) and Gelegu and Ayima Rivers (Alamrew Eyayu, 2019). However, greater than the present result was reported for *B. docmak* in Lake Akata of Nigeria (Ikongbeh *et al.*, 2012). This might be due to differences in environment, quantity and quality of food, feeding rate and water level fluctuations between the water bodies. A high condition factor value indicates favorable environmental conditions and low values indicate less favorable environmental conditions (Bolger and Connolly, 1989).

The condition factor value of both female and male *O. niloticus*, *L. intermedius* and *B. docmak* remained relatively constant with no visible variation throughout the study period. Insignificant depleted fat during gonad development, availability of food throughout the year and continuous feeding during the time of gonadal maturation could be the probable reasons (Hailu Anja *et al.*, 2009).

3.4.2. Reproductive biology of *O. niloticus*, *L. intermedius* and *B. docmak*

Sex ratio: The sex ratio for *O. niloticus* in Tekeze Reservoir was different and the deviation from the expected 1:1 (Female: male) was significant, where females were outnumbered. This was largely observed in the size class between 14-19 and 24-29 cm total length and the wet season of the study period. This agrees with the results obtained for similar fish species in Lake Tana (Dereje

Tewabe, 2014) and Lake Ardibo (Endalh Mekonnen *et al.*, 2018). However, the condition in which males dominated females were reported in Lake Tana (Zenebe Tadesse, 1997), Emiliano Zapata Dam (Peña-Mendoza *et al.*, 2005), Lake Victoria (Njiru *et al.*, 2006) and Lake Naivasha (Otieno *et al.*, 2014), which is different from the present study. The biased sex ratio for the present study might be caused by sexual segregation during spawning, behavioral differences between the sexes, gear type and fishing site (Demeke Admassu, 1994).

Female *L. intermedius* outnumbered males, but the result showed statistically insignificant results throughout the study period. Different authors documented different results about the sex ratio of *L. intermedius*. For instance, the dominance of females over males was reported from Dirma and Megech Rivers (Wassie Anteneh *et al.*, 2007), Infranz River (Shewit Gebremedhin *et al.*, 2013) and in Geba and Sor Rivers (Simagegnewu Melaku *et al.*, 2017), which are in agreement with the present study. Opposed to this result, the dominance of males over females for similar species were reported from some tributaries of Lake Tana (Gizachew Teshome *et al.*, 2015) and in Koka Reservoir (Agumassie Tesfahun, 2011). The occurrence of sex ratio imbalance for *L. intermedius* was most probably related to the spawning behavior of the species. Female *L. intermedius* spent longer time in breeding habitats than males (Wassie Anteneh *et al.*, 2007). This may cause the deviation from 1:1 sex ratio.

The reported sex ratio for *B. docmak* was significantly different from the expected sex ratio. This was comparable with the findings from the Winam Gulf of Lake Victoria (Dadzie and Ochieng-Okach, 1989) where it was found that females predominate over males. The sex variation in the reservoir could be because of the difference in the growth rate of the sexes where females attain a larger size than males. However, Hailu Anja *et al*. (2009) from Lake Chamo, Aruho *et al*. (2013)

from Victoria Nile and Yongo *et al.* (2020) from Lake Victoria have reported a proportional sex ratio.

Size at first maturity: The result of the size at first maturity of *O. niloticus* in the present study showed that females show slight early maturation than males. This is in agreement with different authors in different water bodies for similar fish species (Tesfaye Wudneh, 1998; Peña-Mendoza *et al.*, 2005; Tesfaye Muluye *et al.*, 2016). Conversely, males attained early maturity than females in Lake Ardibo (Asnake Wubshet, 2010). Female *O. niloticus* had reached a size at first maturity at 24.2 cm and males at 24.89 cm total length in the Tekeze Reservoir. This was larger than the estimated values reported in Fincha Reservoir (Fasil Degefu *et al.*, 2012), Lake Beseka (Tirunesh Senait, 2015) and Lake Hawassa (Tesfaye Muluye *et al.*, 2016), but smaller than the reports obtained from Lake Chamo (Yirgaw Teferi *et al.*, 2001) and Koka Reservoir (Gashaw Tesfaye *et al.*, 2016). The difference in size at first maturity of similar species in different water bodies might be related to the difference in ecological conditions. Fish in poor conditions mature at a smaller size than those in good condition (Tirunesh Senait, 2015).

Similar to *O. niloticus*, females of *L. intermedius* mature early than males in Tekeze Reservoir. The female individuals matured at 20.84 cm and males at 22.05 cm standard length. Although the early maturity of the female in this study is in agreement with the reports from Koka Reservoir (Agumassie Tesfahun, 2011), in which the average length at first maturity was largely different. Conversely, male individuals mature at a smaller size than females for similar species in Lake Tana (De Graaf *et al.*, 2003).

Unlike *O. niloticus* and *L. intermedius*, male individuals of *B. docmak* matured relatively at a smaller size than female individuals. The males matured at an average length of 26.79 cm and the females at 27.42 cm standard length. This result agreed with the findings reported by Dadzie and

Ochieng-Okach (1989), Hailu Anja *et al*. (2009) and Aruho *et al*. (2013) in other lakes for similar species. The estimated size at first maturity of *B. docmak* in the present study was much smaller than the values recorded in Lake Chamo (Hailu Anja *et al*., 2009), but somehow similar with the records in Victoria Nile (Aruho *et al*., 2013). The female's size at maturity of *B. docmak* in this study was smaller, but the males were larger than the reports from Lake Victoria for similar sex (Dadzie and Ochieng-Okach, 1989).

Fecundity: The fecundity of *O. niloticus* in the Tekeze Reservoir ranged from 272 to 3,337 eggs. The fecundity for the same species in Lake Tana (Zenebe Tadesse, 1997), Lake Hawassa (Demeke Admassu, 1994) and Lake Chamo (Yirgaw Teferi *et al.*, 2001) were estimated to be in a range of 495 to 1243, 304 to 967 and 1,047 to 4,590 eggs, respectively. The mean fecundity of the species in this study was 1,513 eggs. This was more than the values reported by Zenebe Tadesse (1997) in Lake Tana, Lemma Abera (2013) in Lake Beseka, but fewer than the estimated values reported by Yirgaw Teferi *et al*. (2001) in Lake Chamo. Differences in fecundity of similar fish species in different water bodies could be due to the variation in body condition of the fishes. Fishes in poor condition were reported to have less fecundity than the fishes that are in better condition. In this study, it was found that fecundity and total length in *O. niloticus* have curvilinear relationship while, total weight and gonad weight have linear relationship. Similar results were reported in Lake Hawassa (Demeke Admassu, 1994) and Lake Tana (Zenebe Tadesse, 1997), but a linear relationship of fecundity and total length were also reported in Lake Chamo (Yirgaw Teferi *et al.*, 2001) and Lake Beseka (Lemma Abera, 2013).

Labeobarbus intermedius had absolute fecundity ranging from 1,457 to 10,658 eggs with a mean of 4,788 eggs in the Tekeze Reservoir. This was linearly related to the total weight and gonad weight, but curvilinear to the standard length of the species. Many researchers also reported the absolute fecundity for similar species in different lakes and rivers. Wassie Anteneh *et al*. (2007) in Dirma and Megech, Shewit Gebremedhin *et al* (2013) in Infranz River and Gizachew Teshome *et al* (2015) in Lake Tana Tributaries have reported the average fecundity for *L. intermedius*. The estimated absolute value of the present study was higher than the values reported from Dirma and Megech Rivers, but lower than from Infranz and Lake Tana Tributaries. The difference might be due to the difference in ecological conditions of the water ecosystems.

The absolute fecundity of *B. docmak* in the Tekeze Reservoir was found in the range of 17,862 and 202,310 eggs. This was higher than the values reported from Victoria Nile (Aruho *et al.*, 2013) for similar species. The mean number of fecundities for the species in the present study was 92,321 eggs per female fish. Conversely, Hailu Anja *et al*. (2009) reported that the mean fecundity of *B. docmak* in Lake Chamo is 276,500 eggs per female fish, which is higher than the values estimated in this study. Morphometric measurements, availability of food for the species and egg size can affect the fecundity of fishes (Bagenal and Tesch, 1978). The relationship of the fecundity with the standard length, total weight and gonad weight of the species in the reservoir were linear. Comparable results were reported from Lake Victoria (Dadzie and Ochieng-Okach, 1989; Aruho *et al.*, 2013).

Breeding: The variation in GSI values reflected seasonal variation in the frequency of fish with ripe gonads for *O. niloticus*, *L. intermedius* and *B. docmak*. That is why the lowest frequency of ripe fishes was recorded when GSI values are lowest. This may be related to the increment of the water level in the reservoir, which initiates the development of ovaries.

The high value of gonado-somatic index and frequency of ripe gonads was important to identify the breeding time and breeding area of *O. niloticus* in the Tekeze Reservoir. Although the year-round breeding condition was observed, the wet season (July to October) was the peak breeding time for *O. niloticus*. In tropical water bodies, the low seasonal fluctuation in temperature and photoperiod are favorable for fishes to spawn at any time of the year (Lowe-McConnell, 1987). Therefore, this might be the reason why breeding *O. niloticus* were present throughout the year in the Tekeze Reservoir. The peak reproductive activity of *O. niloticus* coincided with the rainy season of the region. Lowe-McConnell (1987) concluded that breeding among tilapias has a distinct peak just before or at the onset of the rainy season. With the start of the wet season, the reservoir's water level rises and terrestrial nutrients flush into the reservoir. As a result, spawning habitats and food resources for fish could be expanding greatly. Thus, the habitats and food resources might have triggered reproduction in the reservoir.

The maximum GSI value and proportion of ripe gonads of *L. intermedius* indicated the breeding area and peak spawning season of the species. As that of *O. niloticus*, the wet season (July to October) of the sampling period was the peak spawning season for *L. intermedius*. The river mouth habitats of the reservoir were the preferred breeding areas for *L. intermedius*. To some extent, the year-round breeding condition of the species was also observed. Comparable studies were conducted in Lake Tana (De Graaf *et al.*, 2005), in Dirma and Megech Rivers (Wassie Anteneh *et al.*, 2007), Koka Reservoir (Agumassie Tesfahun, 2011), Arno-Garno Rivers (Shewit Gebremedhin *et al.*, 2012) and Lake Tana tributaries (Gizachew Teshome *et al.*, 2015) in which it all reported that the peak spawning season for similar species is during wet season.

The year-round spawning of *B. docmak* with peak spawning season coinciding with rainfall of the area was observed in Tekeze Reservoir. The wet season (July to October) of the area was the peak spawning season for the species. Less intensively, the dry hot season (March to April) was also the spawning season of the species. For similar species, Hailu Anja *et al*. (2009) reported that February to September is the main spawning months with peak breeding month of March in Lake

Chamo. According to Aruho *et at*., (2013), *B. docmak* has bimodal spawning seasons in Victoria Nile. The first spawning season occurred from March to May, which is similar to the present study and the second season occurred from September to November (Aruho *et al*., 2013). Therefore, high rainfall and the subsequent rise in water level are implicated as triggering factors for spawning of *B. docmak* in Lake Victoria (Dadzie and Ochieng-Okach, 1989).

3.5. Conclusions

From the results of the present study the following conclusions were made: The length-weight relationship of *O. niloticus*, *L. intermedius* and *B. docmak* were curvilinear and their body conditions were found in good condition. The sex ratio of *O. niloticus* and *B. docmak* was statistically different, but that of *L. intermedius* was not different from the hypothetical value. Female and male *O. niloticus* matured almost at a similar size. Female *L. intermedius* were found to mature earlier than male individuals, but for *B. docmak,* male individuals matured at a smaller size than females. July to October was the peak spawning season for *O. niloticus*, *L. intermedius* and *B. docmak*. The littoral habitats were the preferred spawning areas for *O. niloticus* and *B. docmak*, but the riverine habitats were the most important habitats for *L. intermedius*.

3.6. Recommendations

More work is essential on mortality and growth rate of *O. niloticus, L. intermedius* and *B. docmak* in Tekeze Reservoir. The capture size of the stock should be determined by considering the size at first maturity of *O. niloticus, L. intermedius* and *B. docmak* in the Tekeze reservoir. To protect the breeding population of *O. niloticus*, *L. intermedius* and *B. docmak*, fishing activity should be restricted to the shallow littoral areas and riverine habitats during the peak spawning season of July to October. November to February could be an open fishing season to the species in the reservoir, as relatively few fish in breeding condition were found during the time of the study.

CHAPTER FOUR

4. FOOD AND FEEDING HABITS OF THE MAJOR COMMERCIAL FISH SPECIES IN TEKEZE RESERVOIR

Abstract

Food and feeding habits of O. niloticus, L. intermedius and B. docmak in Tekeze Reservoir were studied from samples taken between January 2016 and December 2017. The objective of this study was to generate baseline information about the diet composition, feeding periodicity and ontogenic dietary shift of the major commercial fish species. This was studied using the percentage of numerical abundance, frequency of occurrence, volumetric and index of relative importance methods. Phytoplankton for O. niloticus, detritus for L. intermedius, fish and fish remains for B. docmak were the most important food types. During the dry seasons, phytoplankton was the dominant food item in the diet of O. niloticus, but in the wet season, it was dominated by zooplankton. In the dry cold season of the study period, phytoplankton was important, but in the dry hot and wet seasons detritus were the frequently ingested food items by L. intermedius. In the case of B. docmak, detritus during the dry cold season, fish and fish remains during the dry hot and wet seasons were the preferred food types. In some size classes of O. niloticus and B. docmak, complete ontogenic shifts were observed, but all food items in different proportions were ingested by L. intermedius. The juveniles of O. niloticus and B. docmak mostly feed on zooplankton and detritus, but the large-sized O. niloticus feed on phytoplankton and that of B. docmak feed on fish and fish remains. In general, the studied fish species were omnivory. However, a study on the trophic position of the fish species and their trophic role in the reservoir system is required to plan valid strategies for proper utilization and conservation of the ecosystem.

Keywords /phrases: *Detritus, Diet composition, Fish and fish remains, Ontogenic shifts, Phytoplankton*

4.1. Introduction

Fish are key elements in natural food webs and important sources of food and feed for humans and animals, respectively. The establishment of the food and feeding habits of a particular fish species in a particular area requires a dietary survey of such species in their natural environment. This is because the diet of fish in captivity is never a reliable criterion for determining the food requirement of fishes (Ajah and Udoh, 2012). Examining the food and feeding habits of a fish species is important for evaluating the ecological role and position of the species in the food web of the ecosystem (Saikia, 2015).

Fish have an impact on the physicochemical properties of an ecosystem in which they occur. They affect plankton, macrophytes and other aquatic life as well as can serve as environmental indicators (Tesfaye Wudneh, 1998). The study of food and feeding habits of freshwater fish species is a subject of continuous research. Because it makes up a basis for the development of a successful management program on fish culture and capture. (Shalloof *et al.*, 2009). Moreover, studies on natural feeding habits of fish enable the identification of the trophic relationships present in the aquatic ecosystem, identifying feeding composition, structure and stability of food webs in the ecosystem (Otieno *et al.*, 2014). It is also important for the management of the fish in a controlled environment and the formulation of the appropriate dietary give for the fish in aquaculture.

Different fish species including O. niloticus, L. intermedius and *B. docmak* have versatile feeding behavior, which is characterized by generalists and opportunistic omnivores (Adeyemi *et al.*, 2009). However, their diet composition may vary in a wide range of seasonal and spatial conditions of the environment. It may also vary depending on the size of fish and habitat type (Shalloof *et al.*, 2009). Various authors have been reported about the food and feeding habits of *O. niloticus*, *L. intermedius* and *B. docmak* in different Ethiopian water bodies.

However, such information is absent in the focus area of the present study. Therefore, understanding of food and feeding habits of those fish species in the Tekeze Reservoir is important for the successful management of the reservoir ecology as well as it is a key factor for sustainable culture in a controlled environment. Area-specific information on the food and feeding habits concerning the relative contribution of each food item to the diet of *O. niloticus*, *L. intermedius* and *B. docmak*, feeding periodicity and ontogenetic dietary shifts are critical for appropriate management and utilization of the stock in the reservoir.

4.1.1. General objective

To generate baseline information on food and feeding habits *O. niloticus*, *L. intermedius*, and *Bagrus docmak* in Tekeze Reservoir.

4.1.2. Specific objectives

i. To study the diet composition of *O. niloticus*, *L. intermedius* and *B. docmak* in Tekeze Reservoir.
ii. To assess the relative contribution of each food item in the diet of the studied fish species.
iii. To determine the feeding periodicity of the fish species in the reservoir.
iv. To investigate whether there were ontogeny dietary shifts of these fish species.

4.2. Material and methods

4.2.1. Stomach and gut content analysis

To examine the food items, the fish abdomen was split with scissors. The gut of *O. niloticus* and *L. intermedius* and the stomach of *B. docmak* was taken out and preserved in a plastic vial. The volume of the contents of each gut and stomach was measured and 5% formalin was added for preservation. The preserved content was transferred into Petri-dishes. Larger food items were identified by eye, whereas small-sized food items were microscopically examined and each food item was identified to the lowest taxon possible using descriptions, illustrations and identification keys (Macan, 1965). Besides, smaller food items, such as phytoplankton, were examined at high magnification (100_X to 400_X) under a compound microscope. After identification, a list of items found in the gut, stomach content was prepared and counting was performed using a sub-sample of 10 ml. All counts were converted to the number per total volume of the gut and stomach content (Hyslop, 1980).

4.2.2. The relative importance of the major food items

The relative importance and contribution of each food item to the diet of the fishes was determined using the frequency of occurrence, volumetric and percent composition by number methods (Pinkas *et al.*, 1971). In the frequency of occurrence method, the occurrences of food items were expressed as the percentage of the total number of the gut and the stomach containing food. In the numerical method, the number of each food item was articulated as the percentage of the total number of food items found in the gut or stomach. The quantitative importance of each food category in the diet was determined using the Index of Relative Importance (Pinkas *et al.*, 1971; Hyslop, 1980).

$$\mathrm{IRI} = \%\mathrm{F}(\%\mathrm{N} + \%\mathrm{V})$$

Where: IRI = Index of Relative Importance

%O = Percentage frequency of occurrence of the food items

%N = Numerical percentage of the food items in the gut or stomachs and

%V = Percentage by volume of the food items in the gut or stomachs.

4.2.3. Feeding periodicity

Seasonal difference in feeding habit of the commercially important fish species was determined by using frequency of occurrence and volumetric methods. In this case, the relative contribution (%) of each food item was tabulated against each season of the study period.

4.2.4. Fish size and feeding habit relationships

The fish size and feeding habit relationships were estimated by using the frequency of occurrence and volumetric methods. For this purpose, the Food items were grouped into major taxonomic groups and the specimens were classified by a 5 cm length class interval. Thus, the results obtained from each method was graphically represented against the length class of the fishes.

4.3. Results

4.3.1. Diet composition

Five hundred sixty-seven gut samples of *O. niloticus* specimens varying in total length between 5 and 38.5 cm were examined for feeding habits. Three hundred forty-six (61.02%) gut samples were with food items and the remaining 221 (38.98%) were without food. Out of 454 gut samples of *L. intermedius*, 368 (81.06%) contained food while the remaining 86 (18.94%) were empty. The standard length of the examined *L. intermedius* ranged from 5.7 to 45.4-cm. Two hundred ninety-five stomach samples of *B. docmak* specimens in different length classes were also examined for feeding habits. The length of those specimens varied between 16 and 83 cm standard length. About 156 (52.88%) were non-empty and the other 139 (47.12%) were empty.

The composition of the major food items observed in the gut of *O. niloticus* and *L. intermedius* and stomach contents of *B. docmak* are listed in Table 20 below. They were composed of both plant and animal origins. The plant food items were made up of phytoplankton and macrophytes. Food items of animal origin included fish and fish remains, insects and zooplankton. Also, detritus and sand grains were obtained in the stomach content of the fishes. Fish and fish remains were the food items found only in the diet of *B. docmak*. The phytoplankton group contained green algae, blue-green algae and diatoms. Zooplankton group was composed of copepods, cladocerans and rotifers. The fish and fish remains include *L. intermedius*, fish scales, fish fins, fish bones and fish eggs (Table 20).

Table 20. Major food items identified from the gut of *Oreochromis niloticus*, *Labeobarbus intermedius* and stomach of *Bagrus docmak* in Tekeze Reservoir

Major food items		
a) Oreochromis niloticus	***b) Labeobarbus intermedius***	***c) Bagrus docmak***
Phytoplankton	**Detritus**	**Fish and fish remains**
Green algae	**Phytoplankton**	*L. intermedius*
Blue-green algae	Green algae	Fish scales
Diatoms	Blue-green algae	Fish fins
Zooplankton	Diatoms	Fish eggs
Copepods	**Zooplankton**	**Zooplankton**
Cladocerans	Copepods	Copepods
Rotifers	Cladocerans	Cladocerans
Detritus	Rotifers	Rotifers
Macrophytes	**Macrophytes**	**Detritus**
	Insects	**Insects**
	Sand grains	**Phytoplankton**
		Green algae
		Blue-green algae
		Diatoms
		Macrophytes
		Sand grains

4.3.2. The relative importance of major food items

The relative contribution of the food items to the diet of *O. niloticus* was explained by numerical abundance, frequency of occurrence, volumetric and index of relative importance methods (Table 21). Based on the percentage composition by number, phytoplankton (56.55%) was the most important food item followed by zooplankton (43.45%). From the phytoplankton group, Green algae, blue-green algae and diatoms contributed each 30.64%, 16.47% and 9.44%, respectively. The important contributions of zooplankton to the diet of *O. niloticus* were from cladocerans (18.02%), copepods (13.01%) and rotifers (12.43). Detritus and macrophytes were also observed frequently, but they could not be compared numerically as they were difficult to count.

Phytoplankton was the most frequently occurring food item of *O. niloticus,* obtained in 85.84% of the gut samples with food (Table 21). Green algae only occurred in 78.61%, blue-green algae and diatom in 45.95% and 25.43% of the guts with food, respectively (Table 21). Zooplankton occurred in 62. 14% of the guts (Table 21). From this group of food items, cladocerans occurred in 43.93%, copepods in 34.39% and rotifers in 29.77% of the guts (Table 21). However, volumetrically, zooplankton (45.11%) was the most and phytoplankton (42.33%) was the second preferred food items (Table 21). Cladocerans (18.16%), copepods, (15.8%) and rotifers (11.15%) constituted the bulk of the food consumed by the fishes (Table 21). The remaining food items, such as detritus and sand grains contributed least to the diets of *O. niloticus*. Based on the index of relative importance, green algae (42.1%), blue-green algae (16.07%) and diatoms (5.4%) from phytoplankton group (63.57%), cladocerans (17.64%), copepods (11%) and rotifers (7.79%) from zooplankton (36.43%) group contributed to the diet of *O. niloticus* (Table 21).

Table 21. The relative contribution of food items to the diet of *Oreochromis niloticus* using the numeric, frequency of occurrence, volumetric and index of relative importance from Tekeze Reservoir

Food items	No	%No	F	%F	V(ml)	%V	IRI	%IRI
Phytoplankton	**587**	**56.55**	**297**	**85.84**	**229.6**	**42.33**	**5727.04**	**63.57**
Green algae	318	30.64	272	78.61	95.5	17.61	3792.93	42.1
Blue-green algae	171	16.47	159	45.95	81.6	15.04	1447.88	16.07
Diatoms	98	9.44	88	25.43	52.5	9.68	486.22	5.4
Zooplankton	**451**	**43.45**	**215**	**62.14**	**244.7**	**45.11**	**3282.14**	**36.43**
Copepods	135	13.01	119	34.39	85.7	15.8	990.78	11
Cladocerans	187	18.02	152	43.93	98.5	18.16	1589.39	17.64
Rotifers	129	12.43	103	29.77	60.5	11.15	701.98	7.79
Detritus	**-**	**-**	**33**	**9.54**	**55.8**	**10.29**	**-**	**-**
Macrophytes	**-**	**-**	**11**	**3.18**	**12.3**	**2.27**	**-**	**-**

Note: *No – number, %N – numerical percentage, F – frequency of occurrence, %F – the percentage of frequency of occurrence, V (ml) – volume in milliliter, %V – volumetric percentage, IRI – index of relative importance and %IRI – the percentage of the index of the relative importance of the food items.*

Detritus were the most important food items to the diet of *L. intermedius*. Although they were difficult to describe numerically, they were the most frequently ingested and constituted the highest proportion of the bulk of the food consumed by the fishes. They occurred in 81.79% of the gut with food. Volumetrically, detritus contributed about 42.06% of the total volume of the food items (Table 22). Phytoplankton group contributed 49.96% to the diet, which occurred in 73.64% of the guts and constituted 19.69% of the volume of the food consumed by the fish (Table 22). Zooplankton was among the preferred food items of *L. intermedius* numerically contributing 42.52%, occurring in 53.53% and constituting 22.54% of the total volume of the food items.

Macrophytes and insects occurred in 23.91% and 22.01% and constituted 11.51% and 1.71% to the bulk of the food items by volume. Sand grains were also observed in the guts of the fishes (Table 22). The result of the percentage of the index of relative importance (%IRI) indicated that phytoplanktons (59.59%) were the highest contributors. Relatively macrophytes, insects and sand grains were rarely observed food items of *L. intermedius*. Zooplanktons were also among the most important food items for the species (Table 22).

Table 22. The relative contribution of food items to the diet of *Labeobarbus intermedius* using numeric, frequency of occurrence, volumetric and index of relative importance from Tekeze Reservoir

Food items	No	%No	F	%F	V (ml)	%V	IRI	%IRI
Detritus	**-**	**-**	**301**	**81.79**	**429.8**	**42.06**	**-**	**-**
Phytoplankton	**571**	**49.96**	**271**	**73.64**	**201.2**	**19.69**	**3807.39**	**59.59**
Green algae	311	27.21	253	68.75	98.9	9.68	2536.19	39.7
Blue-green algae	193	16.89	169	45.92	82.5	8.07	1146.16	17.94
Diatoms	67	5.86	59	16.03	19.8	1.94	125.034	1.96
Zooplankton	**486**	**42.52**	**197**	**53.53**	**230.3**	**22.54**	**2568.91**	**40.21**
Copepods	121	10.59	99	26.9	45.5	4.45	404.58	6.33
Cladocerans	168	14.7	143	38.86	101.6	9.94	957.51	14.99
Rotifers	197	17.24	175	47.55	83.2	8.14	1206.82	18.89
Macrophytes	**-**	**-**	**88**	**23.91**	**117.6**	**11.51**	**-**	**-**
Insects	**86**	**7.52**	**81**	**22.01**	**17.5**	**1.71**	**12.86**	**0.2**
Sand grains	**-**	**-**	**63**	**17.12**	**25.5**	**2.5**	**-**	**-**

Note: *No – number, %N – numerical percentage, F – frequency of occurrence, %F – the percentage of frequency of occurrence, V (ml) – volume in milliliter, %V – volumetric percentage, IRI – index of relative importance and %IRI – the percentage of the index of the relative importance of the food items.*

The food items identified from the stomach contents of *B. docmak* were fish and fish remains, zooplankton, detritus, insects, phytoplankton, macrophytes and sand grains (Table 23). From these food items, fish and fish remains were outnumbered (53.05%), occurred in the high number of stomachs (81.41%) and constituted the bulk (67.41%) of the food consumed by volume. The fish and fish remains were composed of *L. intermedius*, fish scale, fish fins, eggs and bones. Zooplanktons were among the most important food items numerically contributing 27.16%, occurring in 59.62% of the stomach and constituting 8.04% of the total volume of food items (Table 23). Detritus occurred in 61.54% of the stomach and accounted for 4.11% of the total volume of food items (Table 23). The numeric contributions of unidentified insects and phytoplanktons were 10.59% and 9.21%, which occurred in 41.67% and 35.26% of the stomachs and their volumetric contributions were 6.45% and 4.03% of the total food items, respectively. From the phytoplankton groups, copepods, cladocerans and diatoms were food items identified in the stomachs of *B. docmak*. Macrophytes occurred in 3.21% of the stomachs and accounted for 2.49% of the total volume of the food consumed.

Although the importance of sand grains to the diet of *B. docmak* was not clear, they occurred in 56.41% of the stomachs and accounted for 7.46% of the total volume (Table 23). Therefore, based on the index of relative importance, fish and fish remains and zooplanktons were the most important food items, which contributed 66.23% and 19.58% to the diet of *B. docmak*, respectively (Table 23).

Table 23. The relative contribution of food items to the diets of *Bagrus docmak* using numeric, frequency of occurrence, volumetric and index of relative importance from Tekeze Reservoir

Food items	No	%No	F	%F	V (ml)	%V	IRI	%IRI
Fish remains	**461**	**53.05**	**127**	**81.41**	**827.4**	**67.41**	**4232.43**	**66.23**
L. intermedius	7	0.81	4	2.56	356.5	29.05	76.4416	1.2
Fish scales	155	17.84	105	67.31	106.6	8.69	1785.73	27.94
Fish fins	109	12.54	82	52.56	97.6	7.95	1076.95	16.85
Fish eggs	115	13.23	37	23.72	124.3	10.13	554.099	8.67
Fish bones	75	8.63	57	36.54	142.4	11.6	739.204	11.57
Zooplankton	**236**	**27.16**	**93**	**59.62**	**98.7**	**8.04**	**1251.18**	**19.58**
Copepods	63	7.25	51	32.69	31.4	2.56	320.689	5.02
Cladocerans	112	12.89	63	40.39	39.8	3.24	651.491	10.19
Rotifers	61	7.02	47	30.13	27.5	2.24	279.004	4.37
Detritus	**-**	**-**	**96**	**61.54**	**50.5**	**4.11**	**-**	-
Insects	**92**	**10.59**	**65**	**41.67**	**79.2**	**6.45**	**710.057**	**11.11**
Phytoplankton	**80**	**9.21**	**55**	**35.26**	**49.5**	**4.03**	**196.97**	**3.08**
Green algae	38	4.37	31	19.87	22.5	1.83	123.194	1.93
Blue-green algae	23	2.65	19	12.18	15.7	1.28	47.8674	0.75
Diatoms	19	2.19	13	8.33	11.3	0.92	25.9063	0.41
Macrophytes	**-**	**-**	**5**	**3.21**	**30.5**	**2.49**	**-**	**-**
Sand grains	**-**	**-**	**88**	**56.41**	**91.6**	**7.46**	**-**	**-**

Note: *No – number, %N – numerical percentage, F – frequency of occurrence, %F – the percentage of frequency of occurrence, V (ml) – volume in milliliter, %V – volumetric percentage, IRI – index of relative importance and %IRI – the percentage of the index of the relative importance of the food items.*

4.3.3. Feeding periodicity

A high proportion of empty guts of *O. niloticus* and *L. intermedius* were observed during the wet season. However, in the case of *B. docmak* highest percentage of empty stomachs were reported during the dry hot season (Table 24).

Table 24. Seasonal percentage analysis with food and empty guts of *Oreochromis niloticus*, *Labeobarbus intermedius* and stomach of *Bagrus docmak* in Tekeze Reservoir

a) *Oreochromis niloticus*

Season	Examined gut	Guts with food		Guts without food	
		NGF	%NGF	NEG	%NEG
DCS	131	96	73.28	35	26.72
DHS	153	104	67.97	49	32.03
WS	283	146	51.59	137	48.41
Total	**567**	**346**	**61.02**	**221**	**38.98**

b) *Labeobarbus intermedius*

Season	Examined gut	Guts with food		Guts without food	
		NGF	%NGF	NEG	%NEG
DCS	128	112	87.5	16	12.5
DHS	149	121	81.21	28	18.79
WS	177	135	76.27	42	23.73
Total	**454**	**368**	**81.06**	**86**	**18.94**

c) *Bagrus docmak*

Season	Examined gut	Stomachs with food		Stomachs empty food	
		NSF	%NSF	NES	%NES
DCS	62	36	58.06	26	41.94
DHS	75	32	42.67	43	57.33
WS	158	88	55.7	70	44.3
Total	**295**	**156**	**52.88**	**139**	**47.12**

Note *DCS – dry cold season, DHS – dry hot season, WS – wet season, NGF – number of guts with food, %NGF – the numerical percentage of guts with food, NEG – number of empty guts, %NEG – the numerical percentage of empty guts, NSF, number of stomachs with food, %NSF – the numerical percentage of stomachs with food and %NES – the numerical percentage of empty stomachs.*

The seasonal feeding variation of *O. niloticus* was indicated by the frequency of occurrence and volumetric methods (Table. 25). Phytoplankton, zooplankton, detritus and macrophytes were the major food items identified in the guts of *O. niloticus*. All food items were frequently ingested in all seasons of the study period, but their proportion was different. During the dry cold season, phytoplanktons were the most important food items. They occurred in 98.96% (Table 25a) of the guts and volumetrically their contribution was 50.1% (Table 25b) of the total volume of the food items. Zooplankton occurred in 51.04% (Table 25a) of the guts and accounted for 38.0% (Table 25b) of the total volume of food consumed. Detritus and macrophytes occurred in 9.38% and 2.08% (Table 25a) of the guts, respectively and comprised 10.37% and 1.53% of the total volume of the food items (Table 25b), respectively.

In the dry hot season, phytoplankton was also the most preferred food items of *O. niloticus*. They occurred in 95.15% of the guts (Table 25a) and constituted 46.56% of the total volume (Table 25b) of the food items. The contributions of the zooplankton to the diet of *O. niloticus* were not also insignificant. They occurred in 54.81% of the guts (Table 25a) and comprised 39.42% of the volume of the food items (Table 25b). However, detritus and macrophytes were rarely ingested food items of the fish species. Detritus occurred in 10.58% of the guts with food (Table 25a) and accounted for 11.3% of the total volume of food items consumed by *O. niloticus* (Table 25b). Macrophytes occurred in 3.85% of the guts and their volumetric contribution was 2.72% of the total volume of the food items.

During the wet season of the study period, zooplankton were the most frequently ingested food items in the diet of *O. niloticus* occurring in 74.66% of the guts (Table 25a) and accounting for 53.63% of the food items (Table 25b). Phytoplankton occurred in 70.55% of the guts (Table 22a) and comprised 34.46% of the volume of the foods consumed (Table 25b). During this season, the contribution of detritus and macrophytes to the diet of *O. niloticus* was also low. They occurred in 8.9% and 3.42% of the guts with food (Table 25a) and contributed 9.5% and 2.42% of the total volume of the major food items (Table 25b) in the area, respectively.

Table 25. The seasonal contribution of the major food items to the diet of *Oreochromis niloticus* using the percentage frequency of occurrence (a) and volumetric (b) analysis from Tekeze Reservoir

Food items	**a) Frequency (%)**			**b) Volume (%)**		
	Sampling seasons			**Sampling seasons**		
	DCS	**DHS**	**WS**	**DCS**	**DHS**	**WS**
PHY	98.96	95.15	70.55	50.1	46.56	34.46
ZPK	51.04	54.81	74.66	38	39.42	53.63
DET	9.38	10.58	8.9	10.37	11.3	9.5
MAC	2.08	3.85	3.43	1.53	2.72	2.42

***Note**: PHY – phytoplankton, ZPK – zooplankton, DET - detritus, MAC – macrophytes, DCS - dry cold season, DHS – dry hot season and WS – wet season*

Detritus, phytoplankton, zooplankton, macrophytes, insects and sand grains were the food items obtained in the gut of *L. intermedius*. The frequency of occurrence and volumetric contribution of the different food items consumed by *L. intermedius* varied in proportion with the season. The contribution of detritus and phytoplankton to the diet of *L. intermedius* decreased from the dry cold season towards the wet season. However, the importance of zooplankton, macrophytes and insects increased towards the wet season (Table 26).

The contribution of phytoplankton was the highest during the dry cold season occurring in 97.32% of the guts, followed by detritus occurring in 93.75% of the guts with food (Table 26a). However, volumetrically, the contribution of detritus to the diet of *L. intermedius* was the highest and followed by phytoplankton comprising 48.64% and 26.31% of the volume of the food items (Table 26b), respectively. Zooplankton occurred in 41.96% of the gut-containing food (Table 26a) and constituted 17.83% of the volume of the food items (Table 26b). However, the frequency of occurrence and volumetric contribution of macrophytes, insects and sand grains to the diet of *L. intermedius* in the reservoir was low. Macrophytes occurred in 9.82% of the gut with food (Table 26a) and accounted for 4.77% of the total volume of the food items (Table 26b). Insects occurred in 8.93% of the guts (Table 26a) and contributed 0.62% of the volume of the food items (Table 26b). Although the nutritional contribution of sand grains to the diet of *L. intermedius* was not known, they occurred in 12.5% of the gut (Table 26a) and constituted 1.83% of the volume of the food items (Table 26b) in the dry cold season.

During the dry hot season, detritus were the most important food items. They occurred in 89.26% of the guts (Table 26a) and accounted for 44.29% of the volume of the consumed food items (Table 26b). Phytoplankton and zooplankton were also among the frequently ingested food items by *L. intermedius.* Phytoplankton occurred in 80.99% of the guts (Table 26a) and comprised 20.98% of the volume of the food consumed (Table 26b). Zooplankton was found in 55.37% of the gut with food (Table 26a) and volumetrically contributed 22.54% of the total volume of the food items (Table 26b). Relatively to the dry cold season, the contribution of macrophytes, insects and sand grains was relatively high in the dry hot season. They occurred in 17.36%, 22.31% and 17.36% of the guts (Table 26a) and comprised 8.07%, 1.68% and 2.45% of the volume of the food items (Table 26b), respectively.

Besides, detritus was the most important food item during the wet season, occurring in 65.19% (Table 26a) of the guts and accounting for 34.33% of the total volume of the food items (Table 26b). The contribution of zooplankton to the diet of *L. intermedius* placed it as the second that occurred in 61.48% of the guts (Table 23a) and contributed 26.51% of the volume of the food (Table 26b). Phytoplankton was the third most important food item, which was observed in 47.41% of the gut-containing food (Table 26a). However, volumetrically, macrophytes were the third most important food item, which contributed 20.45% of the total volume of the food items ingested by *L. intermedius* (Table 26b). Insects and sand grains were relatively less important during the wet season occurring in 32.59% and 20.74% of the guts examined (Table 26a) and constituting 2.6% and 3.1% of the total volume of the food items (Table 26b).

Table 26. The seasonal contribution of the major food items to the diet of *Labeobarbus intermedius* using the percentage of frequency of occurrence (a) and volumetric (b) analysis from Tekeze Reservoir

Food items	a) Frequency (%)			b) Volume (%)		
	Sampling seasons			Sampling seasons		
	DCS	DHS	WS	DCS	DHS	WS
DET	93.75	89.26	65.19	48.64	44.29	34.33
PHY	97.32	80.99	47.41	26.31	20.98	13.01
ZPK	41.96	55.37	61.48	17.83	22.54	26.51
MAC	9.82	17.36	41.48	4.77	8.07	20.45
INS	8.93	22.31	32.59	0.62	1.68	2.6
SaG	12.5	17.36	20.74	1.83	2.45	3.1

Note*: DET - detritus, PHY – phytoplankton, ZPK – zooplankton, MAC – macrophytes, INS – insects, SaG – sand grains, DCS - dry cold season, DHS – dry hot season and WS – wet season*

During the sampling seasons, there was a notable variation in the proportions of the food items consumed by *B. docmak*. The relative contribution of fish and fish remains, insects and sand grains to the diet of *B. docmak* increased from the dry cold season to the wet season. On the other hand, the relative importance of detritus and phytoplanktons decreased from the cold season towards the wet season. The contribution of zooplankton to the diet of the fishes increased from the dry cold season to the dry hot season, but to some extent decreased from the dry hot season towards the wet season (Table 27). Volumetrically, fish and fish remains were extensively dominated by the volume of the food items in all seasons.

During the dry cold season, detritus extensively dominated the fish stomachs with food, but its volumetric contribution was relatively low. It occurred in 83.33% of the stomachs (Table 27a) and comprising 7.24% of the total volume of the food items (Table 27b). Phytoplankton occurred in 58.33% of the stomachs (Table 27a) and constituted 8.67% of the total volume of the food items (Table 27b) consumed in the dry cold season. Fish and fish remains and zooplanktons were among the most important food items of *B. docmak* in the reservoir. They occurred in 55.56% and 50% of the stomach and accounted for 59.78% and 8.76% of the volume of the foods (Table 27b), respectively. During this season, the contribution of insects and macrophytes to the diet of *B. docmak* was least. They were observed in 27.28% and 2.78% of the stomachs (Table 27a) and comprised 5.59% and 2.8% of the total volume of the consumed food items (Table 27b), respectively. Sand grains occurred in 41.67% of the stomachs (Table 27a) and contributed 7.16% to the volume of the food items (Table 27b).

However, during the dry hot season, fish and fish remains were the most important food items. They occurred in 78.13% of the stomach (Table 27a) and comprised 64.2% of the volume of the food items (Table 27b). The contribution of zooplankton ranked second. They were found in 71.88% of the stomach (Table 27a) and constituted 9.62% of the total volume of the food items (Table 27b). Detritus, insects, phytoplankton and sand grains occurred in 59.38%, 43.75%, 46.88% and 59.39% of the stomach containing food (Table 27a) and comprised 3.94%, 6.72%, 5.32% and 7.8% of the total volume of the food items (Table 27b), respectively. Similar to the dry cold season, the relative contribution of macrophytes to the diets of *B. docmak* in the dry hot season was low. They were found in 3.13% of the stomachs (Table 27a) and contained 2.4% of the volume of the food items (Table 27b) consumed.

During the wet season, fish and fish remains were also one of the most important food items in the diet of *B. docmak*. They occurred in 93.18% of the stomach contents (Table 27a) constituting 70.69% of the total volume of food items (Table 27b). Next to fish remains, zooplankton and phytoplankton were the most important food items in the diet of *B. docmak* in the wet season. They were observed in 59.09% and 53.41% of the stomach (Table 27a) and contained 7.3% and 3.27% of the total volume of the food bulk (Table 27b), respectively. Insects were found in 46.59% of the stomachs (Table 27a) and constituted 6.61% of the volume of the food (Table 27b). Phytoplankton and sand grains were available in 21.59% and 61.36% of the stomachs (Table 27b) and shared 2.26% and 7.44% of the total volume of the food items, respectively (Table 27b). In addition to the dry seasons, macrophytes contributed least to the diet of *B. docmak* in Tekeze Reservoir, found only in 3.41% of the stomachs containing food (Table 27a) and shared 2.42% of the volume of the food items (Table 27b).

Table 27. The seasonal contribution of the major food items to the diet of *Bagrus docmak* using the percentage of frequency of occurrence (a) and volumetric (b) analysis from Tekeze Reservoir

Food items	**a) Frequency (%)**			**b) Volume (%)**		
	Sampling seasons			**Sampling seasons**		
	DCS	**DHS**	**WS**	**DCS**	**DHS**	**WS**
FFR	55.56	78.13	93.18	59.78	64.2	70.69
ZPK	50	71.88	59.09	8.76	9.62	7.3
DET	83.33	59.38	53.41	7.24	3.94	3.27
INS	27.78	43.75	46.59	5.59	6.72	6.61
PHY	58.33	46.88	21.59	8.67	5.32	2.26
MAC	2.78	3.13	3.41	2.8	2.4	2.42
SaG	41.67	59.38	61.36	7.16	7.8	7.44

Note*: FFR – fish and fish remains, ZPK – zooplankton, DET- detritus, INS – insects, PHY – phytoplankton, MAC – macrophytes, SaG – sand grains, DCS - dry cold season, DHS – dry hot season and WS – wet season*

4.3.4. Fish size and feeding habit relationship

The relationship between the size and feeding habits of *O. niloticus* in the Tekeze Reservoir is shown in figure 17. Individuals belonging to all length classes ingested most of the major food items. In some size classes, a complete dietary ontogenic shift was observed. The fishes that have smaller sizes (< 14 cm) did not consume macrophytes. Detritus was among the most important food items in size class below 14 cm, but was not consumed by the large-sized fishes (≥ 29 cm) (Fig. 17).

In size class, 4-9 cm total length the dominant food items were zooplankton and detritus that occurred in 93.33% and 80% of the guts (Fig. 17a) and constituted 41.34% and 52.64% of the total volume of the food items (Fig. 17b), respectively. The contribution of phytoplankton in this size class was relatively low, which occurred in 20% of the guts containing food (Fig. 17a) and comprised 6.02% of the total volume of the food items (Fig. 17b). Similarly, those food items, such as zooplankton and detritus dominated the size class, 9-14 cm total length, occurring in 83.33% and 72.22% of the guts with food (Fig. 17a) and accounted 39.78% and 51.22% of the volume of the food items (Fig. 17b), respectively. Phytoplankton occurred in 27.78% of the guts containing food (Fig. 17a) and contributed 9.01% of the total volume of the food items (Fig. 17b), respectively. The macrophytes food items were not observed in both (4-9 and 9-14 cm) size classes (Fig. 17).

The contribution of phytoplankton to the diet of *O. niloticus* increased with the size of the fish. They have dominated the food items in size class above 14 cm. In size class, 14-19 cm total length phytoplankton and zooplankton were the most important food items occurring in 80% and 68.75% of the guts (Fig. 17a) and accounting for 40.86% and 51.7% of the total volume of food items (Fig. 17b), respectively. The less important food items namely, detritus and macrophytes occurred in 5.59% and 1.85% of the guts containing food (Fig. 17a) and constituted 12.12% and 18.18% of the volume of food consumed within the size class (Fig. 17b), respectively.

The dominant food items in size class 19-24 cm total length were phytoplankton observed in 95.66% of the guts with food (Fig. 17a) and constituted 47.76% of the total volume of food items within the size class (Fig. 17b). Zooplankton was found in 61.96% of the guts (Fig. 17a) and constituted 45.54% of the total volume of the food items (Fig. 17b). The contributions of macrophytes and detritus were relatively low, obtained in 4.35% and 3.26% of the guts containing food (Fig. 17a) and constituted 3.14% and 3.56% of the total volume of food consumed in that size class (Fig. 17b), respectively.

In size class, 24-29 cm total length the order of the most important of the dominant food items was similar. Phytoplankton and zooplankton constituted the bulk of the food items consumed. These food items occurred in 96.04% and 59.41% of the guts with food (Fig. 17a) and accounted for 50.56% and 46.04% (Fig. 17b), respectively of the total volume of food items consumed within the size class. The less important food items were again macrophytes and detritus, which were observed in 2.97% and 0.99% of the guts (Fig. 17a) and comprised 2.56% and 1.14% of the total volume of the food items in the size class (Fig. 17b), respectively.

The dominance of the phytoplankton group to the diet of *O. niloticus* continued in size classes' 29-34 cm and 34-39 cm total length. They occurred in 100% of the guts with food (Fig. 17a) and constituted 62.97% (29-34 cm SL) and 63.04% (34-39 cm SL) of the total volume of the food items consumed in the classes (Fig. 17b). Zooplankton was the second most important food item in those size classes. They occurred in 36.67% (29-34 cm SL) and 30% (34-39 cm SL) of the guts with food (Fig. 17a) and constituted 33.99% (29-34 cm SL) and 27.84% (34-39 cm SL) of the volume of the food items in the classes (Fig. 17b). Macrophytes contribute least to the diet of *O. niloticus*, but detritus was not obtained in the gut of the fishes in size classes' 29-34 cm and 34-39 cm total length. The macrophytes were observed in 3.33% (29-34 cm SL) and 10% (34-39 cm SL) of the guts (Fig. 17a) and shared 3.04% (29-34 cm SL) and 9.12% (34-39 cm SL) of the volume of the food items in the size classes (Fig. 17b).

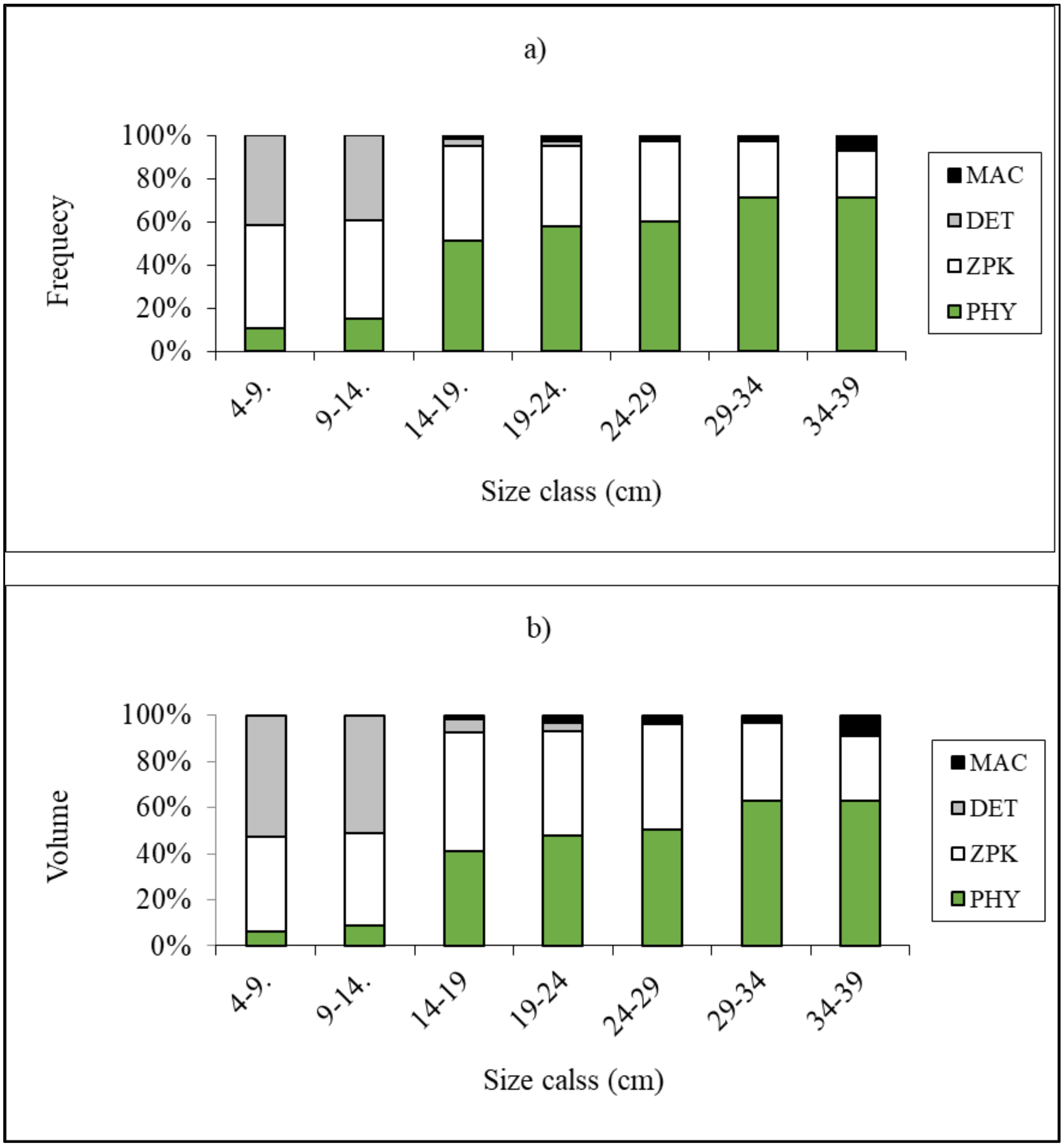

Figure 17. The frequency of occurrence (a) and volumetric (b) contribution of different food items to the diet of *Oreochromis niloticus* in different size classes from Tekeze Reservoir

***Note**: PHY – phytoplankton, ZPK – zooplankton, DET - detritus and MAC – macrophytes*

The relationship between the size and feeding habits of *L. intermedius* is given in figure 18. Individuals belonging to all length classes ingested the major food items including sand grains, but varied in proportion. The food items of all size classes were dominated by detritus, phytoplankton and zooplankton. In the feeding habits of *L. intermedius*, no complete ontogenic dietary shifts were observed (Fig. 18).

In size class, 5-10 cm standard length detritus, zooplankton, insects and phytoplankton dominated the guts of *L. intermedius*. Detritus occurred in 92.59% of the guts (Fig. 18a) and constituted 46.69% of the total volume of the food items (Fig. 18b). Zooplankton occurred in 88.89% of the guts with food (Fig. 18a) and accounted for 36.7% of the total volume of the food items in the class (Fig. 18b). The contribution of phytoplankton and insects to the diet of *L. intermedius* in this size class was not also insignificant. They occurred in 40.74% (each) of the guts with food (Fig. 18a) and constituted 10.68% and 3.11% of the volume of food (Fig. 18b), respectively. The contribution of sand grains and macrophytes to the diet was the least, which occurred in 7.41% and 3.7% of the guts containing food (Fig. 18a) and comprised 1.06% and 1.75% of the total volume of the food items (Fig. 18b), respectively.

Detritus and zooplankton dominated the gut of the size class of 10-15 cm, which occurred in 83.33% of the guts with food (each) (Fig. 18a) and accounted for 42.91% and 35.14% of the volume of the food items (Fig. 18b), respectively. Phytoplankton occurred in 50% of the guts containing food (Fig. 18a) and contributed 13.38% of the total volume of the food items (Fig. 18b). Insects also contributed to the diet of the fishes within the class. They occurred in 44.44% of the guts (Fig. 18a) and shared 3.47% of the volume of the food items (Fig. 18b). The contribution of sand grains and macrophytes was also low to the diet of this size class, appeared in 16.67% and 5.56% of the guts (Fig. 18a) and comprised 2.42% and 2.68% of the total volume of the food (Fig. 18b), respectively.

Phytoplankton were the most important food items in size class 15-20 cm, occurring in 90.51% of the guts (Fig. 18a) and accounting for 24.2% of the total volume of food items (Fig. 18b). Detritus was the second most important food item, observed in 85.44% of the guts with food (Fig. 18a) and contributed 43.95% to the total volume of the food items (Fig. 18b). Zooplankton were the next most important food items occurring in 51.27% of the guts (Fig. 18a) and accounting for 21.58% of the total volume of the food consumed (Fig. 18b) in the size class. The less important food items namely, macrophytes, insects and sand grains occurred in 15.82%, 13.92% and 10.75% of the guts containing food (Fig. 18a) and constituted 7.62%, 1.08% and 1.57% of the volume of food consumed within the size class (Fig. 18b), respectively.

The dominant food item in the guts in size class 20-25 cm standard length were detritus, observed in 86.11% of the guts with food (Fig. 18a) and constituted 42.3% of the total volume of food items within the size class (Fig. 18b). Phytoplankton and Zooplankton were found in 59.26% and 58.33% of the guts (Fig. 18a) and comprised 15.14% and 23.46% of the total volume of the food items (Fig. 18b), respectively. In this size class, the contribution of macrophytes, sand grains and insects to the diet was relatively low, obtained in 32.41%, 22.22% and 16.67% of the guts containing food (Fig. 18a) and constituted 14.9%, 2.97% and 1.24% of the total volume of food consumed (Fig. 18b), respectively.

In size class, 25-30 cm standard length phytoplanktons, detritus, macrophytes and insects were the most frequently ingested food items in the reservoir. These food items occurred in 76.47%, 60.78%, 39.22% and 37.25% of the guts with food (Fig. 18a) and accounted for 23.32%, 35.65%, 21.53% and 3.31% (Fig. 18b), respectively of the total volume of food items consumed within the size class. Sand grain and zooplankton were the less important food items observed in 29.41% and 23.53% of the guts (Fig. 18a) and comprised 4.87% and 11.3% of the total volume of the food items in the size class (Fig. 18b), respectively.

In length class 30 cm and above (≥ 30 cm), macrophytes and phytoplankton were the most important food items. Macrophytes occurred in 100% of the guts with food (Fig. 18a) and constituted 42.68% of the total volume of the food items consumed in the classes (Fig. 18b). Phytoplankton was observed in 83.33% of the guts with food (Fig. 18a) and constituted 19.74% of the volume of the food items in the classes (Fig. 18b). Sand grains were obtained in 50% of the guts (Fig. 18a) and accounted for 6.44% (Fig. 18b) for the total volume of the food items consumed in the class. Insects also occurred in 50% of the guts with food (Fig. 18a) and comprised 3.46% of the total volume of the food items (Fig. 18b). Detritus and zooplankton contribute least to the diet of *L. intermedius*. They were observed in 33.33% (each) of the guts (Fig. 18a) and shared 15.22% and 12.45% of the volume of the food items in the size classes (Fig. 18b), respectively.

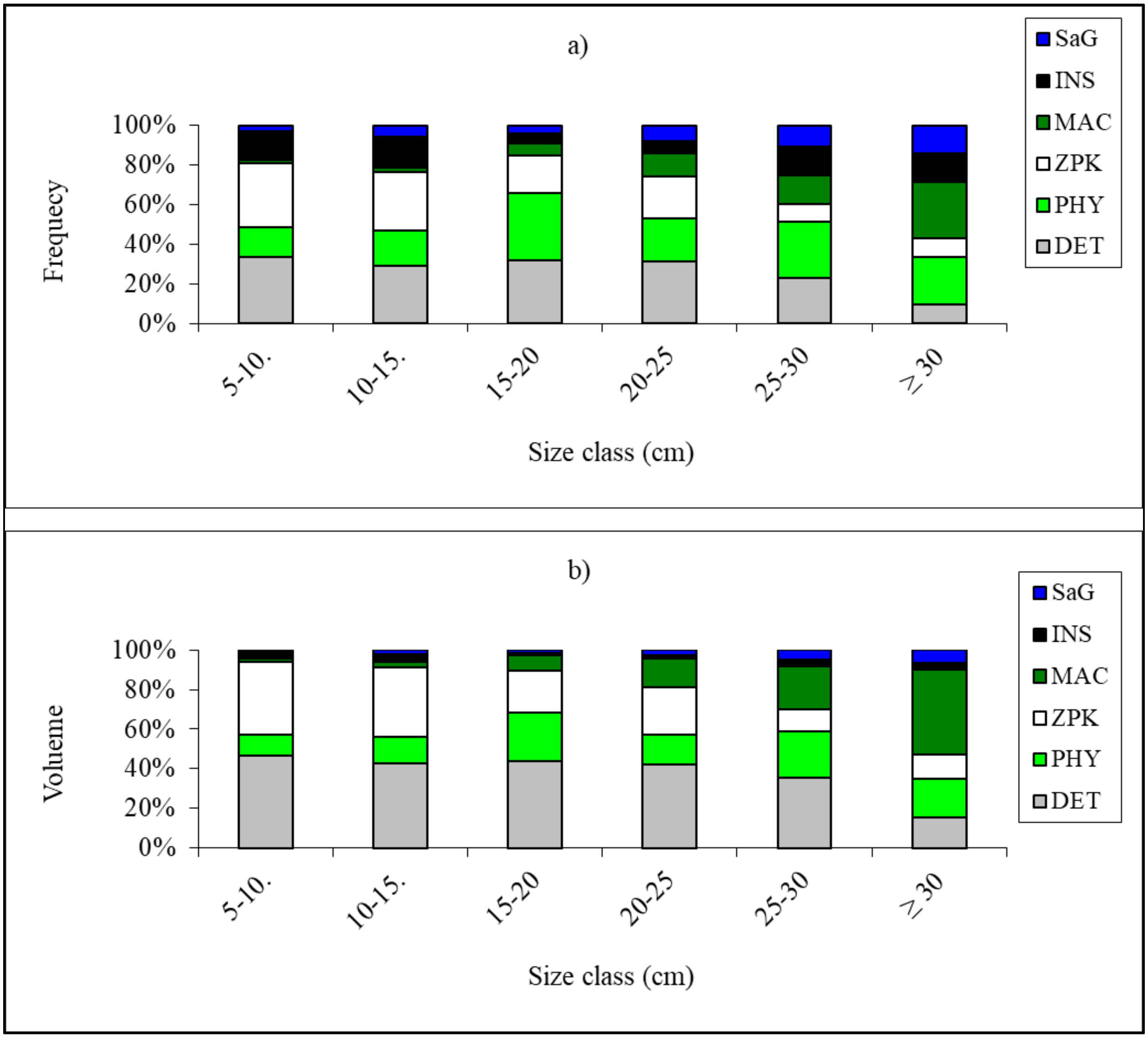

Figure 18. The frequency (a) and volumetric (b) contribution of different food items to the diet of *Labeobarbus intermedius* in different size classes from Tekeze Reservoir

***Note**: DET - detritus, PHY – phytoplankton, ZPK – zooplankton, MAC – macrophytes, INS – insects, SaG – sand grains*

The size and feeding habit relation of *B. docmak* was described in figure 19. Except for phytoplankton, macrophytes and sand grains, which were missed in some size classes, the remaining food items were frequently ingested in all size classes of the fishes. The food items of most of the size classes were dominated by fish and fish remains, zooplankton, detritus and insects.

In the feeding habits of *B. docmak*, complete ontogenic dietary shifts were observed in some size classes (Fig. 19).

In size class, 14-19 cm detritus and zooplankton equally dominated the stomachs of *B. docmak* containing food and followed by insects. Both detritus and zooplankton occurred in 75% (each) and insects in 50% of the stomachs with food in the class (Fig. 19a). However, volumetrically, fish and fish remains, zooplankton and insects were the first, second and third most important food items of the class, accounting for 47.53%, 23.19% and 17.78% of the total volume of the food items, respectively (Fig. 19b). The volumetric contribution of detritus (11.52%) to the diet of *B. docmak* in the size class was placed fourth (Fig. 19b). Based on the frequency of occurrence, fish and fish remains (25%) contributed least to the diet of *B. docmak* (Fig. 19a). Phytoplankton, macrophytes and sand grains were not obtained in the stomach content of the size class fishes (Table 27).

Detritus dominated the stomachs of the size class of 19-24 cm standard length, occurred in 89.74% of the stomachs with food and followed by fish and fish remains, zooplankton, sand grains and insects, which were obtained in 69.23%, 53.85%, 51.28% and 48.72% of the stomachs with food (Fig. 19a), respectively. Volumetrically, fish and fish remains (66.81%) were the most important food items and followed by insects (8.79%) and zooplankton (8.47%). Sand grains and detritus contributed 7.91% and 7% of the volume of the food within the class (Fig. 19b). Phytoplankton contributed least to the diet of the fishes, occurred in 7.7% of the stomachs containing food (Fig. 19a) and comprised 1.03% of the total volume of the food items in the class (Fig. 19b).

Fish and fish remains were the most important food items in size class 24-29 cm standard length, occurring in 88.64% of the stomachs (Fig. 19a) and accounting for 67.76% of the total volume of food items (Fig. 19b). Detritus was the second most frequently occurring food item, observed in

70.46% of the stomachs with food (Fig. 19a) and contributed 4.35% for the total volume of the food items (Fig. 19b). Zooplankton were the next most important food items occurring in 65.91% of the stomachs (Fig. 19a) and accounting 8.21% for the total volume of the food consumed (Fig. 19b) in the size class. Insects, sand grains and phytoplankton also contributed to the diet of *B. docmak* in the size class. Sand grains and insects were obtained in 54.55% (each) and phytoplankton occurred in 34.09% of the stomachs with food (Fig. 19a). Volumetrically, they constituted 7.8% (insects), 6.66% (sand grains) and 3.6% (phytoplankton) of the volume of the food items in the size class (Fig. 19b). The contribution of macrophytes to the diet of *B. docmak* started in this size group that occurred in 2.27% of the stomachs with food (Fig. 19a) and comprised 1.63% of the total volume of the food items (Fig. 19b).

The dominant food item in the stomachs in size class 29-34 cm was fish and fish remains, observed in 91.43% of the stomachs with food (Fig. 19a) and constituted 68.64% of the total volume of food items within the size class (Fig. 19b). Zooplankton, sand grains, detritus and phytoplankton found in 68.57%, 60%, 51.43 and 48.57% of the stomachs (Fig. 19a) and comprised 8.39%, 7.2%, 3.12% and 5.04% of the total volume of the food items (Fig. 19b), respectively. In this size class, the contribution of insects and macrophytes to the diet was relatively low, obtained in 25.71% and 5.71% of the stomachs contained food (Fig. 19a) and constituted 3.61% and 4.02% of the total volume of food consumed (Fig. 19b), respectively.

In size class, 34-39 cm standard length fish and fish remains were the most frequently ingested food items by *B. docmak* in the reservoir. They occurred in 86.67% of the stomachs with food (Fig. 19a) and accounted for 64.66% of the total volume of food items consumed within the size class (Fig. 19b). Zooplankton and sand grains were the second most important and frequently ingested food items observed in 66.67% (each) of the stomachs (Fig. 19a) and comprised 8.1% and 7.95%

of the total volume of the food items in the size class (Fig. 19b), respectively. Phytoplankton and insects found in 40% and 33.33% of the stomachs contained food (Fig. 19a) and shard 4.12% and 4.65% of the total volume of the stomachs consumed by the size class of the fishes, respectively (Fig. 19b). Detritus and macrophytes were the relatively less contributed food items, which observed in 20% and 13.33% of the food contained stomachs (Fig. 19a) and accounted for 1.21% and 9.31% for the total volume of the food items, respectively (Fig. 19b).

In the size class 39-44 cm, fish and fish remain, sand grains and phytoplankton were the most important food items and equally dominated (71. 41% each) the stomach contents of the fishes with food (Fig. 19a), but they were different in volumetric proportion. They contributed 66.64%, 10.61% and 9.16% of the volume of the food items (Fig. 19b), respectively. Insects and zooplankton were the next most frequently consumed food items by the size class fishes. Insects occurred in 42.88% and zooplanktons in 28.57% of the stomachs with food (Fig. 19a). Volumetrically, they contributed 7.45% (insects) and 4.32% (zooplanktons) for the total volume of the food items within the size class (Fig. 19b).

In size class 44-49 cm, phytoplankton occurred in 100% of the stomachs with food (Fig. 19a) and constituted 11.29% of the total volume of the food items consumed in the classes (Fig. 19b). Fish remains and sand grains observed in 75% (each) of the stomachs with food (Fig. 19a) and constituted 61.32% and 9.79% of the volume of the food items in the classes (Fig. 19b). Insects, zooplankton and detritus obtained in 50% (each) of the guts (Fig. 19a) and accounted for 7.65%, 6.65% and 3.3% (Fig. 19b) for the total volume of the food items consumed in the class, respectively. Fish and fish remains (87.5%) dominated the stomach content of the size class 49 and above cm, followed by sand grains (75%) and phytoplanktons (50%) (Fig. 19a). They constituted 76.21%, 10.44% and 6.02% of the total volume of the food items in the class (Fig.

19b), respectively. Zooplankton, detritus and insects contributed least to the diet of *B. docmak*. They observed in 25%, 24.9% and 12.5% of the stomach with food (Fig. 19a) and shared 3.54%, 1.76% and 2.04% of the volume of the food items in the size classes (Fig. 19b), respectively.

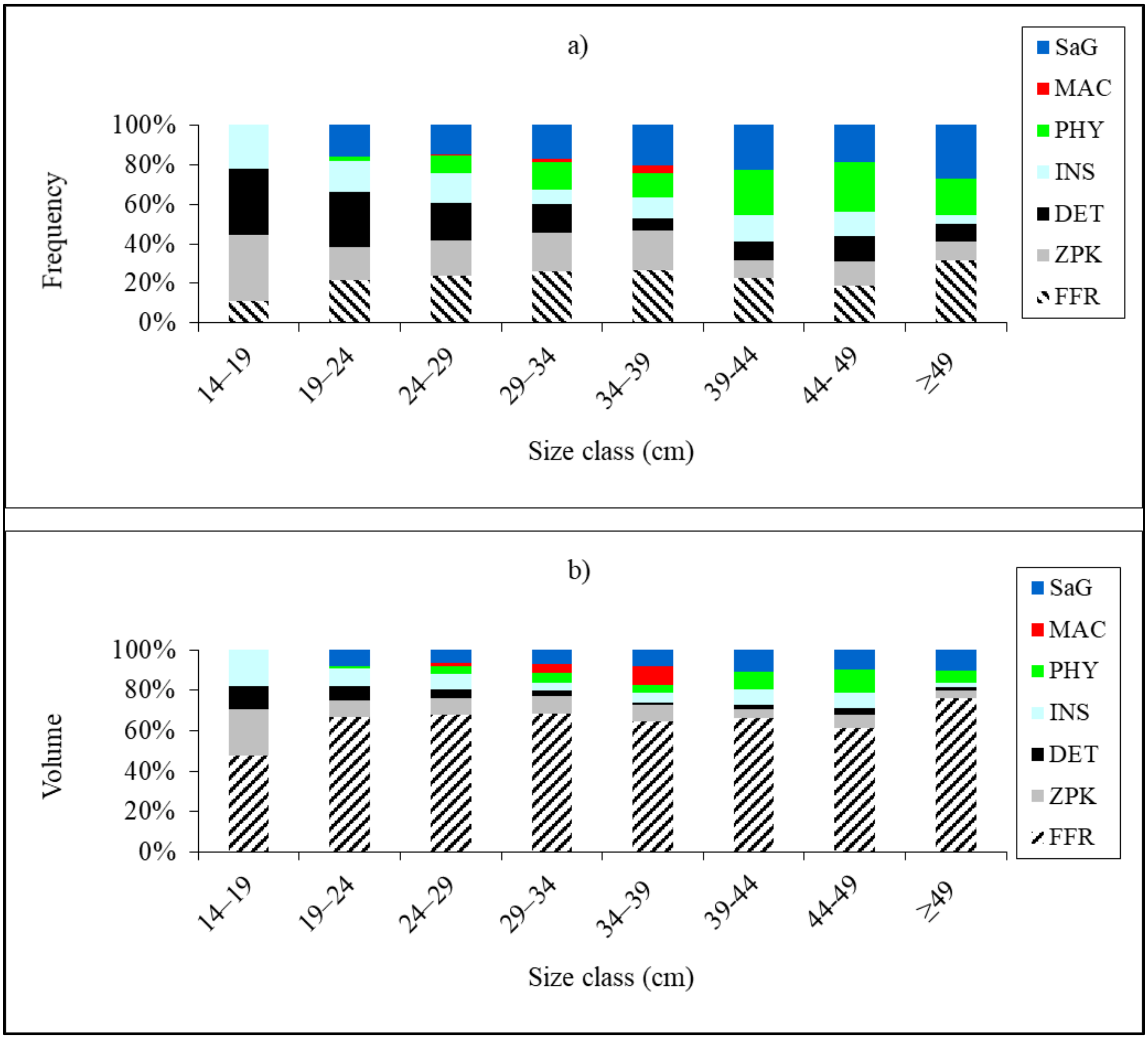

Figure 19. Frequency (a) and volumetric (b) contribution of different food items to the diet of *Bagrus docmak* in different size classes from Tekeze Reservoir

Note: *FFR – fish and fish remains, ZPK – zooplankton, DET- detritus, INS – insects, PHY – phytoplankton, MAC – macrophytes and SaG – sand grains*

4.4. Discussions

4.4.1. Relative contribution

The results obtained in the present study indicated that *O. niloticus* was omnivorous. The diet of the fishes was composed of phytoplankton, zooplankton, detritus and macrophytes. Many authors have reported similar findings for similar fish species from different Ethiopian water bodies (Zenebe Tadesse, 1998; Flipos Engdaw *et al.*, 2013; Mulugeta Wakjira, 2013; Tsegay Teame *et al.*, 2016a; Mathewos Temesgen, 2017; Abidemi-Iromini, 2019). However, in terms of prey importance, food items of plant origin, particularly phytoplankton, were the most dominant food items consumed by the fishes and followed by zooplankton. In agreement with this finding, phytoplankton is the most important food items of *O. niloticus* in Koka Reservoir (Flipos Engdaw *et al.*, 2013), Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013), Lake Hayq (Workiyie Worie and Abebe Getahun, 2015), Lake Langeno (Mathewos Temesgen, 2017), Lake Tinishu Abaya (Yirga Enawgaw and Brook Lemma, 2018) and Lagos Lagoon (Abidemi-Iromini, 2019). However, zooplanktons are the most preferred food items in Lake Hashenge (Tsegay Teame *et al.*, 2016a).

Labeobarbus intermedius feeds on a variety of foods. Detritus, phytoplankton, zooplankton, macrophytes, insects and sand grains were the major food items of the fishes. Similar diet composition was reported for similar fish species in Lake Hawassa (Demeke Admassu and Elias Dadebo, 1997; Zerihun Desta *et al.*, 2006), Koka Reservoir (Elias Dadebo *et al.*, 2013) and Lake Tana (Sibbing *et al.*, 1994; De Graaf *et al.*, 2000; Flipos Engdaw, 2014). However, fish fry, fish eggs, nematodes, benthic invertebrates and mollusks were reported in the diet of *L. intermedius* in those water bodies, which are different from the findings of the present study.

The relative contribution of major food items to the diet of *L. intermedius* was different. The food items of the species were dominated by detritus, phytoplankton and zooplankton. However, macrophytes, insects and sand grains had fewer contributions to the diet of the fishes. In agreement with this result, detritus and phytoplankton dominated the food items of *L. intermedius* in Lake Tana (Flipos Engdaw, 2014). In another report, the diet of the same species in the same water body (Lake Tana) was mainly dominated by a benthic invertebrate, zooplankton and macrophytes (Sibbing *et al.*, 1994; De Graaf *et al.*, 2000). The type of food items consumed by *L. intermedius* depends on prey availability, season, habitat type and fish size (Demeke Admassu and Elias Dadebo, 1997; Zerihun Desta *et al.*, 2006). For instance, the relative contribution of the food items to the diet of *L. intermedius* in Lake Hawassa includes mollusks, aquatic insects and macrophytes (Zerihun Desta *et al.*, 2006). Macrophytes, detritus and insects are the most important food items in Koka Reservoir (Elias Dadebo *et al.*, 2013). Similarly, macrophytes, zooplankton and aquatic insects are the most important prey items consumed by *L. intermedius* in Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013).

The diet composition of *B. docmak* in this study includes fish and fish remains, zooplanktons, detritus, insects, phytoplankton, macrophytes and sand grains. However, Hailu Anja and Seyoum Mengistou (2001) reported that insects, mollusks, different fish species and fish remains (excluding zooplankton, detritus, phytoplankton, macrophytes and sand grains, which were reported in the present study) are the major diet composition for similar species in Lake Chamo. Yongo *et al*. (2020) also reported that detritus, insects and different fish species are the frequently consumed food items of *B. docmak* in Lake Victoria. The result of this study showed that fish and fish remains particularly that of *L. intermedius* were the most important food items for *B. docmak* in Tekeze Reservoir. In other water bodies, different fish preys were reported as major food items for similar species. For example, *Synodontis schall* in Lake Chamo (Hailu Anja and Seyoum Mengistou, 2001), Tilapia and unidentified fish remain in Muess Channel (El-Drawany and

Elnagar, 2015), and *Haplochromis* spp. and *Engraulicypris argenteus* in Lake Victoria (Yongo *et al.*, 2020) were documented as the most important food types for *B. docmak*. One factor for the selection of food by *B. docmak* is the easy availability of prey fish (Hailu Anja and Seyoum Mengistou, 2001), but it was observed that *O. niloticus*, *L. forskalii* and *L. niloticus* were more abundant and available in Tekeze Reservoir. However, they were not preferred and consumed as food by *B. docmak.* Thus, *L. intermedius* might be a specially preferred fish prey for *B. docmak*.

4.4.2. Seasonal contribution

Although the major food items of *O. niloticus* in Tekeze Reservoir were consumed in all sampling seasons of the study period, the food of plant origin (phytoplankton) was the preferred food item during the dry season. However, the food of animal origin (zooplankton) was the most important in the wet season of the study period. Similar findings were also reported in Lake Langeno (Mathewos Temesgen, 2017), Koka Reservoir (Flipos Engdaw *et al.*, 2013), Lake Hayq (Workiyie Worie and Abebe Getahun, 2015) and Omo River (Mulugeta Wakjira, 2016). The relatively low proportion of phytoplankton in the diet of *O. niloticus* during the wet season might be associated with the high flooding from the reservoir's catchments area, which can cause fluctuation in water level and increase the turbidity of the reservoir. However, phytoplanktons were the most important food items in Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013) and Lake Hashenge (Tsegay Teame *et al.*, 2016a). The contribution of macrophytes and detritus to the diet of *O. niloticus* in Tekeze Reservoir was low. Many studies have reported that the feeding habits of tropical fishes are very dependent on the accessibility of the resources in the environment (Silva *et al.*, 2014). This indicates the changing of food item composition in the diet of *O. niloticus* based on the diet composition in the reservoir, which may vary depending on environmental condition, season and habitat types of the reservoir.

Seasonality did not affect the feeding behavior and the type of prey organisms of *L. intermedius* in Tekeze Reservoir because the majority of food items showed no significant seasonal differences. However, the proportions of the consumed food items in different seasons were different. This variation in the proportion of the different food categories could be due to the difference in the availability and emergence of various food items during the dry and wet seasons (Elias Dadebo *et al.*, 2014). During the dry seasons, phytoplankton (dry cold season) and detritus (dry hot season) were the most important food items, but detritus and zooplanktons dominated the food items consumed by *L. intermedius* in the wet season. Relatively, the contribution of detritus and phytoplankton decreased, while zooplankton, macrophytes, insects and sand grains increased their contribution in the wet season. The present study is in agreement with the works that state phytoplankton and detritus are more important during the dry season while zooplankton, macrophytes and insects are more important during the wet season in Lake Hawassa (Demeke Admassu and Elias Dadebo, 1997), Gilgel Gibe Reservoir (Mulugeta Wakjira, 2013) and Koka Reservoir (Elias Dadebo *et al.*, 2013).

Generally, the food items of plant origin of *L. intermedius* were increased during the dry season while the food items of animal origin increased in the wet season. However, reports in different Ethiopian water bodies showed that the contribution of food items of plant origin during the wet season is very high while the contribution of animal prey is low (Agumassie Tesfahun and Mathewos Temesgen, 2017), which contradicted with the present study.

Bagrus docmak consumed all types of food items in all sampling seasons. Therefore, *B. docmak* was found to be an indiscriminate feeder. This was in agreement with results by Hailu Anja and Seyoum Mengistou (2001) in Lake Chamo and Yongo *et al* (2020) in Lake Victoria. However, during the dry cold season, detritus and phytoplankton were the most important food items and in the dry hot and wet seasons fish remains and zooplankton were the dominant food items for *B. docmak*. This was comparable with findings reported for similar species in other water bodies, where food items of animal origin are important in a wet season, while foods of plant origin and detritus become dominant in the dry season (El-Drawany and Elnagar, 2015; Yongo *et al.*, 2019). Volumetrically, fish and fish remains had dominated the diet of the species in all seasons. This might be due to the large size of the food type. As those of *O. niloticus* and *L. intermedius*, the seasonal variation on the feeding habits of *B. docmak* could be due to the easy accessibility of the prey items in the area.

4.4.3. Ontogenic dietary shifts

The size-based feeding habit of *O. niloticus* showed that zooplankton and detritus were the dominant food items for all the length classes below 14 cm. The highest contribution of zooplankton for the length class was supported by different authors in Lake Chamo (Yirgaw Teferi *et al.*, 2000), Koka Reservoir (Flipos Engdaw *et al.*, 2013) and Lake Langeno (Mathewos Temesgen, 2017). Juveniles of *O. niloticus* mainly feed on zooplankton (Flipos Engdaw *et al.*, 2013; Workiyie Worie and Abebe Getahun, 2015; Mathewos Temesgen, 2017). In this length group, macrophytes were not found in the gut, but to some extent, phytoplankton was rarely ingested. This is because juvenile fish need high protein intake to support a high growth rate and metabolism (Benavides *et al.*, 1994). Additionally, having a small stomach volume that cannot support big macrophytes and other plant foods can be another reason for juveniles of *O. niloticus* to feed on zooplankton in the reservoir.

For the larger fish groups (>14 cm TL) of *O. niloticus*, however, the plant origin food types (phytoplankton) were the highly preferred food types in Tekeze Reservoir. According to Benavides *et al*. (1994), *O. niloticus* change their feeding behavior from primarily omnivorous to herbivorous with high-energy demands as they grow in size. The growing demand for energy cannot be met by feeding only on zooplankton. This enables them to shift their feeding behavior from eating only zooplankton to the generalist behavior (Agumassie Tesfahun and Mathewos Temesgen, 2018). Also, the bigger fish are more capable of digesting cell wall material and therefore can be less selective in their feeding pattern (Zenebe Tadesse, 1998). The shift in feeding behavior shows a low degree of intraspecific competition for particular food among different length groups (Ayoade *et al.*, 2008).

The major food items of *L. intermedius* were consumed by all size classes of the fishes in the Tekeze Reservoir. Except in proportion, complete diet shift was not observed and therefore, small and large size fish consumed similar food items in the reservoir. This was in agreement with the findings reported by Flipos Engdaw (2014) in Lake Tana and Elias Dadebo *et al*. (2013) in Koka Reservoir. Opposed to this result, Zerihun Desta *et al*. (2006) in Lake Hawassa studied the feeding habits of *L. intermedius* and reported ontogenic diet shifts. They noted that *L. intermedius* in Lake Hawassa shifted from insectivores to piscivorous feeding habits as its size increased.

The smaller size classes (< 15 cm SL) mostly fed on detritus and zooplankton in large amounts while in larger size classes macrophytes and phytoplankton were the most dominant food items of *L. intermedius*. The contribution of detritus and zooplankton to the diet of the fishes decreased when the size of the fish increased, but the contribution of phytoplankton, macrophytes and sand grains increased with increasing size of the fishes. The slight variation observed was that macrophytes were relatively unimportant in the diet of the smaller size classes (< 15 cm SL) while they were dominant food items in larger size classes (≥30 cm SL). Similar results were reported from Lake Tana (Flipos Engdaw, 2014), Koka Reservoir (Elias Dadebo *et al.*, 2013) and Lake Hawassa (Zerihun Desta *et al.*, 2006). Aquatic insects were relatively unimportant in the diet of *L.*

intermedius in the middle size classes (15-25 cm SL), but they were among the important food items in the smaller size classes (≤ 15 cm SL) and larger size classes (≥25 cm SL). However, insects that are the most important food items in the smallest size class are relatively unimportant in the larger size class in Lake Hawassa (Zerihun Desta *et al.*, 2006) and Koka Reservoir (Elias Dadebo *et al.*, 2013), which is different from the present study.

The diet composition of *B. docmak* in this study varied with its size with the juveniles of less than 24 cm standard length feeding mainly on detritus, zooplankton and insects while excluding phytoplankton and macrophytes. Except in size class 39 – 44 cm standard length that was dominated by phytoplankton, the remaining adult size classes were dominated by fish and fish remains. Similarly, adult *B. docmak* in the Nyanza Gulf of Lake Victoria fed mostly on fish species, whereas, juveniles preferred aquatic benthic invertebrates (Okach and Dadzie, 1988). In Lake Chamo, juvenile *B. docmak* ingested more insects than fish while older fish were largely piscivorous (Hailu Anja and Seyoum Mengistou, 2001). The relative importance of detritus, zooplankton and insects to the diet of *B. docmak* decreased with the size of the individual fishes, but the contribution of fish and fish remains, phytoplankton and sand grains increased with the increment of the size of the fishes. A review of the feeding habits of various *Bagrus* species in African freshwater bodies also reported a similar ontogenetic diet shift (Yongo *et al.*, 2019). However, Yongo *et al*., (2020) in Lake Victoria reported that *Caridina nilotica* is the dominant food item for juveniles of *B. docmak*. The frequent occurrence of sand grains on the diet of *B. docmak* might indicate the bottom feeder and bottom-dweller behavior of the fishes. Similarly, other reports indicated that *Bagrus* species are predatory bottom-dwellers and feed on invertebrates and fish species. They feed predominantly on invertebrates when young and shift to piscivorous feeding habits when reaching an adult stage (Wakil *et al.*, 2014).

Generally, 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). Therefore, ontogenetic changes in fish diet are guided by the development of the fish morphological and physiological features as it grows (Agembe *et al.*, 2019).

4.5. Conclusions

The feeding habits of all the studied fish species such as *O. niloticus*, *L. intermedius* and *B. docmak* were omnivores in Tekeze Reservoir. Phytoplankton and zooplankton were the preferred food items for *O. niloticus*. Detritus, phytoplankton and Zooplanktons were the most important food items for *L. intermedius*. Fish and fish remain, zooplankton, detritus and insects were the major food items for *B. docmak*.

4.6. Recommendations

A study on the trophic position of the species and their trophic role in the reservoir system is required to plan valid strategies for proper utilization and conservation of the ecosystem in general.

CHAPTER FIVE

5. YIELD ASSESSMENT AND EXTENT OF IMMATURE FISH HARVESTING IN TEKEZE RESERVOIR FISHERY

Abstract

Data on the fish production status and exploitation level of the Tekeze Reservoir fishery by commercial fishers were collected for a period of one year from January to December 2017. The reservoir's fish production potential was estimated by using different empirical models represented by $Y = 14.3136MEI^{0.4681}$, *ln* $(Yt)=3.57+0.76ln(A)$ *and* $Yt=8.32A^{0.92}$ *equations and the commercial catch was calculated from 91 regularly operating fishing boats. The extent of immature fish harvesting was also quantified from randomly selected commercial catches at the fishing and landing sites. The average yield was 62.12kg/ha/year and 996.38 tons/year for the whole reservoir. Oreochromis niloticus, Labeobarbus intermedius, Bagrus docmak, Clarias gariepinus and Labeo niloticus were the commercially important fish species. However, the first three were the major important ones. The catch per unit effort of the fishery ranged from 15.98 kg/boat/day to 3.26 kg/boat/day. The highest catch was recorded in October and the least was in January. The catch assessment of the 91 fishing boats (150.38 tons/year) shows underutilization of the stock, but there is also a probability for the cause of over-exploitation by the 612 year-round active fishing boats (1,011.27 tons/year) in the reservoir. The extent of immature fish harvesting by the commercial catch indicated that O. niloticus (33.32%) and L. intermedius (37.72%) and B. docmak (42.17%), were caught before they attain their first sexual maturity. This means about 37.01% of the total catch of the commercial fishery were harvested before they attain sexual maturity. Therefore, utilization of the fishery resources using a recommended fishing effort and mesh size of gillnet is recommended.*

Keywords/phrases: *Catch per unit effort, fishing boats, immature fishing, yield*

5.1. Introduction

The productivity of reservoirs and other inland fisheries is dependent and closely linked to the functioning of freshwater ecosystems (Lymer *et al.*, 2016). Overexploitation, destructive and unsuitable fishing practices, degradation and loss of freshwater ecosystems threaten inland fisheries (Allan *et al.*, 2005; Welcomme, 2011). In many parts of the world, inland waters are overexploited (Allan *et al.*, 2005; Jia *et al.*, 2013) while at the same time, many fish populations, for instance in the northern European lakes are exploited insufficiently (Sipponen *et al.*, 2010). However, reported inland fisheries landings increased steadily with the current level of annual harvest being approximately 11.6 million metric tons (Moffitt and Cajas-Cano, 2014). This growth occurred mainly in Asia (68.4%) and Africa (23.3%) together, which now account for about 91.7% of the reported landings (Lymer *et al.*, 2016).

According to Belete Berhanu *et al.* (2014), water resources in Ethiopia have been developed to a marginal extent. The purpose of these resources is mainly for hydroelectric generation and irrigation development (Gashaw Tesfaye and Wolff, 2014). Their potential for fish production was not taken into account for several years. However, today fishing activities using traditional and to some extent modern fishing methods in lakes, rivers and reservoirs are increasing in the country. Largely, many developing countries in Asia, South America and Africa have recognized reservoir fisheries as an effective way of increasing the supply of fish as food in rural areas at an affordable price and provide additional income to rural farmers, thereby contributing to poverty alleviation (De Silva *et al.*, 2006). This would be a good insight into the development of reservoir fisheries in our country. Fishery production in Ethiopia is growing from time to time, but due to inappropriate fishing practices, water bodies located in the Rift Valleys show signs of overexploitation. However, the majority of rivers, lakes and reservoirs located in remote areas with poor infrastructure remain underutilized (Gashaw Tesfaye, 2010). Therefore, studies on production status and exploitation level of the exploited and underutilized water bodies using relevant models are important in designing fisheries management strategies.

Empirical models have been used in Asian and African lakes and reservoirs for estimating the potential fish yield over many years. These models predict complex biological effects from simple environmental parameters (Marshall, 1984). Yield predictions have been based on a mean depth and morpho-edaphic index (Henderson and Welcomme, 1974) or surface area (Marshall, 1984; Crul, 1992). Such methods have been widely used particularly in Africa, where fisheries data are not readily available since they are simple, quick and cost-effective. Therefore, the estimated potential fish yield is important information required for fisheries exploitation and management. The actual yield of the fisheries is compared with the estimated potential yield. In the absence of historical catch effort data covering several years, empirical models can be used to obtain a quick estimate of potential yield.

Adoption of more highly effective and destructive fishing gears by fishers in many areas coupled with other factors had detrimental effects on the sustainability of the fisheries resources. The booming fisheries of Tekeze Reservoir attracted big communities of fishers and other categories of stakeholders. This leads to intense fishing pressure using destructive gears. Hence, the generated information about the production condition and extent of immature fish harvesting will be important as inputs for policymakers in fisheries development and optimum utilization of the stock in Tekeze Reservoir. Therefore, the following objectives were addressed in this study:

i. To predict the potential fish yield expected from the reservoir fisheries
ii. To estimate the current catch of the commercial fisheries from the reservoir
iii. To assess the exploitation level of *O. niloticus*, *L. intermedius* and *B. docmak*

5.2. Materials and methods

5.2.1. Catch data collection

Fish yield: The potential fish yield in kg/ha/year was predicted using the Morpho-Edaphic Index (Henderson and Welcome, 1974) and other relevant models, while the actual annual fish catch in kilograms was calculated from the catch of selected fishers per boat operating in the reservoir regularly following (Edward, 2013). Data were collected by identifying fish species at the fishing and landing sites of the fisher's cooperatives and taking their weight on a daily bases using a sensitive balance. The production of the reservoir per year was calculated, with an assumption that the fishers avoid working days due to holidays and spawning season.

Immature fishing: To estimate the extent of immature commercial fish harvesting, fish samples were collected randomly from the fishers' catch in different months of the study period (November and February from the dry cold season and April and June from the dry hot season). However, due to the closure of commercial fishing, samples were not collected during the wet season, when it was the peak spawning season for the species (Chapter three). The total length for *O. niloticus* and standard length for *L. intermedius* and *B. docmak* were measured to the nearest mm. To quantify the extent of the immature fish harvesting by the commercial catches, the length measurements were categorized into length intervals and the proportion of the harvested immature fish per length class was calculated and described in percentages. For this purpose, the values of length at first maturity for each species was taken from chapter three of the study. Simultaneously, fishing gear type and mesh size of the commercial gill nets were assessed at the landing and fishing sites of the fishers.

5.2.2. Data analysis

Descriptive statistics as well as different mathematical models were used to analyze the data. For estimating the potential fish yield, the common models that have been used in Asian and African reservoirs were applied. Henderson and Welcome (1974) were probably the first to try to derive a yield model specifically for African lakes and reservoirs. Their original data set of 17 moderately to heavily exploited lakes and reservoirs were used and the model has been subsequently utilized by many other authors.

Model 1: $Y = 14.3136\ MEI^{0.4681}\ \ and\ MEI = \frac{Conductivity\ (\mu S/cm)}{Mean\ depth\ in\ m}$

Where Y = Yield in kg/ha and MEI = Morpho-Edaphic Index

Marshal (1984) reported that the total production of a lake or a reservoir is directly related to its area. The bigger the water body, the higher the total production expected. This model is derived from data on 17 heavily exploited African lakes and reservoirs.

Model 2: $ln\ (Yt) = 3.57 + 0.76\ln(A)$

Where: ln = natural logarithm Yt = yield in tons and A = area of the reservoir in km^2

Crul (1992) developed a model with the same concept as model 2, but it is derived from a much bigger data set. It includes 46 lakes and 25 reservoirs all situated in Africa. It is the most up to date model.

Model 3: $Yt = 8.32A^{0.92}$

Where: Yt = yield in tons A = area of the reservoir in km^2.

Table 28. The input parameters used for the estimation of potential fish yield of Tekeze Reservoir

Study area	**Depth (m)**	**Area (km^2)**	**Conductivity (µS/cm)**	**MEI**
Tekeze Reservoir	58.6*	160.4*	206.83**	3.53***

Note: **From the office of Tekeze Power Station, **From this study and ***calculated by dividing the mean conductivity to the mean depth of the reservoir*

The annual production (yield) of the reservoir was calculated as follows (Edward, 2013):

$$TDC = NFB\ X\ ADC\ and\ AC = TDC\ X\ NCD$$

Where: TDC = Total Daily Catches (kg), NFB = No of fishing boats, ADC = Average Daily Catches (kg), EAPFY = Estimated Annual Potential Fish Yield and NCD = No of Catching Days per year. Finally, the exploitation level of the reservoir fisheries was calculated as follows:

$$\%\ Exploited = \frac{AC}{EAPFY}\ X\ 100$$

Where: AC = annual catch

5.3. Results

5.3.1. Estimation of fish production potential

The three models gave an estimated value of the potential yield ranging from 25.83 kg/ha/year to 105.1 kg/ha/year with an average yield of 62.12 kg/ha/year. The total fish yield of the whole reservoir ranged from 415.31 tons/year to 1685.81 tons/year and the average was 996.38 tons/year. The lowest and the highest potential fish yield were estimated by Henderson and Welcome (1994) and Marshal (1984) models, respectively (Table 29).

Table 29. The estimated annual fish production potential of Tekeze Reservoir

Models	Yield (kg/ha/year)	Total yield (t/year)
Model 1 (Henderson and Welcome, 1974)	25.83	414.31
Model 2 (Marshal, 1984)	105.1	1,685.81
Model 3 (Crul, 1992)	55.43	889.02
Average	**62.12**	**996.38**

5.3.2. Commercial catch assessment

Oreochromis niloticus, *B. docmak*, *L. intermedius*, *C. gariepinus* and *L. niloticus* were the five fish species targeted by commercial gillnet fisheries of Tekeze Reservoir. Especially, the first three were the most commercially important fish species in the reservoir. *Bagrus bajad* and other *Labeobarbus* species were also rarely obtained in the catch of the commercial fishery. From the total catch collected from 91 boats, *O. niloticus* contributed 37.9% (56,996.94 kg), which was the highest of the total catch (Table 30). *Bagrus docmak* (40,933.62 kg), *L. intermedius* (23,017.54 kg) and *C. gariepinus* (20,017.27 kg) contributed 27.22%, 15.31% and 13.31%, respectively (Table 30). However, *L. niloticus* (9,410.31 kg) were the least in contributions, which was about 6.26% of the total catch (Table 30).

Table 30. Contribution of the different fish species to the annual catch of the commercial fishery in Tekeze Reservoir

Species	Total catch (kg/year)	Catch (%)
O. niloticus	56,996.94	37.9
L. intermedius	23,017.54	15.31
B. docmak	40,933.62	27.22
L. niloticus	9,410.31	6.26
C. gariepinus	20,017.27	13.31
Overall catch (kg)	**150,375.68**	**100**

The catch of the fishers on monthly bases varies between months and fish species. As indicated in figure 20 below, the catch of *O. niloticus* shows an increasing trend starting from January (1,660.75 kg) to April (8,550.36), but declined sharply in May (909.09 kg). It is also increased from May to October (15, 338.96) and declined again after October. Similarly, the highest catches of *B. docmak* (13,402.48 kg), *L. intermedius* (5,733 kg) and *C. gariepinus* (4,815. 72 kg) were also recorded in October and declined dramatically towards December. However, the highest catch (1,630.72 kg) of *L. niloticus* was recorded in December.

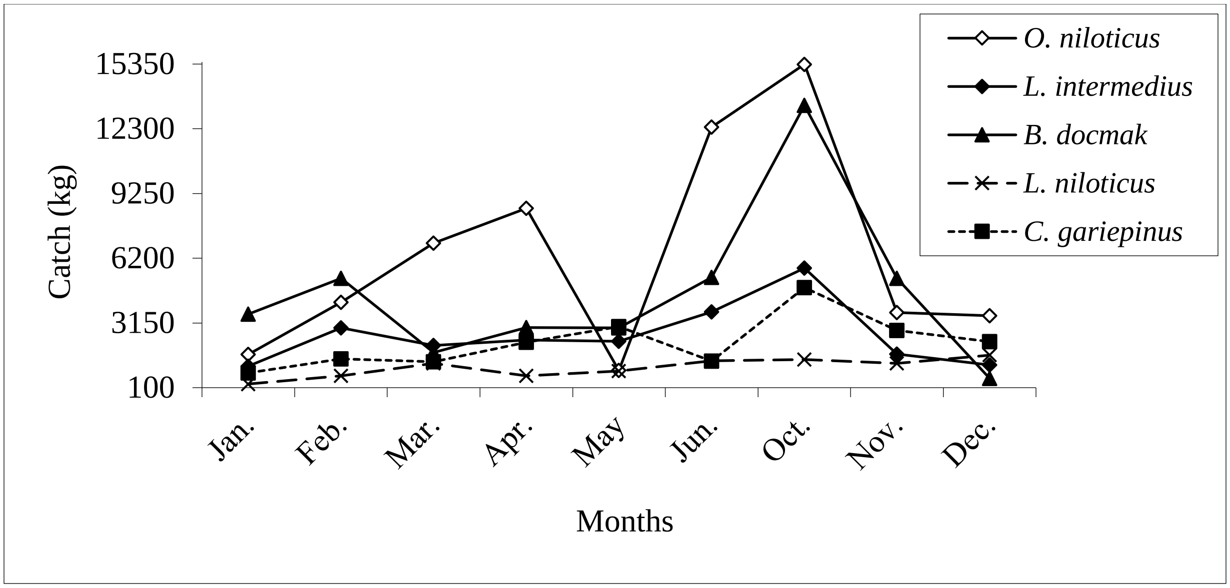

Figure 20. Monthly catch (kg) pattern of the commercial fishery at the species level in Tekeze Reservoir

The total catch distribution of the 91 commercial fishers showed that October (40,717.04 kg) exhibited the highest catch and followed by June (24,062.22 kg), April (16,731.26 kg), November (14,628.25 kg), February (14,422.59 kg) and March (13,326.04 kg), respectively. The least was recorded in January (7,416.5 kg), December (9,096.36 kg) and May (9,975.42 kg) in increasing order, respectively (Fig. 21).

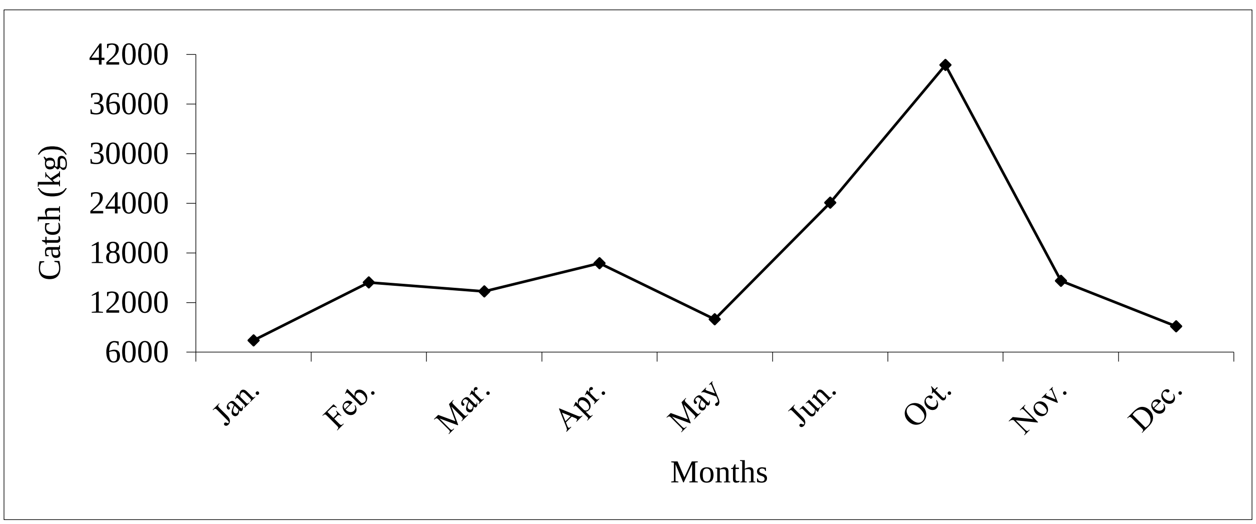

Figure 21. Monthly total catch distribution from catches of Tekeze Reservoir fishers

The fishing days per month for the fishers ranged from 25 (January and November) to 29 (April) with an average of 27 days per month. The catch per unit effort of the fisheries ranged between 15.98 kg/boat/day and 3.26 kg/boat/day (Table 31). The maximum catch per unit effort was recorded in October and the minimum was in January. The second highest (10.17 kg/boat/day) and lowest (3.57 kg/boat/day) catch per unit effort were recorded in June and December, respectively. The catch of the remaining months of the year show in the range of 4.06 kg/boat/day and 6.43 kg/boat/day. The average catch per unit effort for the year was 6.80 kg/boat/day (Table 31).

Table 31. Daily catch per unit effort (CPUE) of Tekeze Reservoir fisheries

Months	**Parameters**		
	Active boats/ day	**Fishing days**	**CPUE (kg/boat/day)**
January	91	25	3.26
February		27	5.87
March		28	5.23
April		29	6.34
May		27	4.06
June		26	10.17
October		28	15.98
November		25	6.43
December		28	3.57
Average	**91**	**27**	**6.80**

Generally, the 91 fishing boats spent an average of 243 days per year in the fishing area. During this time, 618.83 kg/day average daily catch was recorded from the fishing boats. The total catch calculated during the year was 150,375.68 kg/year, which is equivalent to 150.38 tones/year (Table 32). This was less than the estimated annual fish production potential of the reservoir that was 996.16 tons/year. The exploited level of the fishery by the fishing boats was only 15.1% of the estimated production potential and 84.9% were unexploited (Table 32). This indicates the underutilization of the stock by the 91 fishing boats.

However, from the total of 950 fishing boats, an average of 612 year-round active (except the closed months) fishing boats in 38 fishery cooperatives were found in the reservoir. Therefore, there was no reason that those all (612) active fishing boats cannot catch 6.8 kg/day similar to that of the assessed 91 fishing boats. Accordingly, these active fishing boats will have a probability to catch 4,161.6 kg/day and a total catch of 1,011.27 tons/year, which is beyond the predicted maximum sustainable production potential of the fishery. As described in table 34 below, 1.49% of the total catch is beyond the production potentials and indicated the presence of overexploitation of the fish stock in the reservoir.

Table 32. Annual fishing effort and catch assessment of the commercial fishery in Tekeze Reservoir

Total boats	**Active boats/year**	**Fishing days/year**	**Daily catches (kg/day)**	**Total catch tons/year**	**Exploited (%)**	**Unexploited (%)**
	91		618.83	150.38	15.1	84.9
950	612	243	4,161.6	1,011.27	101.49	-

5.3.3. Exploitation level of *O. niloticus*, *L. intermedius* and *B. docmak*

As described in chapter three of the study (section 3.3.5.2) the average length at which 50% of *O. niloticus* reached sexual maturity (L_{50}) was found to be 24.20 cm and 24.81 cm for female and male *O. niloticus*, respectively. *Labeobarbus intermedius* were mature at a standard length of 20.84 cm for females and 22.05 cm for males. Female *B. docmak* matured at the length of 27.42 cm and the males at 26.79 cm.

Oreochromis niloticus: The size range of the catch of *O. niloticus* by the commercial fisheries in Tekeze Reservoir was found between 10 and 39.5 cm; 33.32% of the total catch was below the average length of the first sexual maturity (< 25 cm) (Table 33). Of the immature species, 18.19% were obtained in the length class of 20 – 25 cm and the remaining 10.29% and 4.84% were between the size class of 15 – 20 cm and 10 – 15 cm, respectively (Table 33). This indicates the presence of exploitation of immature *O. niloticus* in the reservoir. The commercial gill nets were fairly wide to allow the escape of *O. niloticus* below 15 cm, but not wide enough to avoid catching between the size intervals of 15 – 20 and 20 - 25 cm that was considered as immature fish species in the present study. Therefore, to protect the fish population in the reservoir, 25 cm should be the cutoff size for *O. niloticus*.

Table 33. The extent of immature *Oreochromis niloticus* in different length classes harvested by commercial fishers in Tekeze Reservoir

Length group (cm)	Catch number	Proportion (%)
10 – 15	112	4.84
15 – 20	238	10.29
20 – 25	421	18.19
25 – 30	751	32.45
30 – 35	440	19.02
35 – 40	352	15.21
Total	**2, 314**	**100**

***Labeobarbus intermedius*:** A total of 1,723 *L. intermedius* were randomly collected from the fisher's catch data (Table 34). The smallest *L. intermedius* caught by the fishers was 7.1 cm and the maximum was 47 cm in standard length. About 37.72% of the total catch was below 22 cm, which is considered below the average length at first sexual maturity. The largest proportion of the immature fish caught by the fishers was found in the size class of 17 – 22 cm standard length, but the 7 – 12 cm size class was less vulnerable to the fisher's gill net (Table 34). These proportions of the species were caught before reaching sexual maturity. This indicates the presence of fishing pressure on immature *L. intermedius* in the reservoir. However, 62.28% of those individuals have the opportunity to replenish themselves.

Table 34. The extent of immature *Labeobarbus intermedius* in different length classes harvested by commercial fishers in Tekeze Reservoir

Length group (cm)	Catch number	Proportion (%)
7 – 12	25	1.45
12 – 17	172	9.98
17 – 22	453	26.29
22 – 27	498	28.91
27 – 32	421	24.43
32 – 37	88	5.11
37 – 42	47	2.73
42 – 47	19	1.1
Total	**1,723**	**100**

***Bagrus docmak*:** As shown in table 38, a total of 1,418 specimens of *B. docmak* were randomly sampled from the landing sites of the commercial fishery. Of the total samples, 42.17% were below the average length at first sexual maturity (Table 35), indicating the presence of heavy exploitation of immature fish of this species. Thus, 57.83% of *B. docmak* caught by fishermen had attained maturity and were able to reproduce at least once before they were caught.

The estimated extent of immature fishing by the fishers in the reservoir shows that more immature *L. intermedius* were vulnerable to the fishing gears than *O. niloticus* while a large number of *B. docmak* were more exposed than the two species (*O. niloticus* and *L. intermedius*).

Table 35. The extent of immature *Bagrus docmak* harvested in different classes by commercial fishers in Tekeze Reservoir

Length group (cm)	Catch number	Proportion (%)
18 – 23	235	16.57
23 – 28	363	25.6
28 – 33	284	20.03
33 – 38	219	15.44
38 – 43	128	9.02
43 – 48	71	5.01
48 – 53	57	4.02
53 – 58	35	2.47
58 – 63	6	0.42
63 – 68	11	0.78
≥ 68	9	0.64
Total	**1, 418**	**100**

5.4. Discussions

5.4.1. Fish production

The average estimated potential fish yield of Tekeze Reservoir based on the empirical models was higher than the values estimated by Dereje Tewabe *et al.* (2009), but lower than the values reported by Tsegay Teame *et al.* (2016b) for the same water body. According to Dereje Tewabe *et al.* (2009), the estimated annual production potential fish yield is 968 tons/year with a productivity of 60 kg/ha/year. However, Tsegay Teame *et al.* (2016b) reported that the estimated potential fish yield is about 1065.63 tons/year with a productivity of 66.16 kg/ha/year. The differences between the authors were because the values were obtained from the Henderson and Welcome (1974) model that was influenced directly by the variation of the measured conductivity of the reservoir or morpho-edaphic index value.

The estimated annual fish production potential of the reservoir fishery was low when compared to other Ethiopian reservoirs such as Tendaho, Koka and Fincha- Amerti Reservoirs, which were estimated at 1, 345 tons/year (Hussien Abegaz *et al.*, 2010), 1, 194 tons/year and 1, 330 tons/year (Assefa Mitike, 2014), respectively. The productivity was also low relative to the Tendaho Reservoir that was estimated at79 kg/ha/year (Hussien Abegaz *et al.*, 2010). The average fish productivity of Tropical lowland lakes and reservoirs was estimated to be 80 kg/ha/year (Oglesby, 1985). Sreenivasan and Thayaparan (1983) and De Silva (1988) also predicted the fish yield for Victoria Reservoir as 75 kg/ha/ and 70 kg/ha/year, respectively, which are above the values predicted in the present study. This could be due to the high mean depth of the Tekeze Reservoir. Shallow lakes and reservoirs support high productivity of fish (Edward, 2013).

The catch assessment of the fishery shows that *O. niloticus*, *B. docmak* and *L. intermedius* were the most important commercial fish species in the reservoir. Especially the first two fish species contributed 65.12% of the total catch of the commercial fishery. In line with this result, Tsegay Teame *et al*. (2016b) reported, in their four months catch assessment, that *O. niloticus* is the most important commercial fish and contributed about 84% of the commercial catch in the reservoir. Similarly, *O. niloticus* contributes about 65% of the total commercial catch in Lake Tana (Dereje Tewabe, 2013). According to Gashaw Tesfaye and Wolff (2014), the landing statistics of Ethiopian fisheries showed that much of the production has been contributed by *O. niloticus*, which is about 50% of the annual average catch from 1998 to 2010.

The contribution of *L. intermedius* and *C. gariepinus* to the commercial catch cannot be underestimated in the present study. Both fish species contributed 28.53% of the total catch in the fishery. On the other hand, Tsegay Teame *et al*. (2016a) also described the contribution of both *C. gariepinus* and *B. docmak* in the reservoir, which is 16% of the total catch of the commercial fishery. According to Tsegay Teame *et al.* (2016b), only three fish species (*O. niloticus*, *C. gariepinus* and *B. docmak*) are targeted by the commercial fishers in Tekeze Reservoir. However, the result of the present study indicated that more than five including the rarely obtained fish species in the commercial catch (*O. niloticus*, *B. docmak*, *L. intermedius*, *C. gariepinus*, *L. niloticus*, *B. bajad and* other *Barbus* species) were targeted by the fishers. As a result, having alternative commercial fish species in the reservoir will have an opportunity to reduce the fishing pressure on few or single fish species.

The highest catch of the commercial fishery was recorded in October and followed by June. These two months alone contributed more than 43% of the total catch. The high catch in October might be due to the fishing pressure at the spawning grounds at the peak spawning season of the major commercial fish species such as *O. niloticus*, *L. intermedius* and *B. docmak* in the reservoir. Dereje Tewabe (2013) in Lake Tana and Assefa Tessema *et al.* (2011) in Mille and Borkena Rivers also confirmed the prevalence of the high catch of fish species during their spawning period. The fishing restrictions for commercial fishers from July to September because of the spawning period in Tekeze Reservoir might be also another reason for the high catch at the end of the closed season (June) and the beginning of the fishing season (October).

The average daily catch per unit effort of the fishery was 6.8 kg/boat/day. This was less than the daily catches reported by Tsegay Teame *et al.* (2016b), which is 8.27 kg/boat/day in the same water body. Hence, the value shows the decline of the catch due to the increased fishing pressure in the reservoir. Although the catch assessment of the 91 fishing boats shows underutilization of the stock, there is also a huge probability for over-exploitation of the stock by all-year-round active fishing boats in the reservoir. This overexploitation of the stock could be due to the distribution of the fishing boats beyond the capacity of the resources. So, the utilization of the fish resources in a sustainable manner using optimum effort is mandatory.

5.4.2. Immature fish harvesting

To maintain the sustainability of aquatic resources, harvesting fishes by commercial fisheries should consider the length at first maturity of the fishes. So, length at first maturity is assumed to be the minimum harvestable size of fish species for commercial fisheries (Tesfaye Wudneh, 1998; Tesfaye Muluye *et al.*, 2016). However, catching fish species below the optimum size by the commercial fishers has become common in the Tekeze Reservoir. During the study period, 33.32% *O. niloticus*, 37.72% *L. intermedius and* 42.17% *B. docmak* were caught before they attained their market size. This means that about 37.01% of the total catch of the fishes by the fishers were below the recommended marketable size.

A relatively high proportion of *B. docmak*, below the length at first maturity, was caught and then followed by *L. intermedius* and *O. niloticus*. This might be because of the incidental catch of *B. docmak* by the fishing gears set to capture *O. niloticus* and the use of longlines in the shore areas of the reservoir. Another reason for the overexploitation of the undersize fish population might be due to the competition between fishery cooperatives and using small size fishing gear by the fishers. Particularly, the narrow mesh size of fishing gear resulted in overexploiting the small size fish stock in the reservoir. Solomon Tesfay and Mekonen Teferi (2017) and Ayalew Assefa *et al.* (2018) also reported that post-harvest loss in Tekeze Reservoir is high due to immature fish harvesting. This can cause the growth overfishing of the fish species in the reservoir. Growth overfishing happens when a small size fish population is overexploited, because the number of fish species attaining recruitment depends on the sexual maturity of the species for the next production (Tesfaye Muluye *et al.*, 2016; Agumassie Tesfahun, 2018).

Immature fish harvesting is also common for several fish species in other Ethiopian water bodies. For example, 15% of the *Labeobarbus* species in Lake Tana (De Graaf *et al.*, 2003), 38.34% of *L. intermedius* in Koka Reservoir (Agumassie Tesfahun, 2011) and 77.6% of *C. gariepinus* and 22.97% of *O. niloticus* in Lake Hawassa (Tesfaye Muluye *et al.*, 2016) are harvested before they reach their average length of first sexual maturity.

As we have observed in the landing sites of the commercial fisheries, the commonly used gill nets by the fishers have a stretched mesh size of 6.8 to 12 cm. Therefore, to create sustainability of the fishery resources in the reservoir, narrow mesh size should be prohibited. According to Tesfaye Wudneh (1998), the optimum catch size of *O. niloticus* for 10 cm stretched mesh size is 25 cm total length, which is the average length at first maturity of that species in the present study. So, the minimum mesh size of gill nets for the commercial fishery should be 10 cm. This can help the fish stock since there are illegal fishing activities in the reservoir using illegal fishing gears.

Besides, De Graaf *et al.* (2003) stated that overfishing is the result of poorly regulated high fishing effort by the commercial gill net. Therefore, using wider mesh sizes of fishing gears and avoid fishing during spawning season would be useful in protecting juveniles and mega spanners for sustainable utilization of fish resources in different water bodies (De Graaf *et al.*, 2003; Agumassie Tesfahun, 2011; Agumassie Tesfahun, 2018). Awareness creation to the fishers and government's follow up in the implementation of fishing regulations are also important tools for the management of the fisheries.

5.5. Conclusions

- ✓ The production potential of the Tekeze Reservoir is low when compared to other Ethiopian reservoirs and estimated to be 996.38 tons/year.
- ✓ The average catch per unit effort of the fishery was about 6.8 kg/boat/day.
- ✓ *Oreochromis niloticus, B. docmak* and *L. intermedius* were the major commercial fish species in the reservoir.
- ✓ The reservoir shows signs of overfishing by the commercial catch.
- ✓ About 37.01% of the total commercial catch of the fishery was below the recommended size for commercial fishing.

5.6. Recommendations

- ✓ The fishing effort should be optimum and should consider the production potential of the fish resources in the reservoir.
- ✓ Restriction of small mesh-sizes gillnets is mandatory to prevent catching of under-sized fish population so that they replenish themselves for the next generation.
- ✓ Awareness creation to the fishers on length at first maturity, fishing gears and fishing grounds of the reservoir is required.
- ✓ Further investigation on estimating the potential fish yield using several years of commercial catch data is mandatory to understand the actual fish production potential of the reservoir.

CHAPTER SIX

6. SOCIO-ECONOMIC ASSESSMENT AND MANAGEMENT PRACTICES OF TEKEZE RESERVOIR FISHERY

Abstract

Inland fisheries play an important role in livelihoods for hundreds of millions of people worldwide. However, due to abundant land-based resources and a sparse population, its contribution to the Ethiopian economy has not been significant. But currently, the rapid population growth and shortage of cultivable land forced people to commercial and subsistence fishing in almost all Ethiopian water bodies including the Tekeze Reservoir. As a result, the fishery sector faced illegal fishing practices that could possibly cause depletion of the fish stock. Therefore, this study aimed at assessing the socio-economic importance and management practices of the Tekeze Reservoir fishery. Qualitative and quantitative data were collected from 356 randomly selected respondents and 73 key informants using questionnaires, focus group discussions and interviews for a period of two years from January 2016 to December 2017. Descriptive statistics were used to analyze and summarize the data. A total of 48 fishery associations with 3,174 members were distributed in the reservoir. The average age of the respondents was close to 30 and about 94% of them were males. The majority (67%) of the fishers were full-timers with the average fishing experience of 4 years and 64% of them had taken formal education. Gillnets and longlines were the commonly used fishing gears and operated for 24 hours in the reservoir. Addis Ababa and Mekelle were the major market destination cities for filleted fish, but Shire and Humera towns were for the gutted and sun-dried fishes. The fishery contributed to the rural communities as source of nutrition and food security, employment opportunity and source of income. However, due to poor management practices and overexploitation of the resources, fish production has declined. Therefore, for the sustainability of the resources, fishery management measures related to the nature of the reservoir fishery and implementing the national fisheries development and utilization proclamation (No. 315/2003) are urgently required.

Keywords/phrases*: Constraints, Fish marketing, Fishing gears, Fishers and socio-economics*

6.1. Introduction

Inland fisheries play an important role in livelihoods for hundreds of millions of people worldwide (Lymer *et al.*, 2016). They contribute about 10 to 12% to annual global fisheries production (Moffitt and Cajas-Cano, 2014) and provide a diverse set of benefits to rural households (Smith *et al.*, 2005). Inland capture fisheries are especially important in landlocked developing countries where they provide an important source of animal protein (Welcomme, 2011; Lymer *et al.*, 2016).

Fishing is an important source of subsistence income and significantly contributes to livelihood security for a large number of households in Africa. According to Ellis (2000), livelihoods comprise the capacities, assets and access to these resources but mediated by institutions and social relations that together determine the living gained by the individual households. They are considered sustainable when they can continuously withstand and overcome constraints and maintain or strengthen capacities and assets without undermining the natural resource base.

The importance of fisheries to the Ethiopian economy has not been significant due to abundant land-based resources and a sparse population density. But, from the 1940s and 1950s, the rapid population growth, which resulted in a shortage of cultivable land and depletion of land resources, forced the people to look for other occupations and sources of food from water resources at a subsistence level. The rapidly growing demand for fish in the capital city of the country (Addis Ababa) by foreigners and modern town-dwellers contributed to the start of commercial fishing as a new practice in Rift Valley lakes and later, in Lake Tana (Alemayehu Abebe and Tamiru Chalchisa, 2019).

In Ethiopia, fishing is carried out on almost all water bodies including the newly constructed reservoirs like Tekeze Reservoir, with commercial production concentrated in the Rift Valley Lakes of Chamo, Ziway and Tana. According to Assefa Mitike (2014), the total number of fishers is estimated at 15,000 of which about 5,000 are active and the remaining being part-time or occasional fishers. Besides, 20,000 people are estimated to be engaged in subsidiary activities related to fishing. The fisheries resources of the Tekeze Reservoir have greater socio-economic significance for the poor rural communities in the area. The fisheries provide the much-needed animal protein as well as the source of income for the fishers and the rural poor communities. Therefore, this study aimed to address the following objectives. The main objectives were:

i. To evaluate the fishing activities of Tekeze Reservoir fisheries
ii. To assess the fish processing and marketing conditions of the fishery products
iii. To assess the socio-economic contribution of the small-scale fisheries
iv. To identify the major challenges and problems of the small-scale fisheries
v. To recommend or suggest management options for the reservoir fisheries

6.2. Materials and methods

6.2.1. Data collection and sample size

Qualitative and quantitative data were collected by developing structured questionnaires, focus group discussions and personal systematic observations during the period of January 2016 to December 2017. Items of the questionnaires were tested and refined based on the information obtained during a preliminary survey. The collected data in the questionnaires include socio-demographic characteristics of the respondents and about the fishing activities including the fishing boats and fishing gears. Relevant information on fish processing, marketing conditions, challenges and problems and socio-economic contribution of the small-scale fishery in the reservoir were also obtained through questionnaires. Primary and secondary data were also used to strengthen the information. The data were collected with the help of local guides who were familiar with the tradition and languages of the fishers in the area. The questionnaires were first developed in the English version and translated by the local guides into Amharic, Tigrigna and

Agewigna languages depending on the language speaking ability of the respondents for ease of communication. These three languages are commonly spoken languages by the fishers and the communities around the reservoir.

Focus group discussions with responsible bodies or key informants were held to get information about the number of fishery cooperatives and shareholders. The data about the fishery associations (both the fishery cooperatives and shareholders) and the number of boats and members in each association were obtained from Agriculture and Rural Development and Minor and Small Trade Enterprise Offices of Tanqua-Abergele, Tselemt, Abergele, Ziquala and Sahala districts. Therefore, the sample size from the fishery association was determined by using the following formula (Yamane, 1967; Singh and Masuku, 2014):

$$n = \frac{N}{1 + N(e)^2}$$

Where: n = sample size, N = population size and e = precision level.

From the total population size, an estimated sample size of 356 fishers were calculated from 48 fishery association in the reservoir with a confidence level of 95% and a precision level of 5%. The fishers were randomly selected to include the need point. The total sample size for the study was 429 including 73 key informants. Thus, results obtained from all components of the previous chapters, focus group discussions with purposely selected 48 management committee of the fishery associations, 20 experienced fishers and 5 fishery experts from each district were used to identify the major problems faced by the small-scale fisheries to propose management options for sustainable development and utilization of the fish resource in the reservoir.

6.2.2. Data analysis

Descriptive statistics such as mean values, percentage and frequency tables using SPSS version 24 were applied to analyze and summarize the data.

6.3. Results

6.3.1. The fishers and fishery associations

The Tekeze Reservoir was shared by five districts, one from Tigray Regional State and four from Amhara Regional State. The districts were Tanqua-Abergele (Tigray Regional State), Tselemt, Abergele, Ziquala and Sahala from Amhara Regional State (Table 36). There is a total of 48 fishery associations. Depending on their organizational structure, the associations were grouped into fishery cooperatives and shareholders (partners). The fishery cooperatives were organized and governed by the office of Agriculture and Rural Development, but the shareholders were established by the Office of Minor and Small Trade Enterprises. Most of the associations were shareholders and covered 62.5% (30) of the total associations. The remaining 37.5% (18) were the fishery cooperatives. Tselemt and Abergele districts had the highest number (12 each) of fishery associations and followed by Tanqua-Abergele (11) and Ziquala (4) covered the lowest portion of the associations. A total of 3,174 members were registered in the 48 fishery associations. Of those, the highest number (1,409) were found in Abergele, but the lowest number (260) were in Tselemt districts (Table 36).

In the Tekeze Reservoir, there were three types of fishing boats. Wooden, steel and motorized boats. The first two were commonly used for fishing activities, but the last one was used for transporting harvested fish products to the landing or market sites. The motorized boat is also used for transporting passengers across the reservoir. Most of the fishing boats were wooden boats and covered about 52% (492) of the total boats (950) in the reservoir. The steel boats comprised 44% (416) and the motorized constituted about 4% (42) of the total fishing boats. More than half of the motorized boats were owned by the fishery association organized by Tanqua-Abergele district (Table 36).

Table 36. Summary of the number of fishery associations with their members and fishing boats in Tekeze Reservoir

Districts	**NoFA**	**Memb ers**	**Number of fishing boats**			
			Wooden boat	**Steel boat**	**Motorized boats**	**Total boats**
Tanqua-Abergele	11	511	108	60	24	192
Tselemt	12	260	27	-	6	33
Abergele	12	1409	251	251	4	506
Ziquala	4	684	104	47	3	154
Sahala	9	310	2	58	5	65
Overall total	**48(62.5/37.5%)**	**3, 174**	**492 (52%)**	**416 (44%)**	**42 (4%)**	**950**

Note*: NoFA = number of fishery associations*

6.3.2. Demographic and social characteristics

The socio-demographic characteristics of the fishers or respondents (n = 356); such as age, family size, fishing experiences, educational status, fisher category, marital status, gender and livelihood background are given in table 37. The age of the respondents ranged from 14 to 62 with a mean of 29.63 years old. Individual respondents of the reservoir had a family size ranging from 1 to 14 with fishing experiences of 1 to 7 years (Table 37). The mean of the family size and fishing experiences of the fishers were 4 individuals per household and 3.48 years, respectively (Table 37).

The educational status of the fishers indicated that 35.67% of the respondents had no formal education. However, except a few individuals, most of them could write and read documented materials. The remaining all (64%) had taken formal education and about 52% of the total respondents have completed grades 4 to 8. However, only 12.36% of the respondents have completed high school (Table 37). About 35% of the respondents were unmarried and the remaining 65% were married. Most of the fishers in the reservoir were males (94%) and only 6% were females (Table 37).

Depending on the number of days spent per year on fishing activities, the fishers of the reservoir were grouped into full-time fishers and part-time fishers. The full-time fishers (67.42%) spend a minimum of 198 and a maximum of 256 days per year on fishing activities. According to the respondents, the full-time fishers on the average had spent 247 days per year on the fishing and landing areas of the reservoir (Table 37). However, the part-time fishers who were engaged in other alternative means of livelihood spent 37 to 88 days per year on fishing. The part-time fishers, on the average, spend 62 days per year in the reservoir for fish harvesting. Those fishers were about 32.58% of the respondents. Most of the fishers (70.79%) were crop and livestock farmers while traders constituted 15.45% of the total respondents (Table 37). Those who had worked as daily laborer and pensioners constituted only 8.43% and 5.34% of the total respondents, respectively (Table 37).

Table 37. Summary of socio-demographic characteristics of the respondents (n = 356) in Tekeze Reservoir

Variable	Min.	Max.	Mean	Educational status	n	%n
Age	14	62	29.63	No formal education	127	35.67
Family size	1	14	4	Primary school (grade 1 – 8)	185	51.97
Fishing experiences	1	7	3.48	High school (grade 9 – 12)	44	12.36
Fisher category	**n**		**%n**	**Marital status**	**n**	**%n**
Full-timer	240		67.42	Unmarried	124	34.83
Part-timer	116		32.58	Married	232	65.17
Fishing days/year	**Min.**	**Max.**	**Mean**	**Gender**	**n**	**%n**
Full-time	198	256	247	Female	22	6.18
Part-time	37	88	62	Male	334	93.82
Livelihood background					**n**	**%n**
Farmers					252	70.79
Traders					55	15.45
Daily laborers					30	8.43
Pensioners					19	5.34

Note: *Min. = minimum, Max = maximum, n = numerical value and %n = numerical percentage*

Construction of the hydroelectric dam near to their surrounding was the main motivating reason for the fishers to engage or participate in fishing business.

6.3.3. Fishing boats and gears

Fishing boats: There are 950 legally recognized fishing boats (motorized and non-motorized) operating in Tekeze Reservoir (Table 36). The motorized boats are made up of steel or fiberglass, but the non-motorized boats are made from both wood and steel. The motorized boats were used for transporting captured fishes to the landing or market sites. They are also used for recreation and transporting passengers across the reservoir. However, usually, the non-motorized boats are also used for transporting captured fish from the fishing sites to the shallower or offshore areas of the reservoir for filleting. The number of fishers operating in the reservoir ranged from 2 to 8 with a mean of 6±2.42 fishers per boat (Table 39).

Most of the fishers (95.51%) in the reservoir did not have their own fishing boats, but they get it from the fishery association members (42.7%) or through renting from private and shareowners (52.81%). Only 4.49% of the respondents owned fishing boats (Table 38). The fishery associations are both the fishery cooperatives and shareholders. Most of the shareholders did not have motorized boats and accessed by renting from the associations who have such kinds of boats (Table 38).

Table 38. The possession of fishing boats by fisher respondents (%) in Tekeze Reservoir

Types of boats	**Private (%)**	**Rent (%)**	**Shared (%)**
Motorized	0	32.87	67.13
Non-motorized	4.49	38.49	57.02
Total	**4.49**	**42.7**	**52.81**

According to the respondents, an unknown number of legally not recognized private and share fishing boats were operating in the reservoir and most of them were engaged in illegal commercial fishing activities even during the period of the closed season.

Fishing gears: In the reservoir, two types of fishing gears such as gillnets and longlines were commonly used by the fishers. The gillnets were the most commonly used fishing gears with panel dimensions of 3 m X 25 m and 3 m X 50 m and stretched mesh-size of 6.8 cm to 14 cm. The 3 m X 25 m panel dimension gillnet was brought from Bahir Dar City and the other imported from

Sudan and Egypt. The imported gillnets had a stretch mesh size of 6.8 cm to 10 cm and 72.25% of the respondents agreed on the use of the un recommended mesh-size for commercials. However, the local gillnets purchased from Bahir Dar City had a stretched mesh-size of 7.5 to 14 cm.

The gillnets are used to catch relatively small sized fishes in the reservoir such as *O. niloticus*, *L. intermedius* and *L. niloticus*. Small sized *B. docmak* are also vulnerable to this type of fishing gear. During the study, monofilament gillnets were also observed at landing and fishing sites. The average number of gillnets set per boat ranged from 5 to 30 with a mean of 11±7.51 (Table 39). Minimum number of gillnets per boat (5 nets/boat) was operating during the period of high fish production usually from October to the first 10 days of December, but the maximum number was observed when the production of the reservoir declined. Longlines were other types of fishing gears used by the fishers. The main targeted fish species by the longlines were *B. docmak*, *C. gariepinus*, *H. longifilis* and *B. bajad*. This gear type was mostly used at times when the catch of *O. niloticus* declined. The average number of hooks per long line was 32±5.23 (Table 39). The gillnets were set for 24 hours in the reservoir.

Table 39. Fishing characteristics of the fishers in Tekeze Reservoir

Variables	**Range**	**Mean**
Number of fishers per boat	2 – 8	6±2.42
Number of nets per boat	5 – 30	11±7.51
Number of hooks per longline	20 – 38	32±5.23
Fishing/duration time	-	24 hrs.

6.3.4. Fish processing and marketing conditions

Fish processing: The fishers in the Tekeze Reservoir have processed the fishes they collected by using knife. According to the respondents and own observations, the fishers had no constant and appropriate place for fish processing. Because of the gorgy and slanted topography, the reservoir area is not suitable for fish processing activity. As a result, almost all of the fishers process their catch inside their fishing boats. The fishers provided the fishes to the market in different forms depending on the choice of customers. *Oreochromis niloticus*, *B. docmak* and other catfish species presented in fillet form, but *L. intermedius* and other *Barbus species* are usually presented as whole-fish. However, some times, individual fishers sold fresh-whole fish directly to local consumers and small restaurants near to the reservoir.

Fish marketing: Marketing between fishers and wholesalers or traders took place mainly at four landing sites of the reservoir such as Ariqua/Harza, Gilidu, Niraq area and Sahala/Ziquala area landing sites. Nevertheless, some fishers also sold their fishes to traders at fishing sites. Most of the fishers sold their catches mainly at the Gilidu landing site. The major market destination for *O. niloticus*, *B. docmak* and *C. gariepinus* was to the Ethiopian large cities of Mekelle and Addis Ababa (Fig. 22). Even though it was in a small amount, the fishers also sold the fish products to other local towns such as Yechila, Abi-Adi and Niraq. Yechila, which is the headquarter of Tanqua-Abergele district was the main marketing town of the fish catch. However, currently, Niraq, Sahala and Ziquala also contribute to the marketing of the fish catches. On the other hand, the market destination of the gutted and sun-dried *L. intermedius* and other *Labeobarbus* species was mainly Shire and Humera towns (North-western and western part of Tigray Regional State); products are also exported to Sudan via Humera town (Fig. 22).

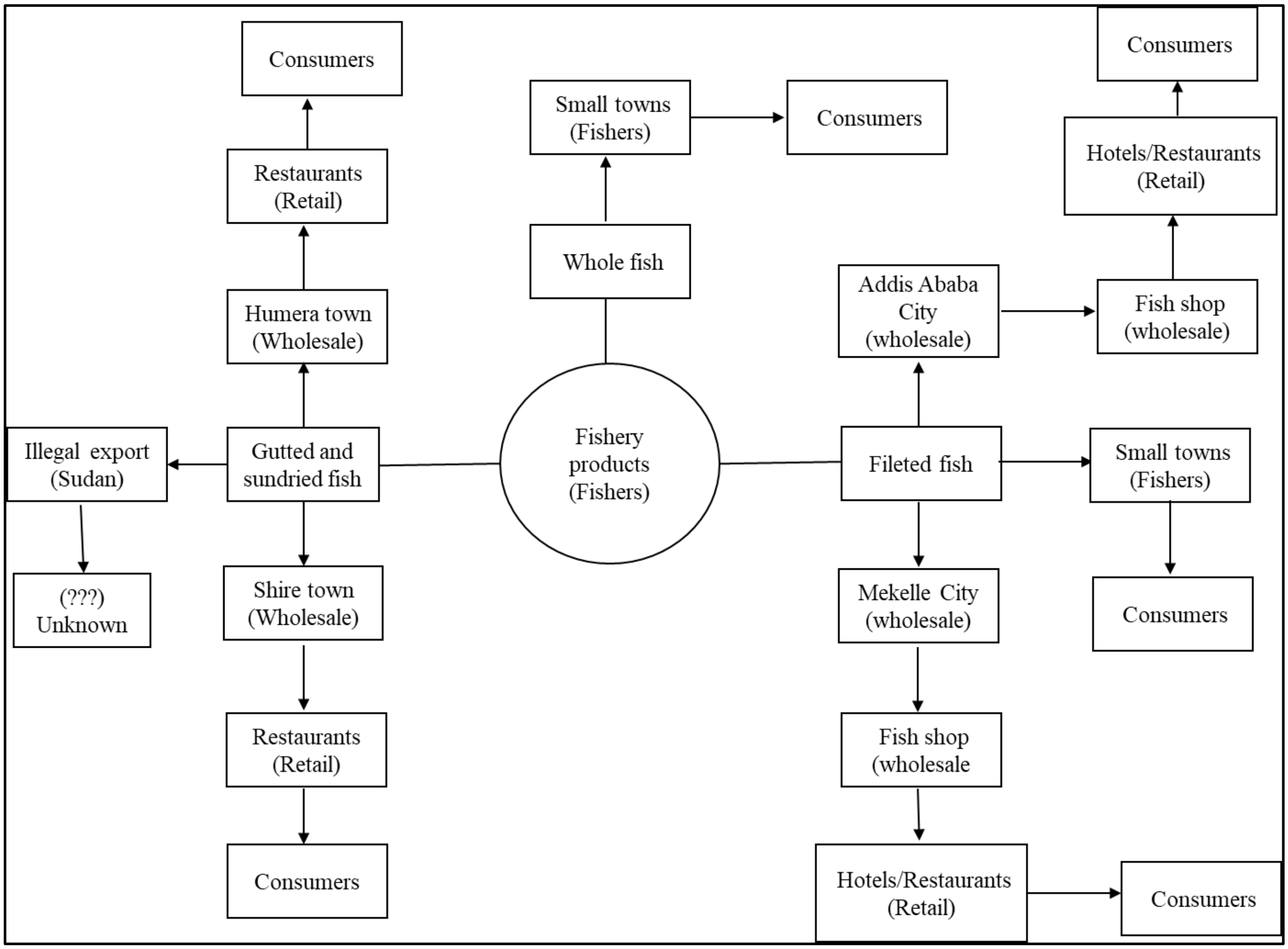

Figure 22. Marketing chain of fish products in Tekeze Reservoir

Note*: the small towns in diagram indicates the local towns located around the Tekeze Reservoir fishery area such as Yechila, Niraq, Abi Adi, Sahala and Ziquala*

Fish prices: Depending on the type of fish species and marketing place, the price of the fish catch was different. *Bagrus docmak* is sold for higher prices than the other fish species and followed by *O. niloticus*. At fishing sites (in the boat while fishing), *B. docmak*, *O. niloticus* and other catfish species were sold 45 – 50, 30 – 45 and 15 – 20 ETB per kg, respectively (Table 40). The fishers sold *Bagrus docmak* for 50 – 70 ETB per kg and *O. niloticus* 50 – 60 ETB per kg to the traders. The price of *C. gariepinus* and *L. intermedius* were 20 – 30 and 20 – 45 ETB per kg, respectively (Table 40). At the stores of different towns around the reservoir area, the price of the fish species was relatively high. *Bagrus docmak* from 80 – 100, *O. niloticus* from 60 – 80, *C. gariepinus* from 35 – 40 and *L. intermedius* from 35 – 45 ETB per kg were sold to traders and consumers (Table 40).

Table 40. The selling price per kg of the different commercial fish species in different market places around Tekeze Reservoir

Species	**Processed form**	**Price of fish in ETB**		
		At fishing sites	**At landing sites**	**At stores**
B. docmak	Fillet	45 – 50	50 – 70	80 – 100
O. niloticus	Fillet	30 – 45	50 – 60	60 – 80
C. gariepinus	Fillet	15 – 20	20 – 30	35 – 40
L. intermedius	Gutted and sun-dried	-	20 – 35	35 – 45
L. niloticus	Gutted and sun-dried	-	20 – 35	35 – 45

Note: *ETB = Ethiopian birr*

6.3.5. Socio-economic contribution

Following the formation of the Tekeze Reservoir, the community around the reservoir gained great opportunities. Almost all of the respondents agreed on the following potential contribution of the reservoir:

- Transportation services for the societies travelling from Amhara to Tigray and from Tigray to Amhara Regional States as well as across districts, particularly within Amhara Regional State.
- Socio-economic contributions such as nutrition and food security, sources of income and employment opportunity.

The contribution and impact of the reservoir fishery on the traditional feeding habits of the community was high. Before the construction of the Tekeze Dam for hydroelectric generation, the fish consumption habit of the community in the area was so poor or almost non-existent and their protein source was solely dependent on meat of domestic animals. But, but after fishing activities started in the area, the rate of fish consumption has increased from time to time. According to the respondents, the current rate of fish consumption of the fishers in the reservoir has reached three to five *O. niloticus* per fisher per day. Nevertheless, the number of fishes consumed per fisher varies depending on the size of the fish species. Usually, they consume only one fish of *B. docmak* per fisher.

According to the data we obtained from the Agriculture and Rural Development as well as from the Minor and Small Trade Enterprise Offices, the reservoir fishery created job opportunity for more than 3, 500 individuals who had no permanent jobs before. Additionally, the respondents confirmed that the fishery played its role or contribution to poverty alleviation, economic growth of private sectors and overall development of the small towns around the area. Following the starting of a fishing business in the reservoir, Amhara Saving and Credit Institute, Dedebit Micro-Finance, Commercial Bank of Ethiopia, Lion International Bank and Wegagen Bank have opened their branches near to the fishery area at different towns. As a result, the trade and business movement in different private sectors including hotels and restaurants in the towns has increased.

Economically many fishers benefitted from the fishery business. Some have purchased public Bus and Isuzu and some others purchased and built residential houses in nearby towns. The respondents stated that due to the reservoir fishery, many individuals lead their lifestyle and their family sustainably. Many individuals were also transferred from fishers to wholesalers as well as opened their own hotels and restaurants in different towns, particularly in Yechila town. Even though they were not voluntary to tell us freely their monthly and annual income, the fishery sector appears to have played a great role in the overall gross annual income of the fishers and the associations as a whole. Approximately, on the average, they can generate 80 to 800 Ethiopian birr per day. Currently, for the majority of the fishers (67.42%) fishing was the only source of income for livelihood, but the sustainability of the resources is in question.

By using the capitals accumulated from the fishery business, one cooperative has started processes to establish and participate in other business forms such as poultry and dairy farms together with the fishing business. According to members of the cooperative, they plan to use the fish offal and post-harvest losses as feed for chickens and dairy cows. However, all of the respondents seriously underlined that the fish production status of the reservoir and their income is declining from time to time. Thus, members of the cooperative who had planned to be engaged in the new business were worried about their success.

6.3.6. Fishers' perceptions related to fish production and management

We assessed the fisher's perception related to the fish production status since they started fishing and fishery management issues in the reservoir. About 92% of the fishers indicated that the fish production has declined, but8% of them were uncertain whether or not the fish production has declined (Table 41). According to the respondents, the possible reasons for the decline of fish production in the reservoir were poor management practices and overexploitation of the resources.

All (100%) of the respondents confirmed that they had no information about the fishery management and regulation measures including the co-management approach between the fishers and government in the reservoir. Similarly, fishery extension services and licensing for capacity building for the effectiveness of the fishers were completely absent. The majority (83.5%) of the respondents also replied that they did not have any information about the national fishery development and resources utilization proclamation (No. 315/2003); only 16.5% of the fishers had awareness about the proclamation (Table 41).

On the other hand, the fishers were asked whether or not the mesh size, gear type, number of gears and fishermen were regulated by the government. Fishers were also asked if they have information about the regulations and follow the recommended management measures. Close to 56% of the respondents indicated that the mesh-size of the gillnets used by the fishers for fishing were not limited by the government while 14% were unsure. However, about 30% of the respondents had some awareness about the standard mesh-size of the fishing gillnets, but the majority of the fishers did not follow the recommended mesh-size. Most of the respondents said that the gear type (71.25%) and the number of fishers and fishing gears (96.5%) were not regulated by any responsible body (Table 41).

A good measure taken by the fishers that was observed during the study period on fisheries management was the closed season for commercial fishing. All (100%) of the fishers had enough information about the spawning season of the fishes, but not on the specific spawning grounds of the fish species (Table 41).

Table 41. Fisher's perceptions on fishery management issues and their attitudes on implementing managemental strategies to the Tekeze Reservoir fishery

Closed questions responded by the fishers (n = 356)	Response rate (%)		
	Yes	No	Uncertain
Are there fishery management and regulation measures?	0	100	0
Do you know the national fishery development proclamations?	16.5	83.5	0
Are there fishery extension services in the reservoir?	0	100	0
Has fish production declined?	91.58	0	8.42
Is the mesh-size limited by the government?	30.12	55.64	14.24
Is the gear type limited by the government?	0	71.25	28.75
Are you following the standard mesh-size?	25.25	72.25	2.5
Is the spawning season of the fishes closed from fishing activities?	100	0	0
Is the spawning area of fishes closed from fishing activity?	0	100	0
Is license given for professional fishers?	0	100	0
Are the number of fishers and gears limited by the government?	0	96.5	3.5
Is there a co-management approach (both government and fisher)?	0	100	0

6.3.7. Major constraints of fish production

Focus group discussions with key informants were held to identify the major challenges of fish production by the small-scale fishery in the Tekeze Reservoir. The most serious problem mentioned by the fishers was the operation of illegal fishers which was described by 97.26% of the respondents in the reservoir (Table 42). Although it was difficult to know the exact number of illegal fishers, the respondents agreed on the presence of more than 360 illegal fishers who are operating in the reservoir. According to the respondents, the number fluctuates in off-farm season during which the number of illegal fishers increases enormously. Near to 96% of the respondents said that lack of modern infrastructures like road, electric service, preservation facility and motorized boats for transporting of the captured fish to the landing sites were also the second critical problem of fish production by the small-scale fishery in the reservoir.

Overexploitation by a large number of fishers was the third critical problem mentioned by close to 92% of the respondents (Table 42). According to the key informants, the main reason for the overexploitation of the fish resources by large number of fishers was due to the free access nature of the reservoir. Close to 81% of the respondents confirmed that anyone interested in fishing in the reservoir was free to join the fishing business (Table 42). The only requirement to enter into the reservoir's fishing business was to be a member of one of the legally recognized fishery associations. Thus, membership to the fishery association was used as a license to join the fishing business. The key informants also stated that the distribution of a large number of fishers in the reservoir destroyed fish breeding sites (53.43%) by using gillnets below the standard mesh-size (89.01%) for commercial fishing (Table 42).

The absence of an appropriate site for post-harvest processing and market chain problems were also among the critical constraints for optimum fish production by the small-scale fishery. About 84% of the respondents confirmed that most of the fishers do not have an appropriate place for fish processing and storage facilities that can preserve the fish until it reaches the consumers. Hence, the fishers sell their product at low prices during periods of high harvest. Poor market linkage and market chain (70%) between fishers and traders who supply fish to different market areas was another serious challenge that the fishers face in the Tekeze Reservoir (Table 42).

According to the key informants (48%), government support and follow up to the fishers were so limited. They revealed that after the associations are established, the support and follow up by the regional governments (Tigray and the Amhara Regional States) and responsible development agents as well as the federal government should have been continuous until they sustain themselves. However, the majority of the fishers revealed that support and professional training about how to use and appropriately manage fish resources were not obtained from the government and private sectors. Discussions with the key informants, on the other hand, indicated that although it was not sufficient and effective, training had been given to members of the fisher community and some other representative farmers from the reservoir area. Lack of adequate modern fishing gears (25%) was also raised as a problem of fish production by the respondents (Table 42).

Table 42. Possible factors raised by the key informants (n = 73) in the focus group discussions for the declining of fish production by the small-scale fishery in Tekeze Reservoir

Problems	Frequency	Frequency (%)
Illegal fishers	71	97.26
Destruction of fish breeding sites	39	53.43
Using of gillnets below the standard mesh size	65	89.01
Open access to the reservoir	59	80.82
Infrastructure problems	70	95.89
Overexploitation by large numbers of fishers	67	91.78
Limited government support and follow up	35	47.95
Market chain problem	51	69.86
No standard fish processing place	61	83.56
Lack of modern fishing gears	15	24.66

6.3.8. Suggested management options

For the sustainability of the fishery resources in the Tekeze Reservoir, the key informant advised to consider the following management measures.

- ✓ Awareness creation to the fishing communities and any other concerned bodies about the destructive fishing gears, overfishing and many other problems that can cause the depletion of the stock.
- ✓ Effective reservoir fishery management systems and regulations concerning renewable natural resources.
- ✓ Implementing national fisheries development and utilization proclamation.

- ✓ Continuous government support and follow up.
- ✓ Employment and job diversification
- ✓ licensing and limiting the number of fishers and fishing gears
- ✓ Limiting the type and mesh-size of the fishing gillnets

6.4. Discussions

6.4.1. The fishers and fishing activities

The study showed that almost all of the fishers in the fishery of Tekeze Reservoir were males and found at an average age of close to 30. This might be due to the difficulty of the fishing work, which required day and night exhaustive labor. The young age of the fishers may allow the continuity of the fishing activity for a long period in the reservoir. Similar results have been reported in the same water body by Tsegay Teame *et al.* (2016b), Solomon Tesfay and Mekonen Teferi (2017) and Ayalew Assefa *et al.* (2018). In line with this result, Ayalew Assefa and Adane Bahiru (2018) also confirmed that most of the agricultural and fishing practices in Ethiopia are dominated by men individuals.

The majority of the fishers had formal education and even most of the fishers who haven't completed formal education could write and read documented materials. This could have positive implications for reservoir fishery management. This educational status should help the fishers to easily understand training related to the sustainable exploitation of the resources. It is also important to develop positive attitudes and actively participate in the fishery management process (Mulugeta Wakjira, 2016). The analysis of the fisher's livelihood background indicated that almost all of the fishers came from the local community telling socio-economic contribution of the reservoir fishery to the local people (Mulugeta Wakjira, 2016; Alemayehu Abebe and Tamiru Chalchisa, 2019).

A large number of fishery associations, fishers and fishing boats were distributed in the reservoir and the number has increased over time. During the present study, 48 legally recognized fishery associations with 3,174 members and 950 fishing boats were operating in the reservoir. This was relatively large in number when compared with other findings reported three years ago (Tsegay Teame *et al.*, 2016b). The authors documented that 11 legally recognized fishery associations, with 2, 291 members and 608 fishing boats were found in the reservoir, which is by far smaller than the report of the present study. This tells us the increasing number of fishers and fishing gears from time to time that could lead to the depletion or overexploitation of the stock in the reservoir.

Similar to most of the Ethiopian fisheries, for instance in Lake Hawassa (Zenebe Tadesse *et al.*, 2015), Lake Hayq (Zuriash Seid, 2016) and Gelegu and Ayima Rivers (Alamrew Eyayu, 2019) and other African inland fisheries, the Tekeze Reservoir fishery was small-scale fishery with gillnetting and longlining fishing practices. The fishing boats used were wooden and metal boats. The wooden boats are common in several Ethiopian fisheries like in Omo River and the Ethiopian part of Lake Turkana (Mulugeta Wakjira, 2016), Lake Hayq (Zuriash Seid, 2016) and other water bodies (Mathewos Temesgen and Abebe Getahun, 2016). Although the price of the steel boats was high, their use for fishing is increasing, but the use of wooden boats, on the other hand, is declining due to the short life span of the wood in the water.

The fishing activity in the reservoir was practiced by using gillnets and longlines. The gillnets were mostly used for the small sized fish species (usually *O. niloticus* and *L. intermedius*) and longlines for large sized fish species (usually *B. docmak* and *C. gariepinus*). The average number of gillnets per boat were 11±7.51 and this was higher than the values reported by Solomon Tesfay and Mekonen Teferi (2017) and Ayalew Assefa *et al.* (2018) for the same water body who reported 8 and 6 gillnets per boat, respectively. The difference might be because of the difference in the fish production status of the reservoir. The respondents confirmed that during the period of high fish production they used below 10 gillnets per boat, but during low fish production period they used up to 30 gillnets per boat. The average number of hooks per longline was 32±5.23, which is similar to reports by Ayalew Assefa *et al.* (2018) (32 hooks per longline) and not very different from the report of Tsegay Teame *et al.* (2016b) (30 hooks per longline) for the same reservoir.

6.4.2. Marketing problems and socio-economic importance

The reservoir fishery was dependent mainly on three commercially important fish species such as *O. niloticus*, *B. docmak* and *L. intermedius*, but rarely *C. gariepinus*, *H. longifilis*, *B. bajad and* other *Barbus species* also observed in the commercial catch and marketing place of the fishers. However, the previous study indicated that the fishery and marketing were largely dependent only on the first three commercially important fish species (Tsegay Teame *et al.*, 2016b). This indicates that the consumption and marketing demand of the community on a wide range of fish species has increased from time to time. Therefore, having several commercial fish species in a water body is important in reducing fishing pressure from a few specific fish species in the same water body.

Like other Ethiopian fisheries, fish processing into fillet and sun-dried forms in the Tekeze Reservoir was traditional. As no middlemen were operating in the reservoir, the fishers themselves sold their product to wholesalers who deliver fish to Addis Ababa, Mekelle, Shire and Humera cities. Nevertheless, during the period of surplus fish production particularly from October to December, the fishers are exposed to massive loss due to the absence of enough market and wholesalers fail to receive the whole products. The respondents and previous study in the reservoir (Ayalew Assefa *et al.*, 2018) confirmed that during this season, the price of fish was much lower than other seasons. This is known as market force loss which is one of the challenges of the fishery sector (Solomon Tesfay and Mekonen Teferi, 2017; Abebe Ejigu and Hossein Azadi, 2018).

Unlike other Ethiopian fisheries, fasting and non-fasting seasons did not affect the price value of the fish from the reservoir. However, although marketing and other problems were facing the fishery business in the reservoir, its contribution to job creation and means of income has continued.

6.4.3. Constraints and management of the fishery

In the present study, illegal fishers, overexploitation, lack of infrastructure, destructive fishing gears, absence of standard fish processing site, open-access nature of the reservoir, market chain problem and others were the main challenges that hinder the fish production. The respondents have stated that the production of the reservoir fishery has declined from time to time. Therefore, the fishery has signs of overfishing. Similar to other Ethiopian lakes such as Chamo, Ziway and Hawassa lakes, inadequate legal and policy frameworks resulted in the overfishing of important fish species (Selamu Abraham and Lelise Mitiku, 2018). Several studies have also confirmed that overfishing, ecosystem changes due to destructive fishing gears, discarding of by-catch, pollution of the water ecosystems are described as the main factors for the decline of fish production worldwide (Gashaw Tesfaye *et al.*, 2016).

In Ethiopia, all lake fisheries predominantly focused on *O. niloticus* (Assefa Mitike, 2014) which was also the main target of the commercial catch in the present study. Due to this, the species in Lake Ziway and Lake Hawassa show signs of overfishing and particularly in Lake Ziway *O. niloticus* is probably at full exploitation level (Tadlo Awoke and Mebratu Melaku, 2017). However, it is only in Lake Tana that *Labeobarbus* species were also heavily fished during the seasonal fishery (De Graaf *et al.*, 2003). The production status of Nile perch from Lake Chamo and Lake Abaya declined and show overfishing (Selamu Abraham and Lelise Mitiku, 2018). As a result, the fishes of many Ethiopian water bodies, for example, Lake Tana, Lake Ziway and Lake

Hawassa are numerically dominated by small fish species (*Barbus* species) which have a low economic value for the fishery (Tadlo Awoke and Mebratu Melaku, 2017). Therefore, if the current unwise fishing activity is to be continued and unless proper fishery mitigation measures are taken, the probability of replacement of the large-bodied commercial fish species by less valuable fish species in the Tekeze Reservoir fishery is high.

Lack of trained manpower and poor perception of the fishers on sustainable utilization of the fishery resources have also contributed to the poor management practices of the reservoir fishery. According to Agumassie Tesfahun (2018), Ethiopia's fishery sector, in general, suffers from limited human resources availability with an acute shortage of trained personnel. This caused a big challenge on fishery management, technical and extension support services in the reservoir fishery. Public and private investment in the fishery sector is also low and the infrastructures are inadequate (Tadlo Awoke and Mebratu Melaku, 2017; Selamu Abraham and Lelise Mitiku, 2018). The constraints and vulnerability of fisheries communities mainly due to resources depletion, increasing competition on open access resources, inequitable use of resources, lack of government support, remote locations, poor services and poor organizational capacities are also other factors that expose fishing communities to poverty (Gashaw Tesfaye and Wolff, 2014; Agumassie Tesfahun, 2018). Therefore, to overcome those problems in the reservoir fishery, the socio-economic contribution, identified fishery problems and suggested management measures should serve as necessary inputs for sustainable fishery resources, sound management and development plans by the federal government and the two regional states. As the reservoir is shared by Tigray and the Amhara Regional States, any management approach that is not involving both regional states and fishers would not be expected to be effective. So, to manage the competing interest between the fishers of the regional states on fishery resources in the reservoir, a co-management approach involving both states should be urgently initiated.

6.5. Conclusions

- ✓ The reservoir fishery has an excellent socio-economic contribution for the rural community around the reservoir.
- ✓ The fisher had poor perceptions of fishery management regulations for sustainable utilization of the resources in the reservoir.
- ✓ Addis Ababa and Mekelle cities are the major market destination of the fish products.
- ✓ Illegal fishing activities, overfishing and infrastructure problems are the major constraints for the decline of fish production and fishery business in the reservoir.

6.6. Recommendations

- ✓ Fishery management measures related to the nature of the reservoir fishery is required. Technology transfer to fishers, traders and other stakeholders about handling, harvesting, processing and preservation of fish is essential to improve the fishery in the reservoir.
- ✓ Investors need to be encouraged and motivated to invest their capitals in the modern value chain, fish production, processing, preservation and marketing.
- ✓ The integration of stakeholders at different levels, extension services and government support of the fishers and fishery associations through finance are crucial for the success of the fishery improvement.

CHAPTER SEVEN

7. GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1. General conclusions

Based on the overall results obtained in this study, the following general conclusions could be drawn:

- The Physico-chemical parameters of the reservoir are found in optimum conditions for freshwater fishes. *Oreochromis niloticus*, *L. forskalii*, *L. intermedius*, *B. docmak* and *L. niloticus* have dominated the catch composition of the reservoir.
- The length-weight relationship of *O. niloticus*, *L. intermedius* and *B. docmak* was curvilinear and their body was found in good condition. The feeding habits of *O. niloticus*, *L. intermedius* and *B. docmak* were omnivory. The sex ratio of *O. niloticus* and *B. docmak* was statistically different from the hypothetical value, but not *L. intermedius*. Both sexes of *O. niloticus* matured almost at a similar size. Female *L. intermedius* were found to mature earlier than male individuals, but for *B. docmak*, male individuals matured at a smaller size than females.
- July to October was the peak spawning season for *O. niloticus*, *L. intermedius* and *B. docmak*. The littoral habitats were the preferred spawning areas for *O. niloticus* and *B. docmak*, but the riverine habitats were the most important habitats for *L. intermedius*.
- The production potential of the reservoir fishery was estimated to be 996.38 tons/year. The average catch per unit effort of the fishery was about 6.8 kg/boat/day. The reservoir fishery had an excellent socio-economic contribution for the rural community around the reservoir.
- Addis Ababa and Mekelle cities were the major market destination of the fish products. Illegal fishing activities, overfishing and infrastructure problems were the major constraints responsible for the decline of fish production in the reservoir.

7.2. General recommendations

- A more detailed assessment of water quality including nitrate, phosphate, silicate, biological and chemical oxygen demand, etc. and their potential impacts on the aquatic resources should be investigated. Further investigation on diversity and abundance of fish species in the down streams of the reservoir is required.
- A study on the trophic position of the species and their trophic role in the reservoir system is required to plan valid strategies for proper utilization and conservation of the ecosystem in general.
- The fishing effort should be optimum and should consider the production potential of the fish resources in the reservoir. Restriction of small mesh-sizes gillnets is mandatory to prevent catching of under-sized fish population so that they replenish themselves for the next generation. Awareness creation to the fishers on length at first maturity, fishing gears and fishing grounds of the reservoir is required.
- Further investigation on estimating the potential fish yield using several years of commercial catch data is mandatory to understand the actual fish production potential of the reservoir.
- Technology transfer to fishers and other stakeholders about handling, processing and preservation of fish is essential to improve the fishery in the reservoir.
- Encourage and motivate investors to incur their capitals in the modern value chain, processing and marketing coordination to enhance the fishery potential in the reservoir.
- The integration of stakeholders at different levels, extension services and government support of the fishers and fishery associations through the financial aspect are crucial for the success of the fishery improvement.

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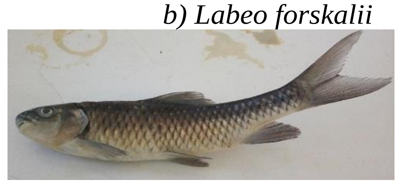
APPENDICES

Appendix 1. Images of fish species identified from Tekeze Reservoir

a) Labeo niloticus

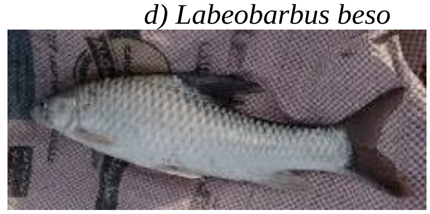
b) Labeo forskalii

c) Labeo cylindricus

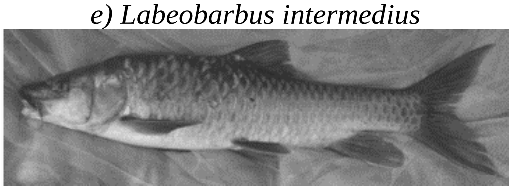


d) Labeobarbus beso

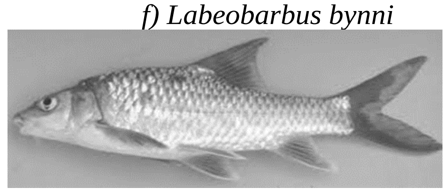
e) Labeobarbus intermedius



f) Labeobarbus bynni



g) Labeobarbus nedgia



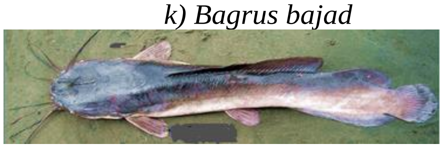
h) Labeobarbus Crassibarbis

i) Raiamas senegalensis

j) Garra dembeensis

k) Bagrus bajad

l) Bagrus docmak



m) Hetrobranchus longifilis

n) Clarias gariepinus

o) Oreochromis niloticus

Appendix 2. A bracketed artificial identification key for the fish species collected from Tekeze Reservoir

Numbers in parenthesis refers to the lead character from which the respective couplets follow. This key is intended for the identification of fish species in Tekeze Reservoir.

1 [a] 14 to 17 branched fin rays on the dorsal fin; 41 to 45 scales on the lateral line……………………………………… *Labeo niloticus*

[b] Less than 14 branched rays on the dorsal fin; less than 40 scales on the lateral line ……………………………………… 2

2 (1[b]) [a] 9 to 11 branched rays on dorsal fin; 38 to 42 scales on lateral line; presence of transverse groove above the snout……………………………… *Labeo forskalii*

[b] Less than 11(8 – 10) branched rays on dorsal fin; 35 to 39 scales on the lateral line; absence of transverse groove above the snout……………………*Labeo cylindricus*

3 [a] Mouth ventral, straight and wide; less than 8 anal soft rays; lower lip sharp-edged; lower jaw rigid; lateral line not interrupted ………………………… *Labeobarbus beso*

[b] Mouth gape inferior; 8 anal soft rays; dark and thick barbless ………………….5

4 [a] Very deep body (usually 36% of standard length); 28 – 37 scales on the lateral line; long dorsal fin (longer than head); lower lip not forming lobe or very small lobe; upper lip without lobe ………………………………… *Labeobarbus bynni*

[b] Shallow body (usually 25% of standard length); 30 to 36 scales in the lateral line; short dorsal fin (shorter than head) ……………… *Labeobarbus intermedius*

5 (3[b]) [a] Dorsal soft ray 11 to 13; anal soft rays 8; 30 to 37 scales on the lateral line; 5 to 6 scale rows above lateral line; 2 to 3 scales below lateral line; lower lip forming large median lobe; well-developed upper lip……… *Labeobarbus nedgia*

b Dorsal fin ray not more than 12; less than 35 scales on the lateral line; 5 to 7 scales above lateral line; 3 to 4 scales below lateral line ………… *Labeobarbus crassibarbis*

6 a 50 to 65 scale on the lateral line with 12 – 16 (usually 12) vertical bars on the flanks ……………………………………… *Raiamas senegalensis*

b 36 to 38 scales on the lateral line; 0 to 3 scales in the pre-dorsal region; no vertical bars on the flank………………*Garra dembeensis*

7 a Both upper and lower lobes of the caudal fin extend in to long filaments… *Bagrus bajad*

b The upper lobe extended in to a long filament but not the lower lobe ………*Bagrus docmak*

8 a Adipose fin present; 29 to 34 soft rays in the dorsal fin ……………… *Hetrobranchus longifilis*

b Adipose fin absent; 61 to 80 soft rays on the dorsal fin………………………*Clarias gariepinus*

9 a 29 to 33 rays on the dorsal fin; dark vertical bars on the body and caudal fin; body covered with cycloid scales …………………………… *Oreochromis niloticus*

Appendix 3. Questionnaires used to collect data for the socio-economic and management study of Tekeze Reservoir

Addis Ababa University

College of Natural and Computational Sciences

Department of Zoological Sciences (Fisheries and Aquatic Sciences)

Dear respondents,

I am **Shibabaw Gebru**, PhD student at Addis Ababa University, department of Zoological Sciences (Fisheries and Aquatic Sciences). I am here to be do my research on "**diversity, biology, yield and socioeconomic assessment of fishes in Tekeze Reservoir**" under supervision of **Professor Abebe Getahun** and **Dr. Mekonnen Teferi**. The study is aimed to contribute to the management of the reservoir fisheries by providing scientific information for sustainable utilization of the aquatic resources in the reservoir. Therefore, to achieve this objective, without your cooperation and participation is impossible. So please, offer your opinion freely on the space provided.

Thank you in advance for your cooperation!

Part I: For respondents

1. Age. **A)** 10–20 **B)** 20-30 **C)** 30-40 **D)** 40-50 **E)** 50-60 **F)** >60

2. Sex: **A)** Male **B)** female

3. Kebele. ---

4. Educational background: **A)** no formal education **B)** elementary **C)** High school **D)** College

E) University

If other specify. ---

5. Occupation. **A)** Farmer **B)** Government employer **C)** Merchant/trader

If other specify. ---

6. If you are a farmer, what is your major work?

A) Farming **B)** Fishing **C)** Fishing and farming **D)** Beekeeping

If other specify. -------------------------------------

7. If your major work is fishing, for what purpose do you fish?

A) Food **B)** Market **C)** Food and market **D)** Recreation

If other specify. --

8. What mode of fishing do you involve in? A) part-time B) full time

9. What species do you catch? --

10. How many fishes do you catch per day? -------------------------------------

11. What type of gear do you use? ---------------------------------- And mesh size? ------------------

12. Is the mesh size and type of gear limited by the government? **A)** Yes **B)** No

If yes, what is the recommended size? ----------------------

13. Are you following the recommended size? **A)** Yes **B)** No

If No, what hindered you? ---

14. How many fishes do you catch per gear? ---

15. Which species is dominant at your landing site? --

16. What is your target species? ------------------------------------ Why? -------------------------------

17. How much is the price per fish or kg? --

18. How much Birr do you get from fish selling per day/month/year? -------------------------------

19. Is there a sufficient market to sell? **A)** Yes **B)** No

To what market do you sell? --

What fish species mainly need the market? ---

20. Do you catch year-round? A) Yes B) No

If no in what season do you stop fishing? -------------- And why? -----------------------

For how many days do you stop fishing? ---

For how many days you catch? --

21. Which season is the highest landing period? ----------- And why? ----------------------------------

22. Are there fishery management and regulation measures? --------------------------------------

23. Do you know the national fishery development proclamations? -----------------------------

24. Are there fishery extension services in the reservoir? ---

25. What looks like the production status of the fishery since you started fishing? A) increased B) decreased C) not sure D) if it is declined what are the possible factors?

Part II: for focus group discussion

1. How many fishery associations are found in the reservoir? --

2. How many members are included in each association? ---

3. Are all fishermen legal? A) Yes B) No

If no how many are legal? ---------------- Illegal? --------------------- Total? ---------------

4. How many fishing boats are found in the reservoir? --

With engine? ----------------------------

Without engine? ----------------------------

5. Is there any follow up by government institutions, NGOs, or research organizations? ----------

6. What is the use of the reservoir for the local community? ---

7. What agricultural chemicals do people use around the reservoir? ----------------------------------

8. What problems do you have in your fishing business and fishery production? --------------------

9. What solutions do you propose to the problem? ---

DECLARATION

I, the undersigned, hereby declare that this dissertation is my original work and that all sources of material used for the dissertation have been correctly acknowledged.

Name: Shibabaw Gebru

Signature: ____________________

Date of Submission: ____________________