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Stock Assessment of Nile Tilapia (*Oreochromisniloticus, L.*) in Gilgel Gibe Reservoir, Omo-Turkana Basin, Southwest Ethiopia

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MSc Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Biology (Ecological and Systematic Zoology)

April, 2022
Jimma, Ethiopia

Declaration

I, the Undersigned, declare that this thesis entitled **Stock Assessment of Nile Tilapia (*Oreochromisniloticus*) in Gilgel Gibe Reservoir Omo-Turkana Basin, Southwest Ethiopia** is my original work and that all sources of materials used for the thesis have been correctly acknowledged.

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ABSTRACT:

Stocks assessment is the first step to determine the level of tolerable exploitation for arriving at maximum sustainable yields from fish resources. Assessment of stocks and study of impact of present level of exploitation on exploited stocks are necessary for maintenance of stocks at maximum sustainable level. A stock assessment of Gilgel Gibe fisheries has never been conducted despitethe reservoir'sfishery importance to the local people. In the presentstudy, length based stock assessment approach was used in order to estimate vital parameters such as fish growth and mortality. A length-based Thompson and Bell model (Thompson and Bell, 1934) was used for analysis of yields and long-term yieldpredictions. Nile Tilapia, Oreochromisniloticus, is one of important commercial fish in Africa and other tropical regions. InEthiopia, it accounts for more than 60% of the total annual landings.A total number of 25,994 specimens of Nile tilapia werecollected from March, 2020 to July, 2021. Stock assessment software FISAT II was used to compute and analyse all the basic parameters and functions. The estimated current annual yields were 251.07 tons /year. The average annual recruitment in the reservoir was 121,955 fish. The mean value of growth parameters The L_∞ *and K values were determined to be 46.67cm and 0.280, respectively, at Rn value of 0.174. The fish growth performance index (Φ'), computed from the fish growth rate and the asymptotic length, was 2.79. Estimation of current rate of exploitation of yield and biomass was 6.48 tons and 28.12 tons respectively. Therefore harvest level should be decrease from maximum sustainable yield to maintain and recover highly depleted biomass.The stock biomass at the current level of exploitation has already declined to 26.32% of the biomass at the unexploited stock. Therefore, there is an urgent management need to regulate fishing effort in order to safeguard the resource and thereby ensure its sustainability and the livelihood of the community that depends on it for its livelihood.*

Keywords: *Stocks assessment, maximum sustainable yield, biomass, Nile tilapia*

Acknowledgements

I thank God every day for giving me the opportunity to pursue and complete this degree and for all the people that helped me throughout my work.

I would like to acknowledge and give my sincere thanks to my advisor Dr. Tokuma Negisho for his immense knowledge, motivation, time, comments and great support and help in this study.

I wish to express my deepest thanks to my Co/advisor Dr. Mulugeta Wakijira for his encouragement, insightful comments, and tireless guidance, and continuous support to my MSC study and research, His guidance and supports helped me in all time of the research and writing of this thesis. Without his support of this work would not have been materialized.

Ithank to my Co/advisor Gadisa Natae for his support, high motivation, and help in this study.

My gratitude also goesto a friend and helpful Kedir Abadiga and his team members for their friendshipand support to the workfrom measuring and recording to the end of data collection.

In addition,I would like to thank my husband Emiru Haile for his encouragement, support, and for his high motivation to the work starting from sampling and recording to the end of thesis.

My thanks go to my families, brothers and sister for their encouragement, moral support and true love especially my mother Etagegn Alemu and my father Alemayehu Yankora. Who encouraged, believed in me and support me spiritually throughout my life.

In addition, I would like to thank Biology department, college of Natural sciences and Jimma University for their support in transportation facilities during data collection.

More over I would like to thank the University for affording my over all activities in the preparation of this paper.

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Acronommy

B:	Biomass
Bmsy:	Biomass maximum sustainable yield
FAO:	Food and Agricultural Organization
Fmsy:	Fishing mortality maximum sustainable yield
FRP:	Fisheries reference points
LRPs:	Limit Reference Points
MSY:	Maximum sustainable yield
RPs:	Reference points
SL:	Standard length
TL:	Total length
TRPs:	Target Reference Points
LCA:	length-based cohort analysis
VBGF:	von Bertalnaffy growth function
VPA:	virtual population analysis
SCAA:	statistical catch-at-age analysis
ASPM:	age-structured production model

CHAPTER ONE: INTRODUCTION

1.1. Background of the study

Fishery is an important sector used for food security and source of cheap protein for the poor living in developing countries. The contribution of small-scale fisheries is significant for livelihoods of millions worldwide. Fisheries have the most significant contribution in economy of developing countries where means of livelihoods are very limited(Mustafa *et al.*, 2018).Capture fisheries remain the most important source of fish for many poor people. For instance, about half a million Ethiopian people depend on capture fisheries directly and indirectly as means of livelihoods (Tesfaye& Wolff, 2014).

However, fisheries are renewable resources i.e. replenish by natural processes at a faster rate than its rate of loss and fishing should not offset this natural balance. At very high levels of exploitation, the removal will surpass a stock's regenerative capacity eventually leading to a collapse of the fishery. Thus, the point somewhere between no effort and very high effort needs to be found that will give the maximum average yield with a maximum regenerative capacity of the stock (King, 1995).In such scenario, information on the ecology and life histories of the fish stocks are prerequisites for fisheries management. Stock assessment comprises the study on the population dynamics controlled by growth, recruitment, natural and fishing mortalities (King, 1995). It also involves forecasting the response of the resource to alternative management scenarios (Hilborn& Walters, 1992; Quinn &Deriso, 1999).

Stock assessment is the part of Fisheries' Science that studies the status of a fish stock as well as the possible outcomes of different management alternatives(Singh, 2009). Stock assessment implies understanding the dynamic system and estimating these fundamental population parameters namely stock abundance, growth, recruitment and mortality. These parameters can be estimated from different types of data set such as length of fish/ length frequencies, age, catch rates (catch per unit effort) (Singh, 2009). Moreover, stock assessments provide fisheries reference points (FRP), the benchmarks on which the status of fish stocks is measured (ICES, 2017). Common FRP include maximum sustainable yield (MSY), the target for sustainable exploitation of fish stocks; fishing mortality rate at MSY (Fmsy), a limit beyond which exploitation becomes unsustainable; fishing mortality rate relative to Fmsy (F/Fmsy); biomass that supports MSY (Bmsy); and current biomass relative to Bmsy (B/Bmsy) (Caddy & Mahon, 1995; Hilborn& Stokes, 2010; ICES, 2017).

Management of fisheries typically involves the assessment of the abundance of stocks using different types of information collected over varying periods. This information typically includes fishery-dependent as well as fishery-independent data. Historically, various statistical methods have been used to estimate abundance from these data (Ricker, 1975).

Until about five decades ago, the contribution of fisheries to the Ethiopian economy was insignificant because of abundant land-based resources and a sparse population density. Ever since the 1940s and 50s, however, the rapid population growth resulted in a shortage of cultivated land and depletion of land resources and forced people to look for other occupations and sources of food at a subsistence level from water resources (Yalew*et al.*, 2015).Reservoirs, lakes, and rivers are essential food security and livelihood resources. Inland water bodies provide multiple community needs, including domestic water supply, irrigation, hydropower generation, recreation, fisheries, and aquaculture harvests (Deines*et al.,* 2017; Lynch *et al.*, 2016).

The Nile tilapia (*Oreochromisniloticus)* is the most commercially viable fish species for Ethiopian capture fisheries (Tesfaye& Wolff, 2014). The species contributes more than 49% of the total annual landing in the country. It is widely distributed in Abay, Awash, Baro-Akobo, Omo Gibe, Tekeze, rift valley and highland lakes and Wabishebele-Genaledrainage basins as well as in manmade reservoirs (Golubtsov& Mina, 2003; Awoke, 2015).The Ethiopian inland water resource faces multifaceted challenges including severe fishing pressure, destructive fishing methods, deteriorating water quality because of land-based activities and lack of scientific information for proper fish resource management (Tesfay, 2016).

The best possible supplies of fish for the future generation could be guaranteed when all those involved in fisheries work together to conserve and manage fish resources and habitats. Giving emphasis to the necessity of fisheries management, in order for countries to manage their fisheries they need to have clear and well-organized fishing policies which are developed in cooperation with all groups that have an interest in fisheries (Garcia & Staples, 2000.). Therefore, this study aimed to describe the current stock status in the reservoir, and what the consequences of alternative harvest levels.

1.2. Statement of the problem

Stock assessments provide fisheries managers with the information that is used in the regulation of a fish stock. A wide array of biological data collected for an assessment include details on the age/size structure of the stock, growth rate of the fish,natural mortality, fishing mortality(Sparre&Venema, 1992).A fishery activity in Gilgel Gibe Reservoir is an important source of income and livelihood to the local people (Wakjira, 2013). At the time of present study, field observations have shown that a large number of young people were organized into cooperatives operating both on the production and marketing chains. Nile tilapia is the predominant species targeted by the fishermen.

The reservoir fishery has not been modeled, and the status of the fish population and its basic dynamics are not known. On the other hand, establishment of appropriate management practices require determination fish population status and its dynamics. There are some studies conducted on Gilgel Gibe reservoir on other issues such as feeding habits and some biological aspects of fish species(Wakjira, 2013).However, a study on stock assessment of its fisheries resources, which is important to generate relevant parameters for management decision, has never been conducted. Therefore, it becomes very imperative to conduct this study in order to ensure sustainability of the fisheries resources of the reservoir for sustained livelihood of the local community that depend on it. Therefore, this study aimed to investigate the stock status of Nile tilapia in Gilgel Gibe reservoir and make predictions of sustainable productions. The stock assessment followed the length-based approach, as it is the most suitable approach for stock assessment in the tropical and subtropical regions where aging is less practical (Sparre, 1998).

1.3. Objectives of the study

1.3.1. General objective

- To investigate the stock status and make predictions of sustainable productions of Nile tilapia in Gilgel Gibe reservoir, Omo-Turkana Basin, Southwest Ethiopia.

1.3.2. Specific objectives

- To estimate growth parameters of the Nile tilapia in the reservoir
- To estimate natural mortality and fishing mortality rate of Nile tilapia in the reservoir
- To estimate exploitation, recruitment rates and population sizesof Nile tilapia in the reservoir
- To analyze long-term yield predictions of Nile tilapia in the reservoir

1.4 Significance of the Study

The present study will provide updated information on the existing status of reservoir and will provide advice on the optimum exploitation of resources because, living resources are limited but renewable, and fish stock assessment describe as the search for the exploitation level which in the long run gives the maximum yield in fishery.This study will also informs the decision makers to formulate and implement appropriate management measures for the reservoir fisheries in order to ensure resource sustainability thereby ensuring continuity of livelihood of the local people that depend on it.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Stock assessment in fisheries science

A fishery is defined as the set composed of a particular stock plus the fishing activities related to its harvest, inclusive of fishers, vessels, gears and even associated facilities. Often the word stock refers to a population or part of the population of a single species but in the frequent case of multi specific fisheries it includes a group of at least two similar or diverse species (Musick& Bonfil, 2005).

Stock assessment makes use of diverse types of information to give managers advice about the status of a fishery and the possible outcomes of management actions. This includes aspects not only related to the resource abundance such as whether the stock is depleted or close to its maximum biomass, but also in regards to other important aspects of fish population dynamics such as the current levels of mortality and expected levels of future recruitment, or even economically relevant features such as likely changes in catch per unit effort. Stock assessment has been defined in many ways, often in terms of its objectives. Sparre&Venema(1992) proposed that the basic purpose of stock assessment is "to provide advice on the optimum exploitation of aquatic living resources". Probably the best modern definition comes from (Hilborn& Walters, 1992) "Stock assessment involves the use of various statistical and mathematical calculations to make quantitative predictions about the reactions of fish populations to alternative management choices".

Reference points (RPs), by definition, rely on some measure of the stock in question that relates (or refers) to status. Reference points can either be targets (levels that management attempts to maintain the stock at or around) or limits (levels that are to be avoided (Caddy & Mahon, 1995; Caddy, 2004). Target RPs (TRPs) therefore reflect desired biological or ecological states, whereas limit RPs (LRPs) relate to resource protection and persistence (Caddy & Mahon, 1995; Botsford*et al*., 2004).

2.2 The purpose of stock assessments

Fish resource utilization is the primary and an important economic activity. Its purpose is to provide a flow of benefits to human society; it serves as a food because of its rich nutritional value in provision of protein (FAO, 2010). Stock assessment is the part of Fisheries Science that studies the status of a fish stock as well as the possible outcomes of different management alternatives. It tells us if the abundance of a stock is below or above a given target point and by doing so lets us know whether the stock is overexploited or not; it also tells us if a catch level will maintain or change the abundance of the stock. However, stock assessment is not the goal of Fisheries Science (Musick&Bonfil, 2005).

While early fisheries management had implicitly or explicitly MSY as it most important objective at present MSY is considered only a biological concept and benchmark to guide management(Gulland, 1968). Although MSY still plays an important role as a guiding light for fisheries management, often specific and multiple objectives of fisheries management may be more important than obtaining maximum yield in the long term (Alverson&Paulik, 1973). According to Hilborn& Walters (1992), the most widely accepted fundamental purpose of fisheries management is “to ensure the sustainable production over time from fish stocks, preferably through regulatory and enhancement options that promote economic and social well-being of the fishers and industries that use the production”.

2.3. Stock assessment and management basics

2.3.1 Stock assessment in the world

The global capture fisheries production in 2008 was reported by FAO Fisheries and Aquaculture Departments, 90 million tones, with an estimated first-sale value of US$93.9 billion, comprising about 80 million tons from marine waters and a record 10 million tons from inland waters. However, the proportion of marine fish stocks underexploited or moderately exploited declined from 40 percent in the mid-1970s to 15 percent in 2008, whereas the proportion of overexploited, depleted or recovering stocks increased from 10 percent in 1974 to 32 percent in 2008 (de Séligny& Grainger, 2010).

The sustainability of marine fisheries became a global concern because of the rapid increase in fishing pressure and arbitrarily exploitation, which may cause negative consequences for the ecosystems and societies (Mora *et al.*, 2009).This situation is worse, particularly in developing countries where proper management tools and political will lack and pervasive illegal fishing of juvenile and brood fishes is the fisheries’ governing features (Froese, 2004; Spaet*et al.*, 2012; Jabado&Spaet, 2017). This worst-case scenario of the stocks provides the impetus for articulating effective management tools, focusing on all concerned stakeholders’ participation to promote conservation the ecosystems and achieve the optimum yields to sustain the livelihoods and sustainable food supply (Jabado*et al.*, 2015).

The high exploitation rate of the resources could be lead to overfished and then reduced biomass, particularly for targeted species. In term of fishery management, is necessary to have the latest information of stock status as a reference to determine management rules (Patrick *et al.*, 2010).

Stock assessment in Africa

Fish stocks assessments support more effective fisheries management. Theseassessments are urgent in Sub-Saharan Africa where inland fisheries contribute significantly to livelihoods but are poorly managed. Inland fisheries in the region support livelihoods for over 4.9 million people (De Graaf& Garibaldi, 2014), but are threatened by stock depletion (Marshall, 2015).

Of the naturally endowed resources fishery sector serves as the base for the development of many developing countries and they serve as reliable sources of income for many rural households to sustain their life (Bene& Friend, 2011). Indeed, it is the key sector for reducing poverty and is considered as a potential strategy that helps in diversifying the income of households (Olale& Henson, 2013). It is also important to serve more than 3 billion people in developing regions (Mustafa *et al.*, 2018).

Stock assessment in Ethiopia

The actual fish production in Ethiopia is far below the potential and the production status is uneven across water bodies. In some lakes such as Tana, Chamo, Abaya, Hawassa, Ziway and Hayq, fishing is beyond the maximum sustainable production potential and the problem of overfishing has been already reported in these water bodies (Tesfaye& Wolff, 2016). However, in some lakes which are located in remote areas such as Lakes Maybar and Golbo the fishery is unexploited and further development is required (Tessema&Geleta, 2013; Tesfaye& Wolff, 2014; Lake *et al.*, 2018).

2.4. Fish stock assessment models

According to Reyntjens (1997) there are three basic groups of models (Empirical models, Surplus production models and Analytical models) each having specific requirements in terms of data and ability to perform calculations.

2.4.1 Empirical Models

Strictly speaking, empirical models are not stock assessment tools since they will not yield any information on stocks. Empirical, models make a link between some easily measured characteristic of a water body, such as its area, the conductivity of the water or the mean primary production and an expected yield. This link needs first to have been established empirically for a group of water bodies for which both the yield and the considered characteristic are known. Basically when an empirical model is applied, a given water body is being compared with the original group (Reyntjens, 1997).

4.4.2 Holistic Models

In situation when data are limited, for example when starting up the exploitation of a hitherto unexploited resource, or in case of limited capability of sampling, one may not have input data of the quality and quantity of required for analytical approach. This approach is, of course, recommendable, because it solves the problem in the end, but that may takes a year, while often advice on an exploitation or development strategy may be needed now. Two types of simple are presented namely, the swept area method and the surplus production model (Reyntjens, 1997).

2.4.3 Analytical Models

Analytical models building on individual fish as the basic unit and where dynamic processes such as age, growth, mortality, and maturity are each represented by a sub-model. These models are age- or length structured and deals with a partial or the entire demographic structure of the population (Thompson & Bell, 1934; Beverton& Holt, 1957).

According to Beverent& Holt (1957) analytical model requires the age composition of catches to known. For example, the number of one year old fish caught, the number of two-year old fish caught, from the input data. The basic idea behind analytical model expressed as, if there are too few old fish the stock is overfished and the fishing pressure on the stock should be reduced and, if there are very many old fish the stock is under fished and more fish should be caught in order to maximize the yield.

Froese (2004) introduced a method that relies on well-established relationships between fisheries management and life history theory (Reynolds *et al.*, 2001) as applied to catch length composition data. Its straightforward approach has gained attention (Jennings, 2005; Lewin*et al.*, 2006; Francis *et al.*, 2007) and is based on three simple ideas: (1) catch length compositions should reflect almost exclusive take of mature individuals (P_{mat}) (

Leaman,1991;Myers & Mertz, 1998) (2) catch length compositions should consist primarily of fish of the size at which the highest yield from a cohort occurs (P_{opt}) (Beverton, 1966), and (3) catch length compositions should demonstrate the conservation of large, mature individuals (P_{mega}) (Berkeley *et al.*, 2004). These proposed metrics are meant to capture catch characteristics indicative of sustainable catches, such as avoidance of growth (Beverton& Holt, 1957) and recruitment overfishing, while using easily collected fisheries data (e.g., length frequencies of catch) (Ricker, 1954).

2.4.3.1 Length-based Models

Length-based fish stock assessment models have progressively been applied for tropical fishery in comparison to age-based methods that are more employed for temperate waters (Sparre and Venema, 1992; Jimenez, 2004; De Graaf& Dekker, 2006). Moreover, in contrast to the difficulty in acquiring age estimates, it is much easier to collect length data (Wang & Ellis, 2005; Hoggarth, 2006). Length-based stock assessment approach was used in order to estimate vital parameters such as fish growth and mortality from the data pooled by gear type and mesh sizes i.e. length frequencies by month (Sparre, 1998).

Length-based methods are widely used to assess the population dynamics and stocks of commercially important fish species (Venema&Zalinge, 1989; Amin *et al.*, 2008; Glamuzina*et al.*, 2017),

2.4.3.2. Age-based models

Broadly speaking, there are two approaches to the incorporation of catch-at-age information in fisheries assessments: virtual population analysis (VPA) and statistical catch-at-age analysis (SCAA). When catch-at-age data are among those used to fit an age-structured production model (ASPM), this approach can become equivalent to SCAA (Bull *et al.*, 2005).

VPA makes the assumption that catch-at-age data are exact (i.e. with negligible error) and requires these to be available for all the years covered by the assessment (Gulland, 1965). SCAA approaches, in their simplest form, make the assumption of an invariant fishing selectivity-at-age pattern over time that determines the true age distribution of the total catch taken each year. This pattern is then estimated in the model-fitting process by comparing this distribution with the observed catch-at-age data (Punt &Hilborn, 1997).

2.5 Fish maturity stage

Knowledge of the reproductive cycle and the factors affecting it are important issues in fish and fisheries biology (Tomkiewicz*et al.*, 2003; Chakrabarti&Barun, 2017). Reproductive studies of fishes, such as assessment of size at maturity, duration of the spawning season and fecundity, require knowledge of the state of gonad development and a large number of macroscopic maturity scales in individual fish (Carrasson&Bau, 2003).

Fish life history is a trade-off of reproductive success with adult growth and mortality risk (Charnov&Berrigan, 1991). Maturation involves changes in morphology, behavior and/or habitat, in some cases even great annual migrations to spawning areas. In summary, maturation requires important energetic, ecological, physiological, anatomical, biochemical and endocrinological adaptations (Rocha, *et al.*, 2008). The onset of fish maturation can be determined by several factors: biometric factors such as size, age or weight (Vallin&Nissling, 2000).

Effective fisheries management depends on having an exact assessment of biological parameters, including growth parameters, reproduction, size at sexual maturity (Lm), and stock assessment (Tracey *et al.*, 2007). The Lm in fish species is a fundamental requirement to find out the reasons on behalf of modifications of the length of maturity (Templeman, 1987).The degree of sexual maturity and sex of each specimen was determined by inspection of the gonads in fresh individuals using maturity scale (Holden &Raitt, 1974). Cyclic changes in the gonads (ovaries and testes) have also been examined in a few closely related species, including the African catfish, Clariaslazera (Hogendoorn, 1979).

2.6 Distribution of Nile Tilapia

Nile tilapia is an important fish in the ecology of tropical and sub-tropical region including Ethiopia and of great commercial importance in the fisheries in many African lakes (Britton &Harper, 2008; Welcomme&Lymer, 2012). Nile tilapia, a member of the Cichlidae, is native to many freshwaters of East Africa. It adapts to a wide range of environmental conditions (Hailu, 2014). It is also the most popular species of the bony fish for aquaculture in Africa (Abdel*et al.*, 2007).

It contributes considerably to global freshwater fish production. The species is by far the most dominant and economically valuable fish in Ethiopia (Getahun&Stiassny, 1998; Welcomme&Lymer, 2012) contributing to more than 60% of the annual fish yield (Reyntjens&Wudneh, 1998).

2.7 Factors Affecting Fish Stock

Global fisheries may underperform due to over fishing, harmful subsidies, and over-capacity (Carvalho*et al*., 2011; Akpalu*et al*., 2015).According to the Millennium Ecosystem Assessment, depletion of fish stocks is one example of a potentially irreversible change to an ecosystem that results from present unsustainable practices. The Code of Conduct for Responsible Fisheries developed in 1995 by the Food and Agriculture Organization (FAO) of the United Nations includes a set of recommendations for reducing the negative impacts of fishing activities on marine ecosystems (Coll*et al*., 2013). Voluntary Guidelines for Securing Small-Scale Sustainable Fisheries (SSF) were developed in 2015 as a complement to the 1995 FAO Code, and the SSF Guidelines are a fundamental tool to promote sustainable development in a strategic framework(Kurien, 2015).

Climate change poses significant threats to fisheries on top of many other concurrent pressures such as overfishing, habitat degradation, pollution, introduction of new species and so on (Brander, 2010).Although, heavy metals are naturally trace components of aquatic systems, their concentration levels may be raised due to natural processes like geological weathering of rocks and soils and/or anthropogenic activities such as chemical damping, application of agrochemicals (fertilizers and certain pesticides), traffic, mining, burning of fossil fuels and industrial activities (Tüzen, 2003; Ali *et al.*, 2011).

The most important factors limiting fish production are the use of traditional fishing methods, food habits of the people, poor facilities along the fish value chains, poor fishery regulation implementation system, pollution, weak coordination among water sectors and generally neglectence to the fishery sector (Hirpo, 2017; Wake &Geleto, 2019). Expansion of agriculture and deforestation were the current problems of Ethiopian fish and fishery. In general, the Ethiopian fishery is under several constraints due to different factors (Kebede*et al*., 2017; Kebede&Gubale, 2016).

CHAPTER 3: MATERIALS AND METHODS

3.1. Description of the study area

The data was collected from Gilgel Gibe reservoir, constructed on Gilgel Gibe River, a tributary of a major Gibe River, located within the Omo-Turkana drainage basin in the southwestern part of the country. It was commissioned in 2004 as a hydropower dam and located at an altitude of 1640 m above sea level (ASL) at geographic coordinates of 07.4253-07.5558°N and 37.1153-37.2033°E. Its maximum and minimum water levels during wet and dry seasons respectively are 1671 m and 1653 m ASL. It has a total surface area of 51 km^2 and max volume of 900 million m^3 (Ethiopian Electric Power Corporation, 1997). Its depth ranges between 2 m and 35 m with a mean depth of about 17.6 m. It drains a total catchment area of 4225 km^2. The mean annual atmospheric temperature is 19.2 °C. The mean annual rainfall ranges between 1300 mm and 1800 mm in the catchment areas (Ethiopian Electric Power Corporation, 1997).

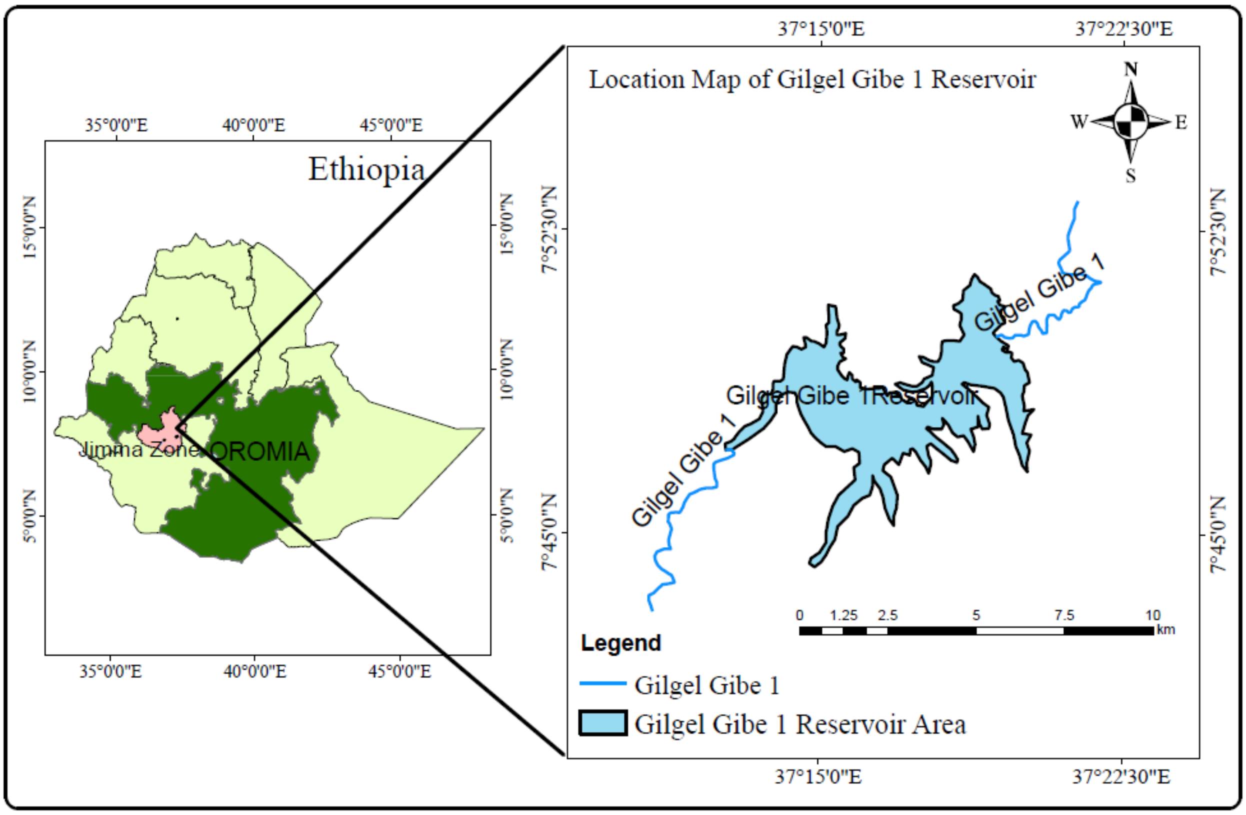


Figure1. Map of the study area, Gilgel Gibe Reservoir.

3.2. Fish sampling and Data collection

Fish sampling and data collection were conducted at Deneba landing site for 15 months between March2020 and July 2021 effectively for 147 days, two month data was not collected because of the outbreak of COVID-19. Deneba is the major landing site where most of the fishing activities are undertaken in the reservoir.Thus, fish sampling through this site is considered as it would providea representative sample.In the present study, a total of 25,994 Nile tilapia specimens were collected, using gillnets of various mesh sizes (6cm, 8cm, 10cm and 12cm, stretched mesh) to allow exhaustive sampling.This sample size has been representative sample to warrant estimation of length distribution of the total annual catch and other parameters, as the reservoir covers smallsurface area (51 km^2).

Fish sampling involved the participation of the local fishers in order to generate sufficient and reliable fish sample for the catch and length frequency data (Ticheter*et al*., 1998). Seven fisher groups, each group consisting of four fishers, were hired for the fish sampling to allow reasonably high fish catch from the commercial gillnets. Moreover, there were no restrictions for the fishers where to fish in order to cover wider area for sampling. Data on catch and length frequency were collected from all fish harvested by the fishers without the need to sample. In addition to data on length frequency, fish specimens were collected every month for maturity stage determination.

3.3. Computations and Data analysis

FiSAT II software, version 1.2.2 (Gayanilo*et al*., 2005) was used for the estimation of growth parameters, fishing mortality, population number, recruitment and fish yield, in sections 3.3.2 and 3.3.4, from the monthly length frequency data.Estimation of these vital parameters and yield was based on the annual length-composition data, which in turn was estimated from the sample catch data following standard equations (section 3.3.1). Moreover, the annual catch data was converted into catch per unit effort (CPUE), by dividing it with the total number of gillnet settings, to standardize estimation of the parameters, especially fish abundance and fishing mortality rates.

3.3.1 Estimation of the annual catch composition and fishing effort

The annual length composition of each size group was estimated as:

$$n_i = \frac{C}{c} x L_i$$

Where,

n_i = the annual frequency of the length group i

L_i = the frequency of the length group i in the measured fish sample

c = the total measured sample fish catch during the study period

C = the estimated total annual fish catch, which in turn is determined using the following equation;

$$C = \frac{D}{d} x c$$

Where,

D = the total number of days in a year (i.e. 365 days)

d = the total number of days sampling was conducted; c is as in the preceding equation.

Similarly, the annual fishing effort for each gillnet of mesh size i was estimated using the following equation:

$$n_i = \frac{N}{n} x\ f_i$$

Where,

n_i = the estimated number of gillnet settings of mesh size i per year

f_i = the number of gillnet settings of mesh size i used to generate the fish sample

n = the total number of gillnet settings of all mesh sizes used during the study period for collection of fish samples

N = the estimated annual total gillnet settings of all mesh sizes, which in turn is determined using the following equation;

$$N = \frac{D}{d} x\ n$$

Where,

D = the total number of days in a year

d = the total number of days sampling was conducted; n is as in the preceding equation.

Similar equation, as for the estimation of gillnets settings, was used to estimate the annual number of fishermen operated in the fishing.

3.3.2. Estimation of growth parameters

The von Bertalanffy growth function (von Bertalanffy, 1934) was used as follows, for the purpose estimating the growth parameters, $L_t = L_\infty(1-\exp(-K(t-t_o)))$

Where,

L_t = Length (cm) at age t (years)

L_∞ = Asymptotic length which a fish might achieve if allowed to grow indefinitely

K = Growth coefficient (1/yr)

t_o = the theoretical age of fish at zero length if fish grows according to the von Bertalanffy growth function

The ELEFAN-I module of Pauly& David (1981) was used to fit the von Bertalanffy growth function in order to estimate asymptotic length (L_∞) and growth coefficient (K). ELEFAN-I is a direct (non-parametric) approach that estimates the growth parameters by fitting a growth curve through a whole set of samples taken through time without a need to estimate the parameters of the cohort distribution such as mean length and number of each cohort. Biased estimation of growth parameters due to the variability in the growth of individual fish within a cohort is an inherent limitation of the ELEFAN method if size classes are arbitrarily chosen. Therefore, in order to circumvent this limitation, optimal class sizes for the length frequency of the catch compositions were determined using the equation of Wang *et al.*, (2020) as class size = $0.23L_{max}^{0.6}$, where, L_{max} is a maximum length recorded in the sample. In the ELEFAN-I routine, the response surface analysis was used to identify best combinations of L_∞ and K based on goodness-of-fit (R_n) values. Then, reliability of the estimate of K was assessed using the K-scan option (Gayaniloet *al.*, 2005).

The theoretical age (t_o) was determined using the empirical equation of Pauly (1983) as$\log(-t_o) = -0.3922-0.2752\log L_\infty-1.038\log K$. The approximate maximum age or longevity (t_{max}) was calculated based on empirical equation of Pauly(1980)as$t_{max} = 3/K + t_0$, based on the assumption that L_{max} of a fish is equivalent to $95\% L_\infty$. Growth performance index (Φ') was computed using Pauly& Munro's (1987) equation as $\Phi' = \log k+2\log L_\infty$.

3.3.3. Estimation of the natural mortality rate (M)

Natural mortality was estimated using Pauly's (1984) empirical formula as $\log M = -0.0066 - 0.279\log L_\infty + 0.6543\log K + 0.463\log T$

Where,

M = Natural mortality (1/year)

K = Growth coefficient (1/year)

T = Mean annual surface water temperature (27.23 °C)

The M/K ratio was used to judge the validity of estimate of natural according to Beverton& Holt (1957).

3.3.4. Recruitment pattern and Breeding Activity

The recruitment pattern of Nile tilapia was obtained from the length frequency data, based on the concept of Pauly (1982), using a routine in FiSAT II. The breeding activity of the Nile tilapia was assessed using the five-scale maturity stages protocol of Harbot&Hogari (1982) (Appendix 1). The percentage of fish that have reached maturity stages, i.e. stage 4 and 5, was used to estimate the likely breeding activity (breeding season) of the fish.

3.3.5. Estimation of population sizes (N) and Fishing mortality rates (F)

The length-based virtual analysis (VPA), also known as Jones' length-based cohort analysis (LCA), was used to estimate population sizes and fishing mortalities from the annual catch estimates using the growth parameters and natural mortality values as inputs(Jones, 1984).Although VPA and cohort analysis were first developed as age-based methods the length-based methods have become available, which are of particular interest to tropical fisheries (Jones, 1984; Sparre&Venema, 1998).LCA deals with the pseudo-cohorts that replace the real cohorts based on the assumption of constant parameter system in which the dynamics presented by all length classes caught in one year is assumed to reflect that of a single cohort during its entire life span. As such, the method uses the following equations to estimate the fish population sizes and fishing mortality rates of the respective length classes (Sparre&Venema, 1998).

Initially, the terminal (oldest) population (N_t) is estimated from the equation, $N_t = C_t \cdot (M+F_t)/F_t$

Where,

$C_t$is the catch taken from the terminal size group

M is the natural mortality rate

Ft is an estimated value of fishing mortality rate of the terminal size group

Then, population sizes and fishing mortality rates for all size groups are estimated by solving the following two equations.

Population sizes are estimated from the equation, $N(L_1) = [N(L_2)*H(L_1, L_2) + C(L_1, L_2)]*H(L_1, L_2)$,

Where,

$N(L_1)$ = the number of fish population that attained size L_1

$N(L_2)$ = the number of fish population that attained size L_2

$C(C_1, C_2)$ = the total catch of fish between lengths L1 and L_2

$H(L_1, L_2)$ = the fraction $N(L_1)$ fish that survived natural mortality as it grows from L_1 to L_2, which in turn is computed as, $H(L_1, L_2) = [(L_\infty - L_1)/ (L_\infty - L_2)]^{M/2K}$

Where,

L_∞ and K are the von Bertalanffy growth parameters

M = natural mortality rate

Fishing mortality rates for each length group are estimated using the equation,

$$F(L1, L2) = M*[\frac{F(L1,L2)/Z(L1,L2)}{1-(F(L1,L2)/Z(L1,L2))}$$

Where,

$(L_1,L_2)/Z(L_1,L_2)$ is an exploitation rate (E) of fish length between L_1 and L_2 computed as, $E = \frac{C(L1,L2)}{N(L1)-N(L2)}$

Exploitation rate (E) was estimated as, E = F/Z, where, Z is the total mortality.

3.3.6. Yield analysis and predictions

3.3.6.1. Yield analysis with Thompson and Bell model

A length-based Thompson and Bell model was used to analyse yield and for its long-term predictions from the annual catch data (Thompson & Bell, 1934;Pauly& Morgan, 1987; Sparre &Venema, 1998).Annual catch data, growth parameters, natural mortality, population abundanceand fishing mortality by length group estimated in the preceding sectionswere used as inputs for the yield analysis.

3.3.6.1.1. Estimation of current yield and biomass

The current yield (in units of weight) and biomass (in units of weight) were estimated by multiplying the current catch and population numbers by mean weight of fish in each size class as follows:

$Y(Li, Li+1) = C(Li,Li+1)*W(Li,Li+1)$

and

$B(Li, Li+1) = N(Li, Li+1)*W(Li,Li+1)$

Where,

Li and Li+1 = length intervals of consecutive length class

Y(Li,Li+1) = the annual yield of each length class

C(Li, Li+1) = the annual catch of each length class

B(Li, Li+1) = the annual yield of each length class

N(Li, Li+1) = the annual number of each length class

W(Li,Li+1) = the mean weight of fish in each length class, which in turn is estimated from the following equation:

$W(Li, Li+1, g) = a\,[(Li+Li+1, cm)/2]^{b}$

Where, ‘a’ and ‘b’ are growth coefficients of the length-weight relationship

3.3.6.1.2. Yield and Biomass predictions under changed levels of effort

Yield analysis and prediction in Thompson and Bell model is was based on the computations of the following underlying equations under the changed levels of fishing effort (Wetheral*et al.*, 1987; Sparre&Venema, 1998; Cadima, 2003):

Total mortality, $Z(L_i,L_{i+1})$, of the respective size class:

$Z(L_i,L_{i+1})_{new} = M + X.F(L_i, L_{i+1})$

Where,

X = Fishing mortality factor

M = Natural mortality rate

$F(L_i, L_{i+1})$ = Fishing mortality rate of the respective size class

Fish abundance,$N(L_{i+1})$, of the subsequent size class:

$$N(L_{i+1}) = N(L_i).\exp(-Z(L_i,L_{i+1}).\Delta t(L_i,L_{i+1})$$

Where,

$N(L_i)$ and $N(L_{i+1})$ = Number of the respective length groups

$\Delta t(L_i, L_{i+1})$ = the time required for an average fish to grow through the length class i.e. Li to Li+1, which in turn is determined as follows:

$\Delta t(L_i, L_{i+1}) = (1/K). \ln((L_\infty - Li)/(L_\infty - Li+1))$, where L_∞ and K are growth Parameters

Fish catch in number, $Catch(L_i, L_{i+1})$, of the respective size class:

$Catch(L_i, L_{i+1}) = (N(L_i) - N(L_{i+1})).X.(F(L_i, L_{i+1})/Z(L_i, L_{i+1})_{new})$

Fish yield in units of weight, Yield(Li, Li+1), of the respective size class:

$Yield(L_i, L_{i+1}) = Catch(L_i, L_{i+1}).W(L_i, L_{i+1})$

Where, $W(L_i, L_{i+1})$ = Average weight of fish in the respective size class computed as in section 3.3.6.2.1

Average biomass in units of weight, $MeanBM(L_i, L_{i+1})$, of the respective size class:

$Mean\ BM(L_i, L_{i+1}) = ((N(L_i) - N(L_{i+1}))/Z(L_i, L_{i+1}).W(L_i, L_{i+1})$

The total annual yield and biomass of the fish stock is obtained by summing the yields and biomass of each size class.

3.3.6.2. Relative yield per recruit analysis

A length-based relative yield per recruit model was used to estimate the maximum exploitation pattern that would give maximum yield per recruit (YPR). The computation of relative yield-per-recruit (Y'/R) was based on the Beverton& Holt (1966) model as:

$$Y'/R = EU^{M/K}\left\{1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)}\right\}$$

WhereE= F/Z, Z = F + M;

$U = 1 - (LC/L\infty)$

$m = (1 - E)/(M/K) = K/Z$

E is the exploitation rate

F is the fishing mortality

Z is thetotal mortality

K is individual fish growth coefficient

$L\infty$ is individual fish asymptotic length

Meanlength at first capture (Lc) was estimated 50% probability of capture using routines in FiSAT II.

CHAPTER FOUR: RESULTS

4.1. Length Frequency and Catch Composition

A length frequency and the estimated annual catch composition of Nile tilapia from Gilgel Gibe Reservoirare presented in Table (1 and 2) respectively.The majority of the fish catch and length frequency composition was observed with the size range of 15-16cm and followed by the size range of 17-18cm.Higher catch composition was observed during the month of February (13,177) and followed the month of June (10,245).Total estimated annual catch composition of Nile tilapia was 64,543.

Table 1. Length frequency composition of Nile tilapia (*Oreochromisniloticus*, L.) sampled during the study period from Gilgel Gibe Reservoir (Class size = 2 cm; Minimum TL = 9 cm; Maximum TL = 42 cm).

Gro leng	**M 20**	**Ap 20**	**Ju 20**	**Au 20**	**Se 20**	**Oc 20**	**No 20**	**De 20**	**Ja 20**	**Fe 20**	**M 20**	**Ap 20**	**M 20**	**Ju 20**	**Jul 2021**	**Total**
9-	5	0	21	2	0	0	0	0	0	2	0	0	5	0	2	37
11-	12	88	70	36	11	43	1	1	3	25	14	5	10	10	9	1174
13-	77	36	11	47	32	33	2	28	56	47	41	14	10	29	38	4913
15-	77	58	13	45	39	12	11	36	54	21	10	22	80	45	28	9266
17-	71	54	51	44	15	88	18	26	67	16	64	90	17	25	13	6480
19-	35	27	25	16	4	22	56	71	27	62	26	61	86	16	4	2585
21-	88	91	96	10	1	67	15	18	66	22	12	16	24	4	4	845
23-	31	12	39	3	0	35	9	10	39	85	43	12	16	1	1	336
25-	2	8	18	4	0	17	4	9	10	28	23	2	13	2	4	144
27-	3	1	8	1	0	5	1	2	10	15	9	0	10	1	5	71
29-	2	1	11	0	0	5	0	2	8	11	3	0	6	3	4	56
31-	2	1	4	0	0	0	0	0	7	9	2	0	8	6	2	41

33-	0	0	0	0	0	1	1	0	6	8	2	0	2	1	4	25
35-	0	3	0	0	0	1	0	1	3	1	0	0	4	1	0	14
37-	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	4
39-	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
41-	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
Tot	28	19	41	20	10	28	39	77	16	53	25	55	22	14	118	25994

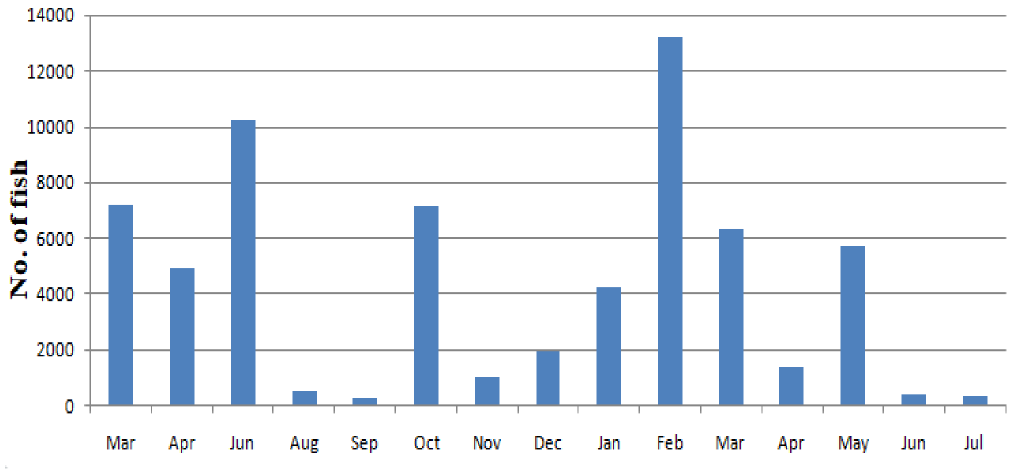


Figure 2. Monthly composition of fish in Gilge Gibe reservoir collected during the present study

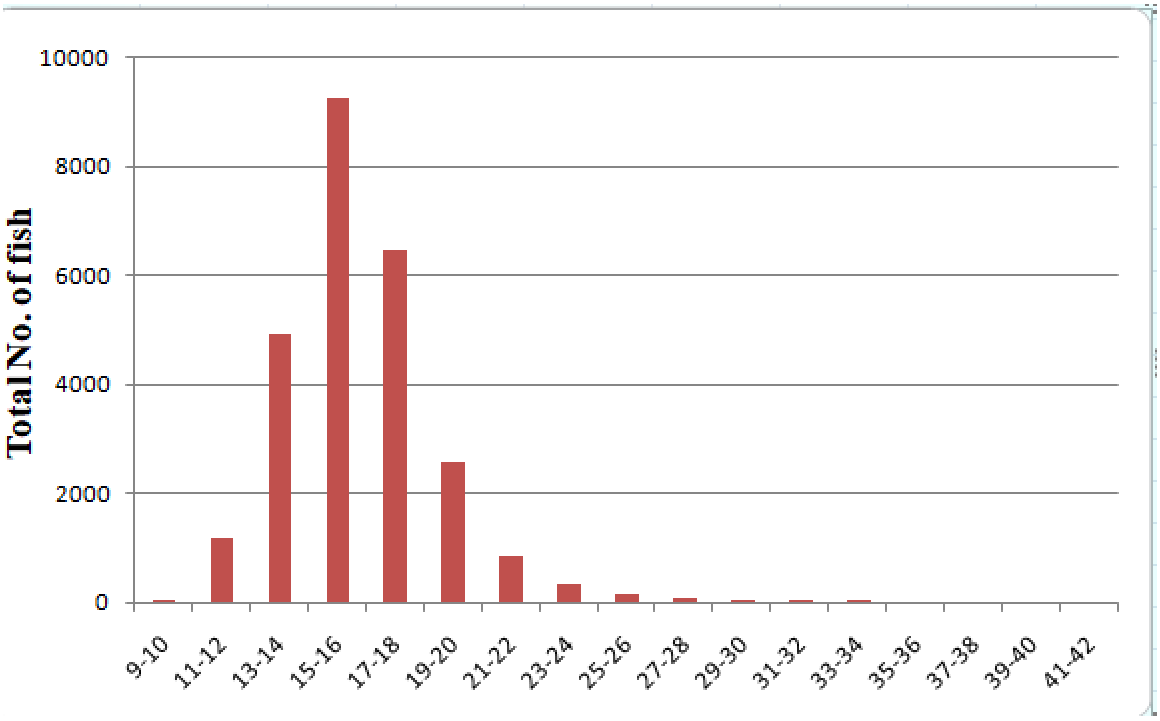
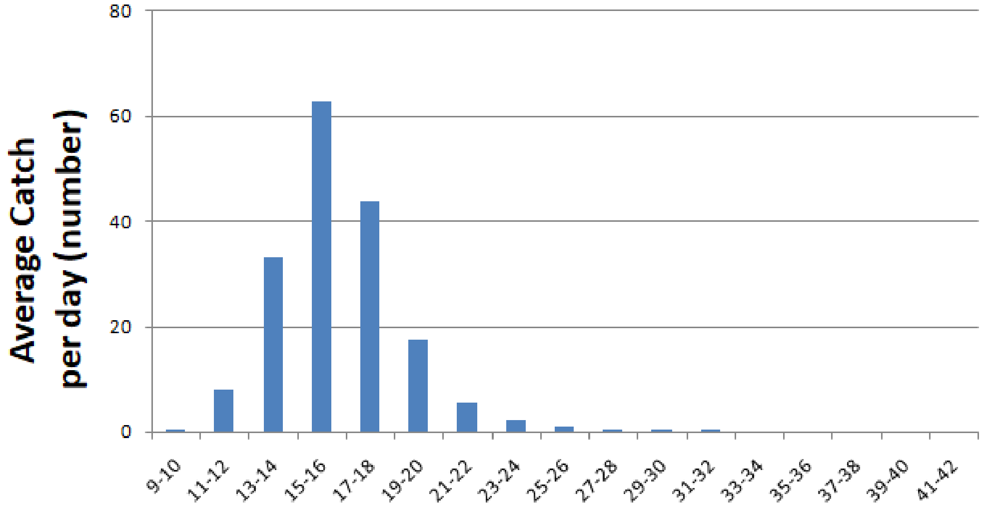


Figure 3. Total Number of fish with length group in Gilgel Gibe

Table 2. The estimated annual catch composition of Nile tilapia (*Oreochromisniloticus*, L.) sampled from Gilgel Gibe Reservoir during the study period (Class size = 2 cm; Minimum TL = 9 cm; Maximum TL = 42 cm).

Group length	**Ma 20**	**Ap 20**	**Ju 20**	**Au 20**	**Se 20**	**Oc 20**	**No 20**	**De 20**	**Ja 21**	**Fe 21**	**Ma 21**	**Ap 21**	**Ma 21**	**Ju 21**	**Jul 21**	**Tot**	**% Total**	**ACD**	**ACGD**
9-10	12	0	52	5	0	0	0	0	0	5	0	0	12	0	5	92	0.1	0.3	0.03
11-12	308	219	1748	89	27	107	2	2	7	62	35	12	248	25	22	2915	4.5	8.0	0.95
13-14	1924	916	2833	117	79	822	5	70	139	1179	1025	358	2565	72	94	12199	18.9	33.4	3.99
15-16	1934	1453	3263	112	97	3136	293	901	1341	5234	2508	566	1989	112	70	23007	35.6	63.0	7.53
17-18	1768	1346	1286	109	37	2197	457	665	1666	4194	1609	223	437	62	32	16090	24.9	44.1	5.27
19-20	891	673	626	40	10	561	139	176	670	1554	663	151	214	40	10	6419	9.9	17.6	2.10
21-22	219	226	238	25	2	166	37	45	164	559	298	40	60	10	10	2098	3.3	5.7	0.69
23-24	77	30	97	7	0	87	22	25	97	211	107	30	40	2	2	834	1.3	2.3	0.27
25-26	5	20	45	10	0	42	10	22	25	70	57	5	32	5	10	358	0.6	1.0	0.12
27-28	7	2	20	2	0	12	2	5	25	37	22	0	25	2	12	176	0.3	0.5	0.06
29-30	5	2	27	0	0	12	0	5	20	27	7	0	15	7	10	139	0.2	0.4	0.05
31-32	5	2	10	0	0	0	0	0	17	22	5	0	20	15	5	102	0.2	0.3	0.03
33-34	0	0	0	0	0	2	2	0	15	20	5	0	5	2	10	62	0.1	0.2	0.02
35-36	0	7	0	0	0	2	0	2	7	2	0	0	10	2	0	35	0.1	0.1	0.01
37-38	2	0	0	0	0	0	0	0	0	0	5	0	0	2	0	10	0.0	0.0	0.00
39-40	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0.0	0.0	0.00
41-42	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	5	0.0	0.0	0.00
Total	7158	4896	10245	516	253	7149	971	1919	4201	13177	6347	1386	5671	360	293	64,543	100.0	176.8	21.13

Figure 4. Estimated average catch per day in Gilgel Gibe Reservoir



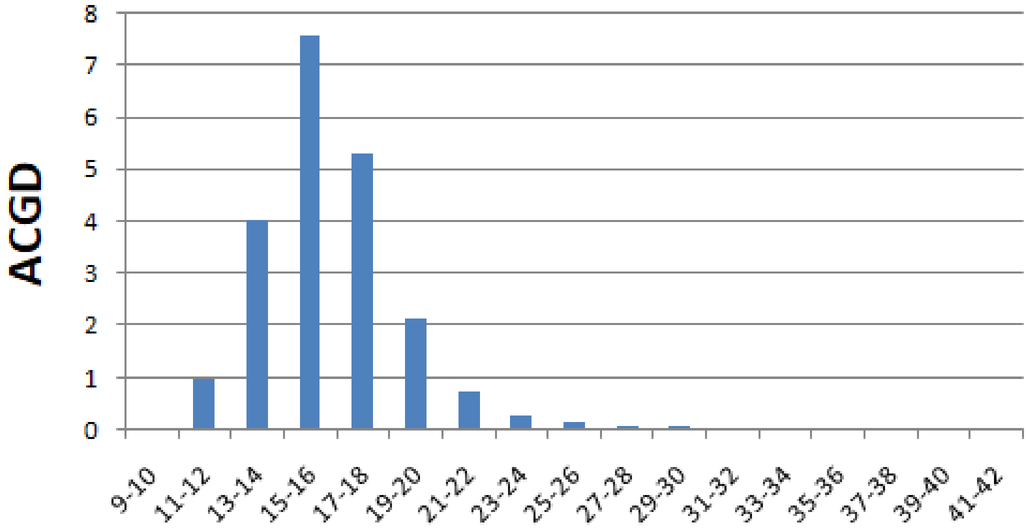


Figure 5. Estimated Average Catch per gillnet setting per day in Gilgel Gibe

The total number of fishermen operated during the sampling period, the average number of gillnets set per day and the total catch using gillnet of different mesh size are presented in Table 3. The average number of fishermen operating on the reservoir was 22. Thefishermen owned on average 8 nets were set daily on the reservoir. From different sized gillnets the highest number of gillnet was 8cm which is 850 and the maximum number of gillnet was set on February month.

Table 3. Summary of the fishermen and gillnet settings per mesh size (6 cm-12 cm) and their estimated annual total number.

Sampling Month	FS	FA	**6cm**		**8c**		**10c**		**12c**		**Total**	
			GS	GA	G	G	G	G	G	G	G	GA
Mar 20	275	682.82	68	169	99	246	0	0	2	5	169	420
Apr 20	221	548.74	28	70	86	214	0	0	0	0	114	283
Jun 20	274	680.34	51	127	62	154	1	2	0	0	114	283
Aug 20	25	62.07	5	12	4	10	0	0	0	0	9	22
Sep 20	46	114.22	7	17	4	10	0	0	0	0	11	27
Oct 20	441	1095.00	72	179	53	132	1	2	1	2	127	315
Nov 20	26	64.56	0	0	8	20	0	0	0	0	8	20
Dec 20	89	220.99	25	62	5	12	3	7	0	0	33	82
Jan 21	365	906.29	12	30	93	231	2	5	3	7	110	273
Feb 21	736	1827.48	2	5	249	618	8	20	0	0	259	643
Mar 21	349	866.56	15	37	103	256	4	10	0	0	122	303
Apr 21	58	144.01	1	2	21	52	0	0	0	0	22	55
May 21	279	692.76	38	94	42	104	9	22	11	27	100	248
Jun 21	39	96.84	2	5	16	40	0	0	2	5	20	50
Jul 21	32	79.46	5	12	5	12	0	0	2	5	12	30
Total	3255	**8082.14**	331	822	850	2111	28	70	21	52	1230	**3054**
%Total	-	-		27		69		2		2		100
AGD	-	-		2.25		5.78		0.19		0.14		**8.37**
AFD		22.14	-			-		-		-		-

FS = the total number of fishermen operated during the sampling period
FA = the estimated annual total number of fishermen operated

GS = number of gillnets used for fish sampling during the sampling period
GA = the estimated annual total number of gillnet settings
AGD = the average number of gillnets set per day;
AFD = the average number of fishermen operated per day

4.2. Growth Parameters

The L_∞ and K values were determined to be 46.67cm and 0.280, respectively, at Rn value of 0.174, where Rn is the measure of goodness of fit of the growth curve to the data. A plot of the von Bertalanffy growth function based on restructured frequency is given by Fig.2.

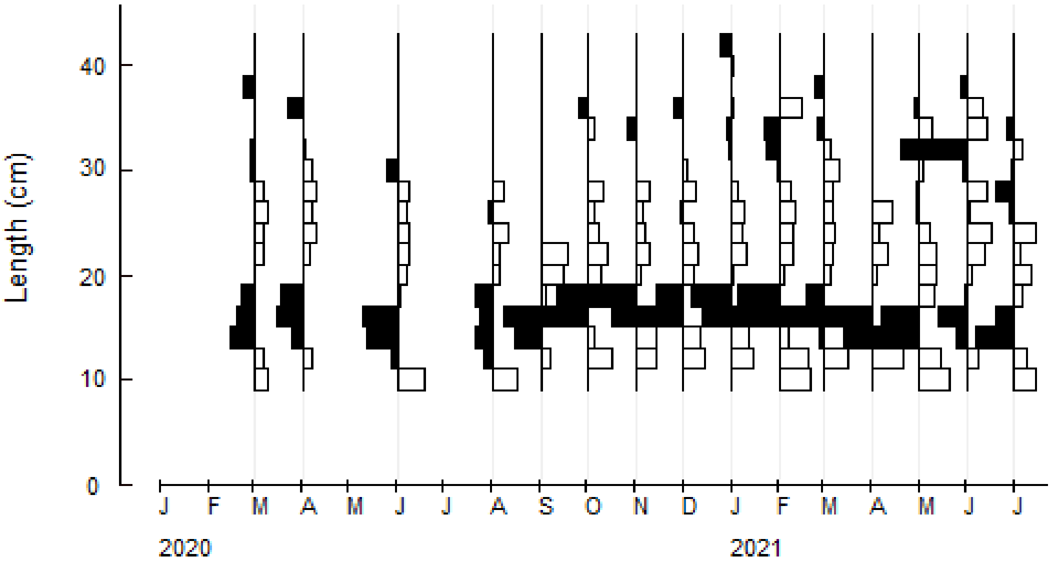


Figure 6. A plot of the von Bertalnaffy growth function (VBGF) of Nile tilapia in Gilgel Gibe Reservoir collected during the preset study

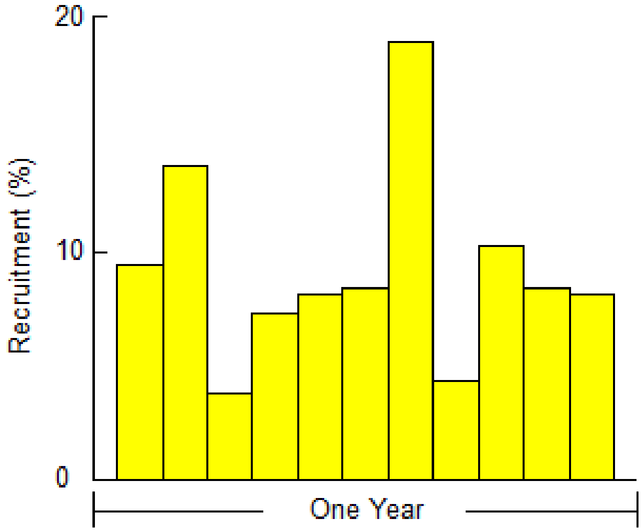
The age of fish at zero length (t_o), according to VBGF, was determined to be -0.53 years while the maximum age (t_{max}), determined from growth rate (K) and fish age at zero length (t_o), was 10.19 years. The fish growth performance index (Φ'), computed from the fish growth rate and the asymptotic length, was 2.79.

4.3. Natural mortality rate (M)

The present study result showed that the natural mortality rate of Nile tilapia in thereservoir is 0.68 per year, which was estimated from fish growth rate (K), asymptotic length (L_∞) and mean surface water temperature (T).The ratio of natural mortality and fish growth rate of the Nile tilapia in the reservoir is 2.42.

4.4. Recruitment pattern and Breeding activity

The recruitment pattern, in terms of relative recruitment value, of Nile tilapia in the reservoir is presented in Fig. 3.Average annual recruitment of Nile tilapia in the reservoiris 121,955 fish, which is equivalent to a mean biomass of 2,792.77 kg per year.



	J	F	M	A	M	J	J	A	S	O	N	D
%R	9	14	4	7	8	8	19	4	10	8	8	0

Figure 7. Recruitment pattern of Nile tilapia in Gilgel Gibe Reservoir

The recruitment of Nile tilapia was observed highest during the month July (19%) and the next at the month of February (14%).

The breeding activity of the fish estimated from the relative proportion of mature fish (stages 4 and 5) is presentedbelow in Table 4.The result showed that, Nile tilapia in the reservoir reach higher percentageof relativematurity during the month of July (64%) and followed by the month of April (33%). However, there was no recorded data on the relative percentage of maturity of the fish during the month of November.

Table 4.The relative percentage of mature fish foreach sampling month

M	C	N	D	J	F	M	A	M	J	J
% re	8	0	6	15	15	11	33	13	16	64

4.5. Estimation of current population abundanceand Fishing mortality

The VPA estimated number of Nile tilapia that should be in the water to produce the annual catch for each length group along with the respective fishing mortality rates as a function of the size classes is given by Figure 4. The tabular result is provided in Appendix 2.

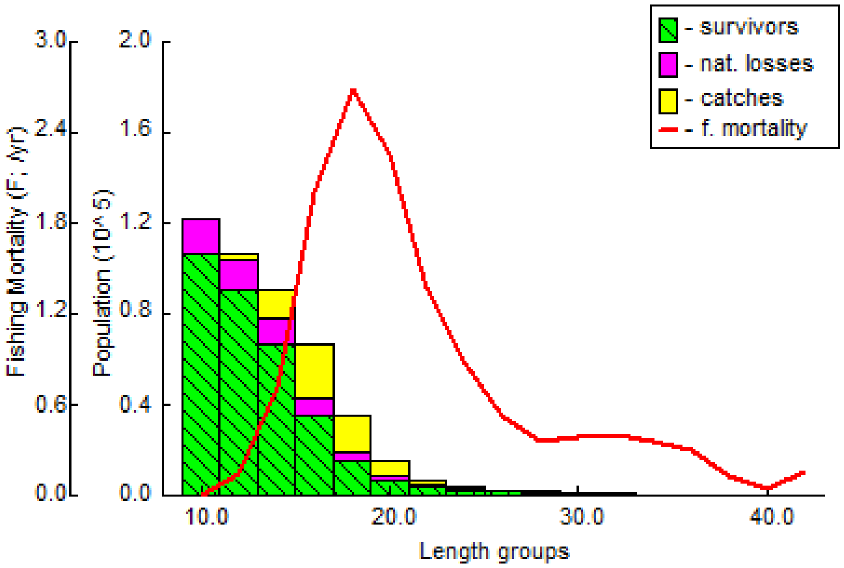


Figure 8.Estimated population number and fishing mortality rates of Nile tilapia as a function of the size classes from length-structured VPA.

The population number was highest when there is no fishing pressure on the population. Fishing mortality rate was high when the catch was maximum and fish from 16cm-22cm have high catch and highest mortality rate.

4.6. Yield analysis and long-term predictions

4.6.1. Estimation of current fish yield and biomass

The amount of fish yield and biomass under the current rate of exploitation is summarized in Table 5. Total yield and biomassshown in Table 5were obtained under the current fishing effort levelwhich resulted infishingmortality.According to the analysis, the value of maximum sustainableyield of the tilapia stock is 6.48 tonsand biomass is 28.12 tons.

Table5. Estimation of fish yield and biomass under the current rate of exploitation

The totalEstimation of fish yield and biomass under the current rate of exploitation was 6.48 and 28.12respectively**.**

Group length	**Catch (n)**	**Pop. (n)**	**W (tons)**	**Yield (tons)**	**BM ons)**
10	91	121,955	0.023	0.002	2.794
12	2,913	106,737	0.038	0.110	4.044
14	12,198	90,067	0.058	0.707	5.222
16	23,009	66,329	0.084	1.929	5.560
18	16,088	35,506	0.116	1.867	4.120
20	6,418	15,345	0.155	0.996	2.381
22	2,099	6,991	0.202	0.424	1.411
24	834	3,854	0.257	0.214	0.989
26	358	2,366	0.320	0.115	0.758
28	173	1,554	0.393	0.068	0.610
30	137	1,047	0.475	0.065	0.497
32	101	664	0.568	0.057	0.377
34	61	392	0.671	0.041	0.263
36	32	217	0.786	0.025	0.171
38	9	113	0.912	0.008	0.103
40	2	57	1.051	0.002	0.060
42	5	26	1.203	0.006	0.032
Total	64,528	453,223	-	**6.48**	**28.12**

4.6.2. Yield and Biomass prediction

4.6.2.1. Yield prediction with Thomson and Bell model

The fish yield and biomass predicted under different levels of fishing efforts with Thompson and Bell model are presented in Fig. 6while its accompanying tabular result is provided in Table5.Prediction of maximum sustainable yield is 6.49 tons and biomass 30.20 tons at f-factor 0.9, but biomass below 50% is not recommendable. Fish yield and biomass at f-factor 0.4 is 5.53 tons and 52.01 tons respectively.

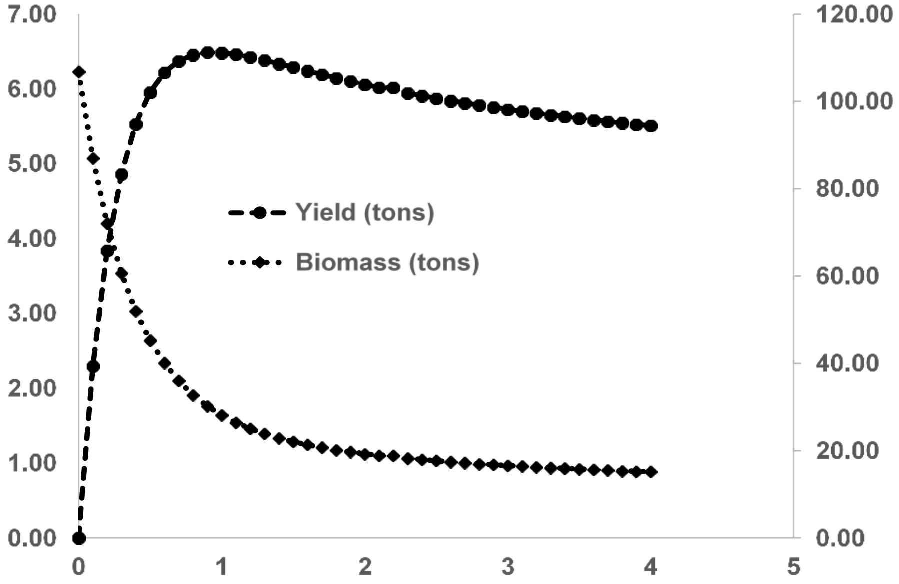


Figure 9.The Thompson and Bell model prediction of yield and biomass under different levels of fishing effort

Table 6. Tabular Result of the Thomson & Bell analysis of Nile tilapia yield prediction

f-factor	**Yield (tons)**	**Biomass (tons)**	**f-factor**	**Yield (tons)**	**Biomass (tons)**
0	0.00	106.83	2.1	6.02	18.90
0.1	2.30	87.02	2.2	6.02	18.90
0.2	3.84	72.07	2.3	5.94	18.23
0.3	4.86	60.70	2.4	5.91	17.94
0.4**	5.53	52.01	2.5	5.88	17.68
0.5	5.96	45.30	2.6	5.84	17.43
0.6	6.22	40.09	2.7	5.81	17.20
0.7	6.37	36.01	2.8	5.78	16.98
0.8	6.45	32.78	2.9	5.75	16.78
0.9*	6.49	30.20	3	5.73	16.59
1	6.48	28.12	3.1	5.70	16.41
1.1	6.46	26.43	3.2	5.68	16.24
1.2	6.43	25.03	3.3	5.65	16.08
1.3	6.38	23.87	3.4	5.63	15.93
1.4	6.34	22.90	3.5	5.61	15.78
1.5	6.29	22.06	3.6	5.59	15.64
1.6	6.24	21.35	3.7	5.57	15.51
1.7	6.19	20.73	3.8	5.55	15.38
1.8	6.15	20.19	3.9	5.53	15.26
1.9	6.10	19.71	4	5.51	15.14
2	6.06	19.28			

*Level of fishing effort that corresponds to predicted MSY

**Recommended level of fishing effort (Reference point) to manage the fishery

4.6.2.2. Relative yield per recruit

The length at first capture obtained from the plot of probability of capture of Nile tilapia under the current exploitation rate was determined to be12 cm (Appendix 3). The plot of relative yield and biomass per recruit prediction, using a length at first capture, is given by Fig. 6.

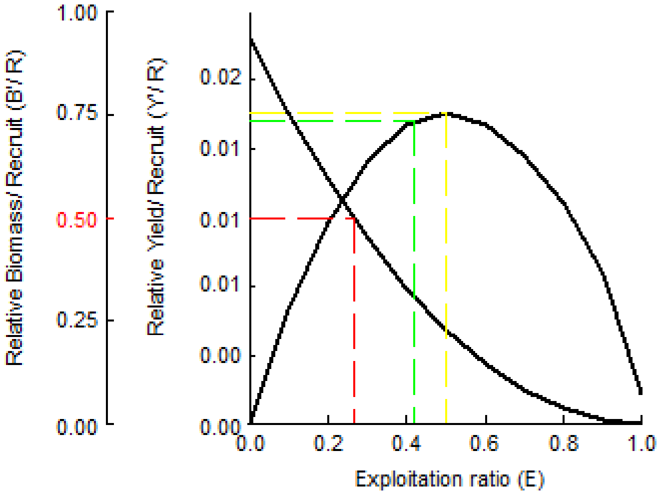


Figure 10. The plot of relative yield and biomass per recruit prediction

CHAPTER FIVE: DISCUSSION

Stock assessments provide important science information necessary for the conservation and management of fish stocks. Growth,recruitment and mortality parameters provide vital scientific information needed for the management and sustainability of a fishery thereby determining the resilience of a fishery (Udoh&Ukpatu, 2017). The present study has measured various stock assessment parameters for Nile tilapia stock in Gilgel Gibe Reservoir and discussed in the subsequent sections.

5.1. Length Frequency composition, Annual catch and fishing effort

In the present study, the catch composition was consisted of fish of 9 cm – 43 cm SL, with fish in the size range of 13-19 cm constituting the bulk (79.4%) of the total catch. This sample size has been representative sample to warrant estimation of length distribution of the total annual catch and other parameters, as the lake is small surface area 51km^2. Similar study conducted in Koka reservoir showed that the minimum and maximum lengths of Nile were 18 cm and 42 cm respectively for Nile tilapia (Tesfaye&Wolff, 2015) which is in line with the maximum length with the present study.

On the other hand, a study from Alwero Reservoir, Gambella reported that Tilapia measuring in length from 14 cm up to 36 cm total length (TL). Amongst these, over 99 % of the catch ranged in length between 22 to 34 cm in TL. More importantly the length groups 24 to 34 cm TL composed about 96 % of the total catch(Mengist&Fakana, 2020).Theobserved differences in length frequency potentially are because of the biotic and abiotic environmental factors as well as the trophic status of a given aquatic ecosystem.It is an indicator of different biological and ecological factors in relation to fish feeding habits (Nehemia*et al.*, 2012).

The current annual fishing effort expanded over fish stock in the reservoir constituted a total of 3,054 gillnet setting and 8,082.14 fishermen operated in the fishing activity. The average values of effort exerted per day were 8.37 gillnet setting and 22.14 fishermen operated. The total annual catch realized under these levels of effort was estimated at 64,543 fish, which is equivalent to an annual yield of 6.48 tons that corresponds to 28.12 tons of fish biomass in the water (Table 5).

5.2. Growth Parameters

Fish growth parameters can change over time because of fishing, which removes large-sized fish and gradually reduce the alleles associated with large sizes in an exploited population (Dieckmann*et al.*, 2005; Enberg*et al.*, 2012). Growth parameters can also change due to climate effect which will tend to modify growth parameter in the same direction as fishing itself (Cheung *et al.*, 2013).However, these changes are much smaller than the rapid population decrease and size reduction due to removal of large individuals by intense fishing, and which are reflected in Y/R and related analyses. Nile tilapia can live up to and more than 10 years and reach weights of 5kg (FAO, 2009; GISD, 2022), which is in agreement with longevity value of Nile tilapia in the present study (10.71 years). The value of $L\infty$ and K estimated in the present study is 46.67cm and0.28 respectively. In Lake Kokainvestigation reported $L\infty$ 44.5 cm and K 0.41 values (Tesfaye& Wolf 2015) and in Lake Hawassa $L\infty$ and K were estimated to be 36.23 cm and 0.33 per year, respectively(Alemu*et al* 2017). Growth parameters could also differ for stocks within the same species depending on environmental conditions (Lowe-McConnell, 1982; Sparre&Venema, 1998).

5.3. Natural mortality

The natural mortality rate (M) is a key parameter for modeling age-structured fish population dynamics. M can be defined as the proportion of fish dying from all causes except fishing (e.g., senescence, predation, cannibalism, disease, and pollution) (Froese&Pauly, 2019).The cause of natural mortality is different at different water bodies.

The M/K ratio of 2.42 is within the recommended range of 1.12-2.50, validating the estimate of natural mortality (Beverton& Holt, 1957). In Lake Koka, the estimate of natural mortality is 0.74 (Tesfaye 2006), which is in agreement with the present study. However, the estimated natural mortality of Nile tilapia reported fromLakeZiway (1.21) (Tesfaye 2006) and from LakeTana (0.97)(Wudneh 1998) is not coincidewith the present result showed.

5.4. Recruitment Pattern

Recruitment pattern provides rough estimates of the relative proportion of the population that is recruited every month of the year to give information on the number and duration of breeding seasons. However, it should be noted that recruitment occurs, after a delay, over a period that is shorter than the spawning season (Moreau &Cuende, 1991). The observed spawning pattern is well aligned with the breeding activity or season of the fish that has reached the highest peak during the month of July (Table 4). The average annual recruitment index of Nile tilapia in Gilgel Gibe reservoir is 121,955 fish, which is equivalent to a mean biomass of 2,792.77 kg per year. Recruitment of Nile tilapia in the reservoir is virtually continuous and year-around with two peaks of unequal pulses except for the month of December when recruitment is nil. The major recruitment pulses happen in July (19%), during the rainy season, followed by February (14%), the dry season.

Apart from the month of December, recruitment is also at its lowest value during the months of March and August, following the peak months of recruitment.

In Tekeze Reservoir, Nile tilapia spawned all year round. However, the main breeding season occurred between July and September followed by a minor one between January and March (Teame*et al*., 2018).Several studies indicated that the peak breeding season of Nile tilapia could be triggered by increase in temperature, solar radiation or rainy season and rise in water level (Trewavas, 1983)

5.5. Population Abundance, Biomass, Yield and Exploitation pattern

The virtual population analysis (Fig. 4; Table 5) indicates that the amount of fish in the reservoir that produced a total annual commercial catch of 64,528 fish (6.48 tons) under the current level of fishing is estimated at 453,223 fish (28.12 tons).The contributions of the different size groups to the estimated fish population abundance and biomass have been variable with the lower size classes accounting for the most proportion. Fish in the size range of 9-21 cm constituted 96.19% and 82.07% of the total estimated fish abundance and biomass, respectively. The most contributors to the total abundance are those in the size range of 9-21cm, ranging from the highest to the lowest, respectively, as 9-11cm (26.91%), 11-13cm (23.35%), 13-15cm (19.87%), 15-17cm (14.64%), 17-19cm (7.83%), and 19-21cm (3.39%). Fish larger than 21cm constituted only negligible proportion of the total estimated abundance only at 3.81%.

Similarly, the contributions to the catch of the various size groups have also been variable. Nearly 80% of the catch originated from fish in the size range of 13-19cm. Fish withthe size classes below and above this range accounted only for 4.66% and 15.85% of the total annual catch, respectively. The fishing mortality rate is also higher, 2.0-2.69 per year, for fishes in the same size class range of 15-21cm, the highest fishing mortality (F = 2.69 per year) being experienced by fishes of 15-17 cm length class (Fig. 4; Appendix 3).

On the other study the length group’s 30 to 34 cm fish shouldered heavy fishing mortality rate bearing above 0.5 fishing mortality per yearand tilapia starting from 14 to 16 cm was recruited to the fishery, most of the fishing pressure relied up on length groups starting 28 cm to 34cmin Alwero Reservoir (Mengist&Fakana, 2020).Although most of the fishing pressure relied up on length groups starting 22 cm to 28 cm in Lake Hawassa (Negese, 2016).

5.6. Yield predictions

The length-based Thomson and Bell model analysis has predicted that the maximum sustainable yield (MSY) of the fishery, 6.49 tons per year, reached at 10% less than the present level. Thus, the current level of exploitation that produces 6.48 tons of fish per year has already exceeded the MSY that the stock can support. The stock biomass at the current level of exploitation has already declined to 26.32% of the biomass at the unexploited stock. Therefore, there is an urgent management need to regulate fishing effort in order to safeguard the resource and thereby ensure its sustainability and the livelihood of the community that depends on it for its livelihood. On the other hand, safe level of fisheries exploitation is recommended to be at a fishing mortality rate that is 20% lower than the fishing mortality that correspond MSY (F_{MSY})(Sparre&Venema, 1998).

However, the present level of fishing effort is well beyond the biological optimal level of exploitation. The stock level in the Reservoir also seems to be so low as to be in danger of collapsing. Therefore, in the case of Nile tilapia stock in Gilgel Gibe Reservoir the management measure needs to be more stringent mainly due to the fluctuation in the water level that is typical of any reservoir, and could potentially affect productivity of the stock.

In particular, reservoirs suffer from flow-related habitat disturbances and sediment erosion, transfer and deposition resulting from inflow and pulses flow. Too rapid withdrawal of water can cause stranding of fish and loss of breeding sites and eggs attached to marginal bottom substrata, reducing survival and reproduction (Welcomme, 2001).Natural fluctuations in water level are a common feature of most lakes and reservoirs as a result of seasonal and climatic variation in rainfall (Ploskey, 1986).

The problem is, however, exacerbated in lakes and reservoirs used for water supply and hydroelectric power generation, which control the water level in response to supply demand and power generation requirements. This drawdown, and the way in which it is achieved, may be disadvantageous to the development of fisheries in reservoirs (Ploskey, 1986).

Moreover, it is likely that climate impact could have a bearing on the stock productivity besides the uncertainties related to natural mortality and recruitment estimations that are inherent with any stock assessment processes. Possibly, the most important pressures acting of lake and reservoir fisheries are linked to water quality and water level perturbations (Moss, 2009) and less to physical habitat modification as in rivers.

The quality of water is influenced by pollutants including organic wastes, nutrients, metals, poisons, suspended solids and cooling water from urban, industrial and agricultural sources. These drivers can act directly on the fishes, for example, toxicity of chemicals, or indirectly by changing environmental conditions and consequently the suitability of the habitat for fishes, mainly througheutrophication.Additionally at a fishing level that is 20% lower than the present pressure, the stock biomass is still at its lower level i.e. only 36.01% of the original population.

Therefore, it is recommended to fix the fisheries management reference point for the stock at an f-factor of 0.4 that would give a maximum yield of 5.53 tons per year and the stock biomass is greater than 50%. The implementation of the recommended fisheries management requires the adjustment of both the current number of gillnets and the fishermen engaged in fishing, respectively, from 8 gillnet settings/day and 22.14 fishermen/day, to 3 gillnet settings/day and 9fishermen/day. Moreover, as the potential total estimated stock biomass of the reservoir is very low, only at 28.12 tons per year, the management intervention should also involve culture-based fisheries practice in order to boost the resource base or productivity of the stock.

Gillnet fisheries have the advantage that they provide the opportunity to regulate mesh- size and allocate exploitation to segments of fish stocks. Such rationing can be manipulated to balance welfare of the fish stock and societal profits (Miranda *et al.*, 2000). The mesh size limit will reduce fishing mortality of immature fish, increase yield-per-recruit, and result in an increase in recruitment.

The relative yield per recruit analysis, at a length at first capture (Lc) of 12 cm, showed that the maximum sustainable yield per recruit is obtained at relative E-value of 0.4, which is in agreement with recommendation of reducing the predicted level of fishing effort from f-factor of 0.5 down to an f-factor of 0.4. Therefore, the reduction of fishing effort from the present level down to 0.4 times of the present level helps maximize both yield and biomass from each recruit and the stock.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Stock assessments provide important information necessary for the conservation and management of fish stocks. It provides scientific advice to decision-makers on the current health and future trends of a fish stock and its biomass.

In the present study the estimation of fish yield and biomass exploitation under the current rate was 6.48 and 28.12 tons respectively.Thompson and Bell analysis of fish yield MSY and biomass at f-factor0.9 shows 6.49 and30.20 tons respectively. But the biomass already decline from its recommended level that is 50%. Then at f-factor0.4 the prediction of yield and biomass was 5.53 and 52.01 tons respectivelyit is the recommended level of fishing effort or reference point to manage the fishery. In general it could be concluded that the biomass of Gilgel gibe reservoir was highly depleted because the number of fishermen and gillnet was high.The maximum fishing effort has most likely been reached no further increase in the number of gill nets should be allowed rather the number of gill net will be reduced.

6.2. Recommendations

- The ultimate goal of stock assessment is to devise management systems to mitigate fishery resource depletion, then need to focus on the reservoir biomass it was highly affected to recover its biomass the number of fisher men and gillnet setting were minimized.
- The other condition that brings the negative impact on the reservoir was the size of the mesh's being around 6 cm. This condition influences the population size of the fish in the reservoir. The broods were caught due to small mesh size. Catching brood results small amount of yield, and minimizes the number of fish in the reservoir. So the future studies focus on giving awareness creation for the fisher men.
- For successful implementation, responsible stakeholders, fishermen, agricultural office,Jimma zonal agricultural and rural development office, Oromiyaregional livestock and fishery agency, Jimma agricultural research sub center,and JimmaUniversity, should work hard in creating other source of livelihoods for the fishermen till the depleted biomass is well recovered.
- Further work to determine the length at first maturity is required in order to precisely determine if there is growth overfishing.
- For enhancements to achieve biomass full potential and provide benefits on a sustainable basis, improvements are required in both policy and research support.

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Appendix 1. Maturity stages of Cichlid species*(O*reochromis *niloticus*, *Sarotherodongalilaeus*, *and C*optodon*zillii*) (Harbot&Ogari, 1982)

Maturity	Female	Male	Definition Female	Definition Male
Stage-I	Immature	Immature	Sexes not distinguishable in eld	Sexes not distinguishable in the
Stage-II	Virgin	Virgin	Ovaries narrow, cylindrical ansparent**; oocytes small ranular**	Testes thin, threadlike and arent
Stage-III	Starting	Starting	Eggs small and whitish **but id mass**; ovaries are ning vascularized	Testes whitish, broader and ning vascularized; milt released cut and squeezed
Stage-IV	Mature	Mature	Eggs large, yolky, whitish w in color separating only pressed firmly; ovaries very , filling most of the body , and well vascularized	Testes large, white, highly larized, releasing milt when ed
Stage-V	Ripe	Ripe	Ovaries large, turgid, full of yellow eggs; the eggs ate and are expelled easily the ovaries are pressed	Testes are large, white, and ce copious quantities of milt under pressure

Appendix 2. The current fish population abundance and fishing mortality estimated from the length-structured VPA

(ML)	Catch (n)	Pop. (n)	F
10	91	121,955	0.00
12	2,913	106,737	0.14
14	12,198	90,067	0.72
16	23,009	66,329	2.00
18	16,088	35,506	2.69
20	6,418	15,345	2.25
22	2,099	6,991	1.38
24	834	3,854	0.87
26	358	2,366	0.54
28	173	1,554	0.35
30	137	1,047	0.38
32	101	664	0.40
34	61	392	0.36
36	32	217	0.30
38	9	113	0.13
40	2	57	0.05
42	5	26	0.16
Total	64,528	453,223	-

Appendix 3. Plot of probability of capture of Nile tilapia under the current exploitation rate