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Reproductive biology of common carp (*Cyprinus carpio* Linnaeus, 1758) in Lake Hayq, Ethiopia

Assefa Tessema^{1*} , Abebe Getahun¹, Seyoum Mengistou¹, Tadesse Fetahi¹ and Eshete Dejen²

Abstract

This study was conducted in Lake Hayq between January and December 2018. The objectives of this study were to determine the growth, condition, sex ratio, fecundity, length at first sexual maturity (L_{50}), and spawning seasons of common carp (*Cyprinus carpio*). Monthly fish samples of *C. carpio* were collected using gillnets of stretched mesh sizes of 4, 6, 7, 8, 10, and 13 cm and beach seines of mesh size of 6 cm. Immediately after the fish were captured, total length (TL) and total weight (TW) for each individual were measured in centimeters and grams, respectively, and their relationship was determined using power function. Length at first maturity (L_{50}) was determined for both males and females using the logistic regression model. The spawning season was determined from the frequency of mature gonads and variation of gonadosomatic index (GSI) values of both males and females. Fecundity was analyzed from 67 mature female specimens. The length and weight relationship of *C. carpio* was $TW = 0.015TL^{2.93}$ for females and $TW = 0.018TL^{2.87}$ for males that indicate negative allometric growth in both cases. The mean Fulton condition factor (C_F) was 1.23 ± 0.013 for females and 1.21 ± 0.011 for males. The value of C_F in both cases was > 1 that shows both sexes are in good condition. Among the total 1055 *C. carpio* collected from Lake Hayq, 459 (43.5%) were females and 596 (56.5%) were males. The chi-square test showed that there was a significant deviation between male and female numbers from 1:1 ratio ($\chi^2 = 22$, $df = 11$, $P > 0.05$) within sampling months. The length at first sexual maturity (L_{50}) for females and males were 21.5 and 17.5 cm, respectively. Males mature at smaller sizes than females. The spawning season of *C. carpio* was extended from February to April, and the peak spawning season for both sexes was in April. The average absolute fecundity was $28,100 \pm 17,462$. *C. carpio* is currently the commercially important fish while Nile tilapia fishery has declined in Lake Hayq. Therefore, this baseline data on growth, condition, and reproductive biology of common carp will be essential to understand the status of the population of carp and design appropriate management systems for the fish stock of Lake Hayq, Ethiopia, and adjacent countries.

Keywords: Growth, Fulton condition factor, Sex ratio, Length at first sexual maturity spawning seasons, Fecundity

Introduction

Common carp (*Cyprinus carpio*) is one of the widely cultured commercially important freshwater fish species in the world (FAO 2013). *C. carpio* is native to Eastern Europe and Central Asia. It can tolerate a wide range of water quality parameters. In natural water bodies, this

species can survive in very low water temperature and it can tolerate low concentrations and supersaturation of dissolved oxygen (Banarescu and Coad 1991).

Common carp is omnivorous fish species that consume animals (aquatic insects, macroinvertebrates, and zooplankton) and plant origin (phytoplankton, macrophytes) (Rahman et al. 2008, 2009; Weber and Brown 2009). *C. carpio* grows rapidly, achieves sexual maturation in the second year of life, and is highly fertile (about 2 million eggs per female) (Balon 1975; Hossain et al. 2016). The

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combination of these features allows developing invasiveness potential (Troca and Vieira 2012).

Knowledge of fish reproductive biology is very important for the rational utilization of fish stocks and their sustainable production (Cochrane 2002; Temesgen 2017). Understanding the reproductive aspects of fish is also very important for providing sound scientific advice in fishery management (Hossain et al. 2017; Khatun et al. 2019).

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

Cyprinus carpio was first introduced to Aba Samuel Dam (Awash River basin) in 1940 from Italy (Getahun 2017). Later, *C. carpio* has been introduced in Lake Ziway in the late 1980s (FAO 1997; Abera et al. 2015), in highland lakes such as Ashengie, Ardibo, and Maybar (Golubtsov and Darkov 2008) for food security purpose, and the introduction was successful. Common carp were introduced to Lake Hayq accidentally from Lake Ardibo in 2008 (Wolde Mariam, Personal Communication 2018) through Ankerkeha River that connects the two lakes during the rainy season. Though common carp have established recently in Lake Hayq, it is dominating the other commercially important fish species, Nile tilapia and catfish. Fishermen of Lake Hayq believe that the current stunt growth of Nile tilapia (*Oreochromis niloticus*) is due to the recent invasion of common carp in the lake.

Though there are some research works conducted in different water bodies of Ethiopia on common carp reproductive biology such as Hailu (2013) in Amerti Reservoir, Abera (2015) in Lake Ziway, and Asnake (2010) in Lake Ardibo, there is no information on the reproductive biology of common carp in Lake Hayq. Therefore, the purpose of this study was to establish baseline data on growth and condition, sex ratio, fecundity, length at first sexual maturity, and spawning seasons of common carp and design management strategy for the population of common carp in Lake Hayq.

Materials and methods

Study area and sampling techniques

Study area

The study was conducted in Lake Hayq. Lake Hayq is located in the North Central highlands of Ethiopia. It is a typical example of highland lake of Ethiopia with volcanic origin. Geographically, it lies between 11° 3' N to 11° 18' N latitude and 39° 41' E to 39° 68' E longitude with an average elevation of 1911 meters above sea level. The lake has a closed drainage system, and the total

watershed area is about 77 km² of which 22.8 km² is occupied by Lake Hayq. According to Demlie et al. (2007), the average depth of the lake is 37 m, and the maximum depth is 81 m. The only stream entering the lake is the Ankerkeha River, which flows into its southeastern corner. According to Fetahi et al. (2011), Lake Hayq is classified as a small highland freshwater (Fig. 1).

Climate

Among the climate variables, only maximum and minimum temperature and rainfall of Lake Hayq were available at Kombolcha Meteorological Agency. In 2018, the average monthly maximum and minimum temperature around Lake Hayq was 25.9 and 9.9 °C, respectively (Fig. 2). The annual rainfall were 1200 mm (Fig. 3). The rainfall and the temperature variability around Lake Hayq for the last 10 years (2009–2018) were very low. The average monthly minimum and maximum temperature and annual rainfall were 9.8 °C, 26.6 °C, and 1205.6 mm, respectively (Kombolcha Meteorological Agency, 2019).

Sampling techniques

Fishery data Three sampling sites were selected based on the impact of human and livestock activities. These are littoral site with intensive human activities related to recreation in lodges; pelagic site, less impact from human and livestock; and river mouth (Ankerkeha River), carrying huge silt every year (Table 1). The sampling sites were fixed with GPS, and a map was generated (Fig. 1). Fish specimens were collected each month for 1 year using gill nets of 4, 6, 8, 10, and 13 cm stretched mesh sizes through setting the nets overnight in the lake and beach seines of 6 cm mesh size. Data such as length, weight, sex, and maturity stages were collected in the field immediately after the fish were caught.

Some biological aspects of common carp

Length-weight relationship

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

$$TW = aTL^b$$

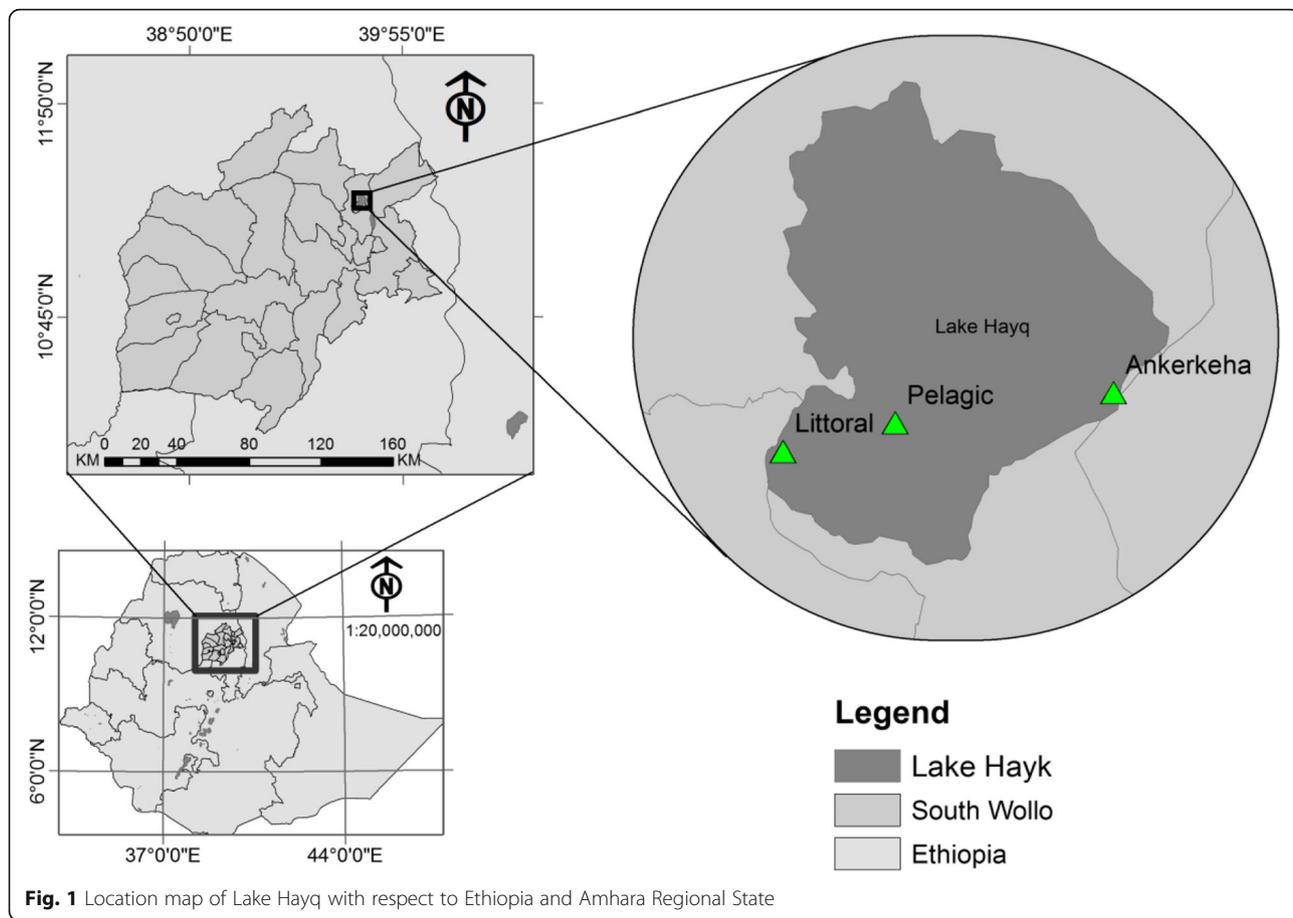
where

TW Total weight (g)

TL Total length (cm)

a Intercept of the regression line

b Slope of the regression line



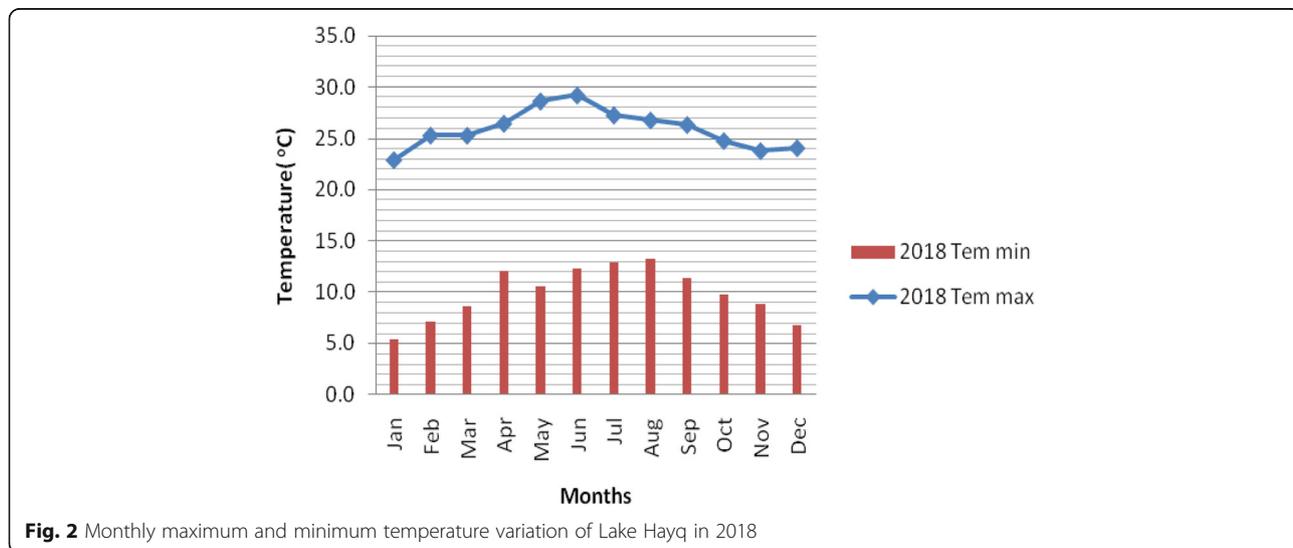
Condition factor (Fulton factor)

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

Fulton condition factor was calculated as:

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

where TW is the total weight in grams and TL is the total length in centimeters



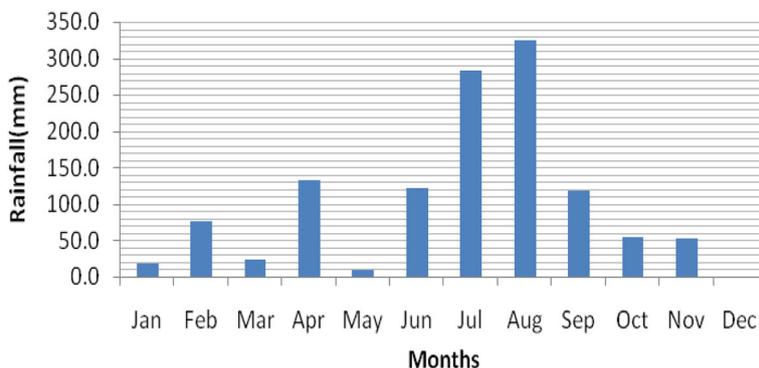


Fig. 3 Monthly rainfall variation of Lake Hayq in 2018

Sex ratio

Sex ratio was determined using the formula:

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

Fecundity

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

Spawning season

The spawning season was determined from the percentages of fish with ripe gonads taken each month (Hossain and Ohtomi 2008) and from monthly GSI variations (Hossain et al. 2017). The spawning seasons of *C. carpio* were determined based on monthly variations of the gonadosomatic index (GSI):

$$GSI = \frac{W_g}{W - W_g} \times 100$$

where W_g is the gonad weight (g) and W is the total weight (g) of the fish (Ricker 1975).

Maturity estimation

Total length (cm) and total weight (g) of each specimen of common carp were measured at the sampling sites using measuring board and sensitive balance, respectively. After dissection, the gonad maturity of each specimen was identified using a 5-point maturity scale (Wudneh, 1998). The length at which 50% of both sexes reached maturity (L_{50}) was determined from the percentages of mature fish selected from peak breeding seasons (March–April) and fitted to the logistic equation described by Echeverria (1987).

Data analysis

Descriptive statistics (frequency, percentages, and graphs) and inferential statistics (chi-square, independent t test, linear, and logistic regression) were used to summarize the collected data. SPSS Software Package version 16 and R 3.3.1 were used to summarize the collected data.

Results

Length-weight relationship

The total length of female and male *C. carpio* ranged from 11 to 50 cm and 10.5 to 52 cm, respectively, and the total weight of females and males ranged from 19 to 1697 g and 18 to 1378 g, respectively. The length-weight relationship of both female and male *C. carpio* in Lake Hayq was curvilinear, and as a result, the line fitted to the data was described by the regression equation (Table 2). In this study, the “ b ”

Table 1 Sampling site description

Sampling sites	Characteristics	Depth (m)	Altitude (m)	Coordinate points (UTM)	
				X	Y
Ankerkeha River Mouth	Silt load	5.3	1900	579715.383	1253117.123
Pelagic	Open water (less impact)	55.4	1907	576688.51	1252693.02
Littoral	Near lodges (more pressure)	6.3	1903	575131.78	1252295.8

Table 2 Length-weight relationship of *C. carpio* in Lake Hayq

Sex	<i>n</i>	Regression equation	R^2	Sig.
Female	454	TW = 0.015TL ^{2.93}	0.97	0.001
Male	589	TW = 0.018TL ^{2.87}	0.98	0.05

values of both female and male *C. carpio* were significantly different from 3, showing allometric growth (Figs. 4 and 5)

Fulton's condition factor

The Fulton condition factor values of female and male *C. carpio* ranged from 1 to 1.98 and 1 to 1.83, respectively. The mean and SE values of FCF of females and males were 1.23 ± 0.013 and 1.21 ± 0.011 , respectively. The independent *t* test analysis showed that there was no significant difference ($P > 0.05$) in mean FCF between male and female *C. carpio* in Lake Hayq.

Sex ratio

From 1055 specimens of *C. carpio* collected from Lake Hayq, 459 (43.5%) were females and 596 (56.5%) were males. The chi-square test showed that there was a significant deviation between males and females from 1:1 ratio ($\chi^2 = 22$, $df = 11$, $P > 0.05$) within sampling months.

Reproductive aspects of common carp

Length at first sexual maturity

Size at first maturity (L_{50}) is the size at which 50% of the fish get matured for the first time. From the logistic regression model analyzed, male *C. carpio* matured at smaller size (17.5 cm) than female (21.5 cm) in Lake Hayq as shown in Fig. 6.

The occurrence of mature males and females

The number of mature males (stage 4) of *C. carpio* was higher than that of females during sampling months. The number of mature female and male specimens was higher from January to April. The highest number of mature females and males was observed from February to April (Fig. 7). The 10-year (2009–2018) meteorological data analysis showed that the average atmospheric temperature around Lake Hayq from February to April was 27.2 °C. Rainfall distribution around Lake Hayq is bimodal. Rainfall was available in these months for the same year around the lake. This warm weather condition and rainfall availability might trigger the spawning of common carp in the lake.

Fecundity

Sixty-seven fully mature *C. carpio* with TL (21–49 cm) and TW (104–1230 g) were selected for fecundity study. The average absolute fecundity (AF) was 28100 ± 17462 . The relation between AF with TL, TW, and GW was linear (Figs. 8, 9, and 10). There was a significant relation in absolute fecundity with TL, TW, and GW ($P < 0.05$).

Gonadosomatic index

Cyprinus carpio in Lake Hayq has more than one peak spawning season starting from February to April. However, the highest peak spawning season for both sexes was in April (Fig. 11).

Discussion

This reproductive biological study of *C. carpio* in Lake Hayq is the first report which will be used as basic and baseline information. The result of the study helps to know the population status of the fish and design the possible strategies for sustainable utilization of fisheries of the lake.

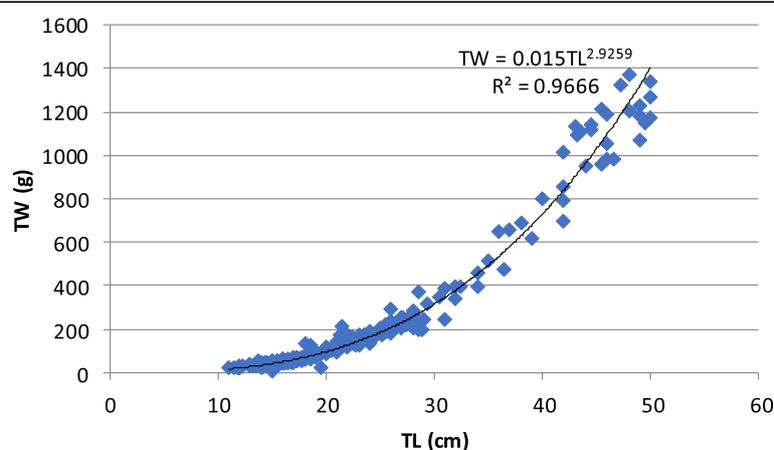


Fig. 4 Length-weight relationship of female *Cyprinus carpio* in Lake Hayq ($N = 459$)

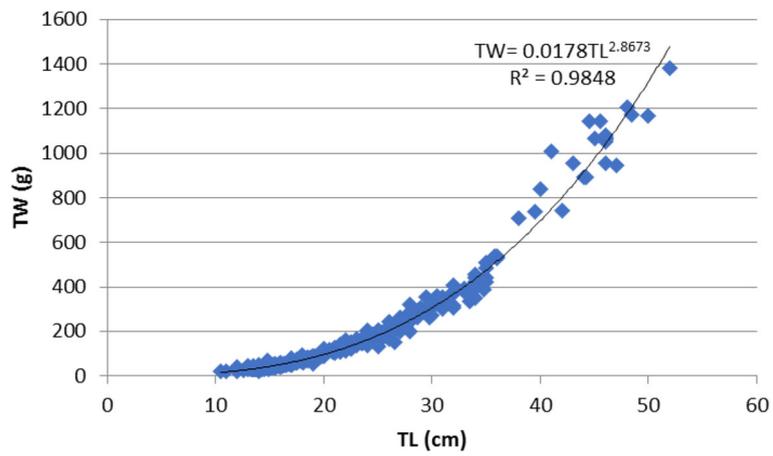


Fig. 5 Length-weight relationship of male *Cyprinus carpio* in Lake Hayq (N = 596)

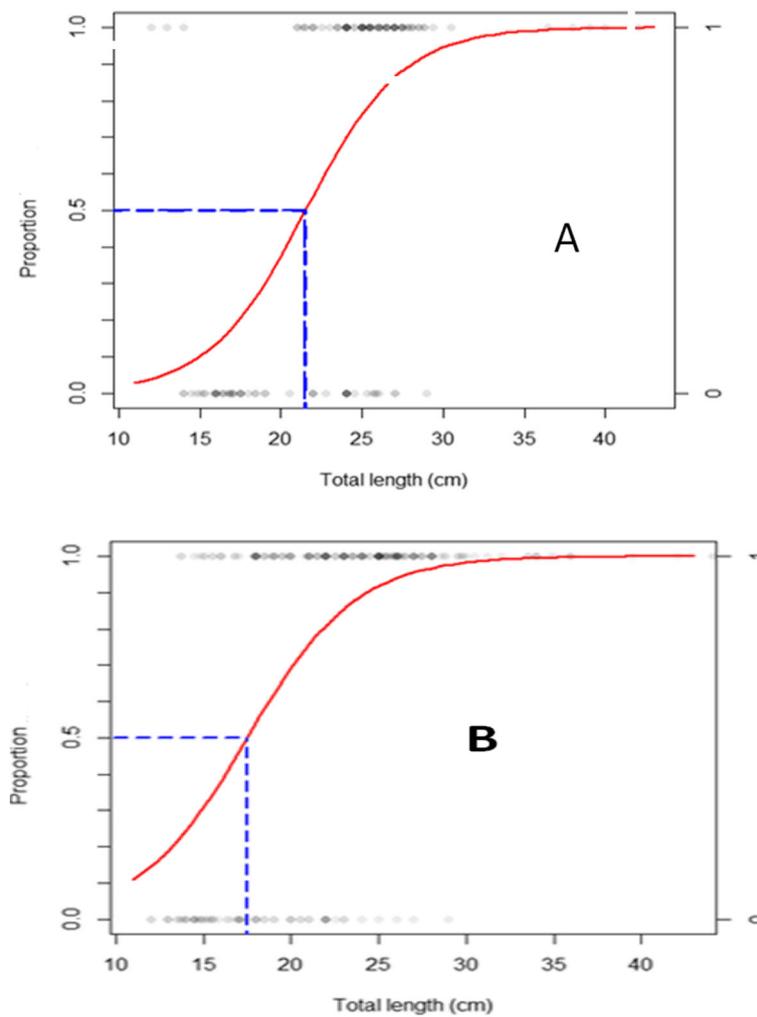


Fig. 6 Length at first sexual maturity (L_{50}) of female (a) and male (b) *C. carpio* in Lake Hayq

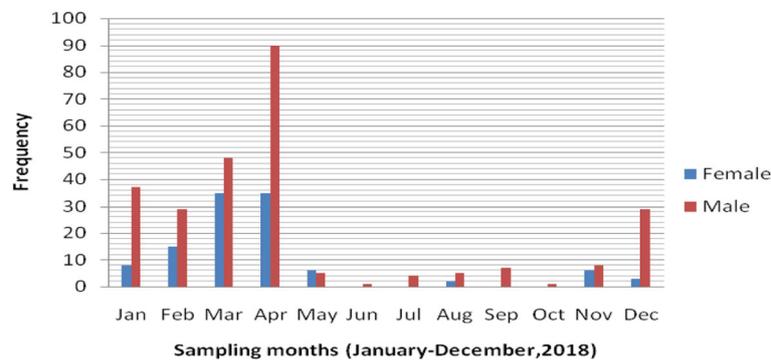


Fig. 7 Monthly frequency of mature specimens of *C. carpio* in Lake Hayq

Length-weight relationships in fishes are an important tool in fish stock assessment to know the growth status and management of the fishes (Ujjania et al. 2012). The length-weight relationship of *C. carpio* in Lake Hayq was negative allometric growth with a “b” value of 2.93 for females and 2.87 for males. These values were similar to 2.82 for *C. carpio* in Lake Ardibo for both sexes (Asnake 2010), 2.87 and 2.77 for female and male *C. carpio* in Foum El-Khanga Dam in Algeria (Sahtout et al. 2017), but different from 1.9 and 2.3 for female and male *C. carpio* in Lake Naivasha in Kenya (Aera et al. 2014) and 2.92 for *C. carpio* in Lake Amerti (Hailu 2013). These situations may be caused by several factors including the seasonal effect, habitat type, degree of stomach fullness, gonad maturity, sex, health, preservation techniques, food availability, differences in the observed length ranges, and fatness of the species as well as physical factors such as temperature and salinity (Wootton, 1998; Rahman et al. 2012; Hossain et al. 2016). The variations in “b” values between males and females may depend on various factors such as the number of specimens examined, and the sampling season.

The FCF of females and males of *C. carpio* were 1.23 ± 0.13 and 1.21 ± 0.011 , respectively. These values were similar to 1.22 ± 0.14 for *C. carpio* in Amerti Reservoir

(Hailu, 2013), but different from 1.58 and 1.57 for female and male *C. carpio* in Damsa Dam Lake in Turkey (Mert and Bulut 2014), 1.57 for both sexes of *C. carpio* in Foum El-Khanga Dam in Algeria (Sahtout et al. 2017), and 1.39 and 1.27 for female and male *C. carpio* in Almus Dam Lake in Turkey (Karataş et al., 2007). These variations in FCF of *C. carpio* in different water bodies could be based on the difference in age, sex, season, stage of maturity, the fullness of gut, the type of food consumed, the amount of fat reserve, and the degree of muscular development (Pauker and Coot, 2004; Hossain et al. 2013).

The sex ratio (F:M) in this study was 1.3:1, and there was a significant deviation from hypothetical female to male ratio (1:1). The result of this study disagrees with Hailu (2013) that has reported non-significant variation (1.15:1) female to male ratio in Amerti Reservoir. However, this result agrees with the report (1.53:1) female to male ratio in Damsa Dam Lake in Turkey (Mert and Bulut 2014).

In the present study, the size at first sexual maturity of *C. carpio* was 17.5 cm for males and 21.5 cm for females. These values were similar to 15.8 and 22.5 for male and female *C. carpio* in Sidi Saad Reservoir in Tunisia (Hajlaoui et al. 2016). But these

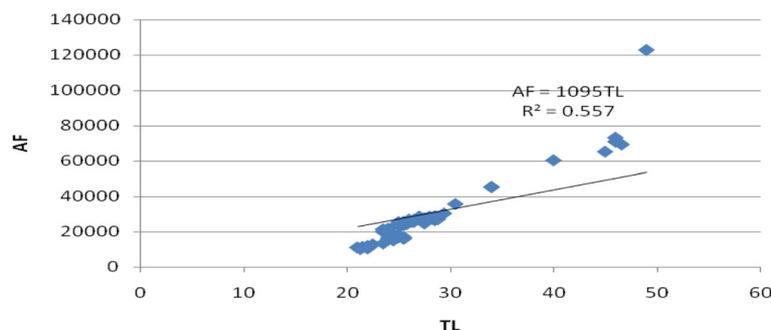


Fig. 8 Relationship between absolute fecundity (AF) and total length (TL) in *C. carpio*

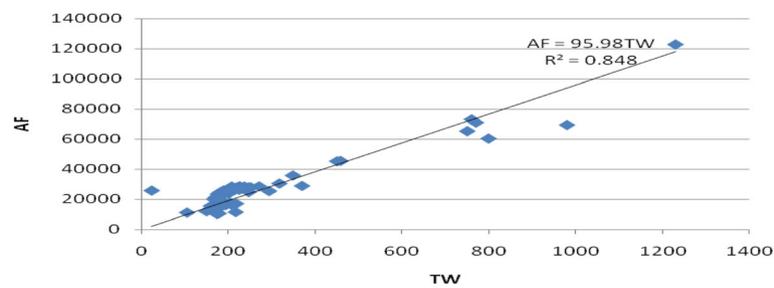


Fig. 9 Relation between absolute fecundity (AF) and total weight (TW) in *C. carpio*

values were different from 27 cm and 28.3 cm for male and female *C. carpio* in Amerti Reservoir (Hailu 2013), 27 cm and 28.7 cm for male and female *C. carpio* in Lake Ziway (Abera et al. 2015), and 34 and 42 cm for male and female *C. carpio* in Lake Naivasha in Kenya (Oyugi 2012).

Knowledge on the fecundity of fish is important to examine the potential of its stocks, life history, practical culture, and actual management of the fishery (Islam et al. 2012). The range and the mean fecundity of *C. carpio* in Lake were 10,316–122,600 and 28100 ± 17462 , respectively. These values were greater than the absolute fecundity range of 1610–99,737 for *C. carpio* in Lake Ardibo (Asnake 2010). However, the fecundity of *C. carpio* of Lake Hayq was lower than most water bodies of Ethiopia; it is less than a range of 36955–318584 and mean of 170937 ± 1308 fecundity recorded for *C. carpio* in Amerti Reservoir (Hailu 2013) and a range of 75645–356745 and mean of 210538 for *C. carpio* in Lake Ziway (Lemma et al. 2015). Fecundity of *C. carpio* depends on body size and produce between 500,000 and 3 million eggs per spawning (Smith 2004). Thus, the reproductive potential of *C. carpio* is exceptional as they mature early, are highly fecund, increase reproductive effort with age over their life span, and reproduce at least once each year when conditions are appropriate for survival of larvae. The lower absolute fecundity in Lake Hayq

could be due to the smaller size of fish compared to the *C. carpio* in Amerti and Lake Ziway.

Appropriate identification of the maturity status of fishes is a fundamental strategy for the appropriate management of exploited stocks in the fishery and is commonly used tools by fisheries' biologists and managers (Rahman et al. 2018). The monthly average GIS values of males and females were higher from February to April and were highest in April (Fig. 11). The lowest and highest GSI values were 1.1 and 4 for males and 3.5 and 10 for female *C. carpio*. The GIS values of females were higher than those of males due to the higher gonad weight of females. The observed higher values of GSI of both males and females between February and April and the highest values in April might be associated with higher atmospheric and water temperature values of 26 and 23 °C, respectively. Rainfall availability might also contribute for more food (planktons, macrophytes, and detritus) together with temperature, and triggers the spawning of *C. carpio* in Lake Hayq. The mean monthly average water temperature of Lake Hayq was 23 °C, and better rainfall was recorded during the spawning months. In agreement with the current study, peak breeding season was recorded in Amerti Reservoir (Hailu 2013) and Lake Ziway (Abera et al. 2015) when water temperature becomes higher and rainfall is available. *C. carpio* in Lake Hayq has more than one spawning season similar to Amerti Reservoir (Hailu 2013),

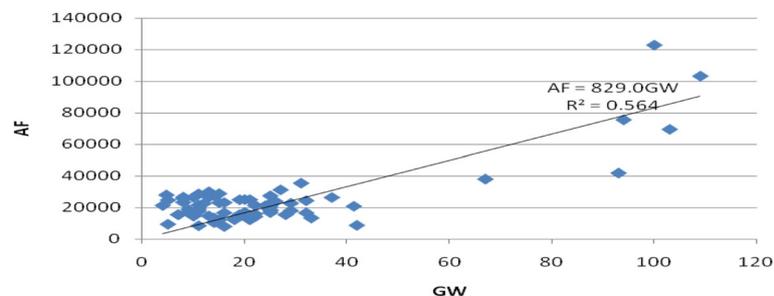


Fig. 10 Relation between absolute fecundity (AF) and gonad weight (GW) in *C. carpio*

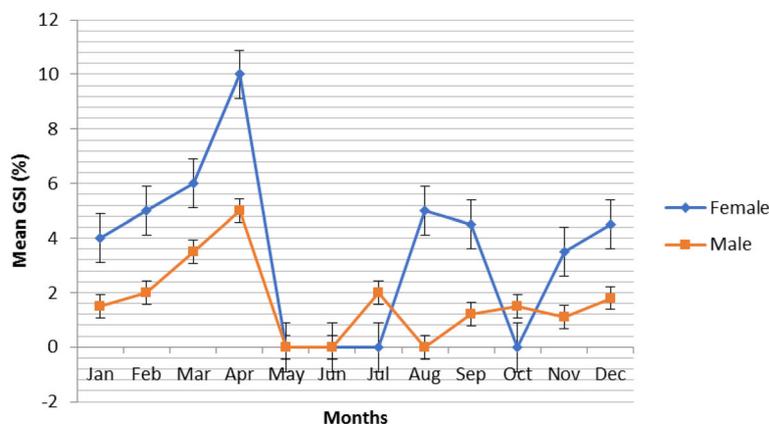


Fig. 11 Mean monthly gonadosomatic index (GSI) of *C. carpio* in Lake Hayq

Lake Ziway (Abera et al. 2015), and Lake Naivasha in Kenya (Oyugi, 2012). This might be related to the thermally stable warm environment and unlimited food resources (Muchiri et al. 1995). The mean monthly surface water temperature that ranged from 21.1 to 25.1 °C during the study period appears to favor year-round spawning of common carp in Lake Hayq.

Conclusion and recommendation

The growth and condition of common carp in Lake Hayq were good. The absolute fecundity of common carp in Lake Hayq was lower compared to other Ethiopian and African water bodies which could be due to smaller size of fishes used for fecundity analysis. The L_{50} values of common carp were smaller (17.5 and 21.5 cm for male and female) which might be associated with illegal fishing activities, and narrow-sized gillnets of mesh size of 4–6 cm. Hence, the mesh size of the gillnets should be regulated at least to 8 cm which is the national standard. Furthermore, common carp have extended spawning seasons in Lake Hayq (February–April) with peak spawning in April. Therefore, these intense spawning months should be used for closing seasons (no fishing activities). Thus restricted gillnet use and closed season practices could bring better recruitment and better fish size. Long-term monitoring on reproduction potential, spawning season, and population status of common carp should be done for sustainable fishery utilization of Lake Hayq.

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Declaration

Not applicable

Authors' contributions

TA, the corresponding author, has prepared the report from the collected data where GA, MS, FT, and DE are co-authors who have edited the paper. The authors read and approved the final manuscript.

Authors' information

TA is currently a PhD student in Addis Ababa University. The co-authors, GA and MS, are professors, and FT is an associate professor working in Addis Ababa University department of Zoological sciences. They have published many articles in fisheries and Aquatic Sciences and have advised MSc and PhD students. The last co-author, DE, is a senior and energetic researcher in fishery and aquaculture areas. He is a PhD holder and working in IGAD at senior fishery expert.

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Availability of data and materials

Data sharing is not applicable.

Ethics approval and consent to participate

Not applicable, since there is no ethical approval process for fishery data in Ethiopia.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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