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Gillnet selectivity of commercially important fish species in lake hashenge, Ethiopia

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Abstract
The present study was aimed to evaluate the selectivity of gillnets and the size at first maturity of commercially important fish species in Lake Hashenge mainly the Nile tilapia *Oreochromis niloticus* and common carp *Cyprinus carpio*. Experimental fishing was conducted using gillnets of different mesh sizes (60, 80, 100, 120 and 140 mm) in six sampling occasions from 2010 – 2011. A total of 2671 fish specimens consisting of 1184 *O. niloticus* and 1523 *C. carpio* were analyzed. Gillnet selectivity parameters for each mesh sizes were estimated for each species using the SELECT method. The size at first maturity (L_m) and its 95% CI for *O. niloticus* and *C. carpio* were estimated at 23.9 cm (23.3 – 24.5 cm), and 32.5 cm (31.6 – 33.4 cm), respectively. Results showed that a Log-normal model best described gillnets selectivity for *C. carpio*, while a Normal location model best described for *O. niloticus*. Capture probability estimates indicate that the optimum length of capture (L_{CAP}) of < 80 mm mesh size nets are smaller than the L_m of both target species, while L_{CAP} of >120 mm mesh net selects above the L_m value for both *O. niloticus* and *C. carpio.* Although the 100 mm mesh selects above the size of L_m value for *O. niloticus*, it still selects below the L_m value for *C. carpio*. Based on the results obtained, it was concluded that gillnets of mesh size 100 and 120 cm may safely be applied in Lake Hashenge fishery if proper level of effort is applied that ensures sustainability of both target species.

Keywords: Common carp, Nile tilapia, optimum length of capture, SELECT model, gonad maturity

1. Introduction
Fishing is one of the most important livelihood activities in many developing countries. Different tools and catching methods have been used with a various degree of success in terms of catching efficiency and reducing impact on non-target species (bycatch). Different studies showed that improper fishing practice can also cause the collapse of fish populations and the destabilization of the ecosystem [1, 2]. Gillnets are the most important fishing gears used in Lake Hashenge fishery. It is a passive gear set in the water column or sea/lake bottom and let the fish encounter the net by themselves. Unlike trawl net or beach seine (an active gear) which is towed along the littoral area and capture all fish sizes beyond the minimum size at capture, gillnets are only selective for a certain size range [3]. It excludes the capture of very small and very large fish [4]. Knowledge of the size selectivity of gillnet is, therefore, essential for fisheries management to sustainably maximize yield and protect the size distribution of the fish population [5, 6].
Studies on gear selectivity of freshwater fish species in Ethiopian water bodies are scarce. Tesfaye *et al.* [3] studied the selectivity of three different gears (gillnets, longlines and beach seines) for Lake Koka Nile tilapia *Oreochromis niloticus*, catfish *Clarias gariepinus*, common carp *Cyprinus carpio* and barbs *Labeobarbus intermedius*, while Wudneh [7] studied the selectivity of gillnets for Lake Tana's *O. niloticus*, *C. gariepinus* and *Barbus tsanenis*. Gillnet selectivity of Lake Tana's 15 *Labeobarbus* species flock and of Amerti Reservoir's *O. niloticus* were also studied by de Graaf *et al.* [8] and Hailu [9], respectively. Although gillnet is the predominant fishing net used for tilapia and common carp fishery in Lake Hashenge, its selectivity on these target populations has not been assessed yet.
In order to use the gear selectivity results for fisheries management, knowledge of the reproductive biology of exploited fish species is a further essential prerequisite. The breeding period of the two commercially important fish (*O. niloticus* and *C. carpio*) were previously studied by Tadesse and Alemayehu [10]. Size at first (massive) maturity symbolized as L_m is an important parameter of fish life history.

It refers to the length at which 50% of the population matures. It is thus the most widely considered biological information to design harvest strategies by adjusting the mesh size of the net to catch the desired size of fish, to optimize exploitation and/or ensure sustainability [3]. The present study, therefore, aims at evaluating the selectivity of the commonly used gillnets in Lake Hashenge in relation to the size at maturity of the two commercially important fish species and recommend minimum mesh sizes for regulation of the fishery in this lake.

2. Materials and Methods

2.1 Description of the study area

Lake Hashenge, also written as Ashenge in some literature, is a creator lake located in Northern Ethiopia (12°34'50 N; 39°30'00 E) near Korem town at an altitude of 2409 m above sea level, which is about 628 km away from Addis Ababa. The lake has a maximum length of 5 km and 4 km wide, with a total surface area of 15 km^2. It also has a maximum and mean depth of 25.5 m and 14.2 m, respectively [11]. The Lake has no obvious outlet but receives water from the surrounding catchment (129 km^2) during the rainy season. The climate is characterized as cool and humid conditions. The rainfall in the lake basin appears to be bimodal: the main rainy season extends between June and September, and the short rain occurs between mid-February and April. The dry season extends from October to February. The lake area receives an annual total rainfall of about 818mm and the mean annual temperature is reported to be about 20.1 °C [12].

Lake Hashenge is not rich in fish diversity. It has only two commercially important fish species: the Nile tilapia *Oreochromis niloticus* and common carp *Cyprinus carpio*. Both species are not native to the lake, although the former is native to Ethiopia. They were introduced in the late 1980s & early 2000s by the National Fishery & other Aquatic Life Research Center in collaboration with the Ministry of Agriculture and the Tigray Bureau of Agriculture following the native *O. niloticus* population mass kill due to a strong algal bloom and unfavorable anoxic condition that followed. Common carp is an exotic species that has been widely introduced in many water bodies in the country. Now, both species formed well established breeding populations and forms the fish catch in Lake Hashenge [10].

2.2 Sampling and data collection

A total of 2671 fish samples (1184 *O. niloticus* and 1523 *C. carpio*) were collected in six field trips and 29 sampling occasions undertaken from March 2010 to December 2011 using gillnets of different stretched mesh. Gillnets (50m x 3m) of 60, 80, 100, 120 and 140 mm stretched mesh size were used for sampling and their catches were recorded separately. From the specimen collected, the total length of tilapia and the fork length of common carp, as well as their total weights were recorded to the nearest 0.1cm and 0.1g, respectively. Each fish specimen was dissected to examine their gonad development and maturity stages were noted on a scale of five distinct maturity stages according to Wudneh [7].

2.3 Data Analysis

2.3.1 Size at massive maturity (L_m)

The fish length at which 50% of the population matures (L_m) was estimated by classifying the gonads as immature and mature fish. The relationship between the percentage of mature fish (P) per length class and fish length (X in cm) was described by a logistic curve and L_m was estimated according to Gunderson *et al.* [13]:

$$P_x = \frac{1}{(1+e^{(bx+a)})}$$

where, P_x is the proportion of mature fish at length class x; *a* and *b* are an intercept and slope of the logistic regression, respectively.

The L_m was then derived from the model parameters of "*a*" and "*b*" as

$$L_m = -\frac{a}{b}$$

Sigma Plot version 12.3 was used for this analysis. The 95% confidence interval (CI) of the estimated L_m value was determined using the regression wizard for logistic curves.

2.3.2 Gillnet selectivity

For the selectivity analysis, the fish catch of each gillnet variants were organized in a cm size class length frequency. The SELECT method was then applied using R version 3.1.2 [14] and the R code developed by Millar [15] to estimate selection curves from comparative gillnet catch data. The unimodal statistical models included in SELECT (Normal location, Normal scale, Gamma and Log-normal) uses a generalized linear model (GLM) and applies maximum likelihoods to estimate selectivity parameters [16]. Each model contains two parameters to be estimated that describe the location (mean) and the spread (standard deviation) of selection curves [6, 16].

Of the four models, the Normal scale, Gamma and Log-normal follows the Baranov's principle of geometric similarity, that is the location and the spread of the retention curve shifts proportionally to mesh size [3]. The Normal location model is the same as the traditional approach proposed by Holt [17], which also assumes a proportional increase of the mean with mesh size but has a fixed spread, which means all gillnet variants would have the same standard deviation. The Normal location and Normal scale models assume normal distribution, while Gamma and Log-normal models assume skewed distribution. The expected catches of length *L* fish that encounter gillnet j are assumed to be observations of independent Poisson random variables [6, 16]. Relative fishing intensity of a gillnet is a combined measure of fishing effort and fishing power [16]. It is a conditional probability that a fish contacted gillnet panel j, with the assumption that it made single contact with the entire combined gillnet panel [16]. But this assumption might be violated as a fish may make multiple contacts with the gear if it is not caught on the first occasion. Thus, each model was run twice by assuming equal fishing power and fishing power proportional to mesh size through the relative fishing intensities p_j. Then, the best fitting model for each species was identified based on the model deviance (likelihood ratio goodness of fit statistics) value; the best fit model presents the lowest deviance value [6, 16]. Moreover, the goodness of fit was evaluated by calculating the dispersion parameter [18] and the deviance residual plots [6], where randomly distributed smaller residuals indicate a good fit. The dispersion parameter is calculated as the ratio of the model deviance to the degree of freedom and dispersion parameter greater than one indicates over-dispersion. Over-dispersion indicates either lack of fit or violation of the assumption of an underlying Poisson distribution [18].

3. Results

3.1 Size at first maturity

The smallest mature female *O. niloticus* caught during the sampling period measured 18.5 cm, while mature female *C. carpio* measured 20.5 cm. However, as expected the estimated size at maturity (L_m) and corresponding 95% confidence intervals (CI) of both species were larger than the values indicated (Fig. 1).

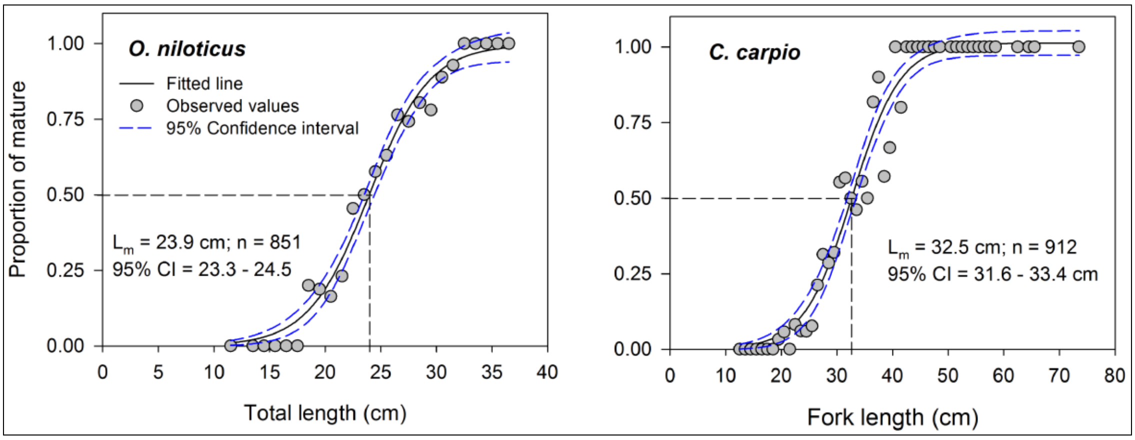

Fig 1: Size at first maturity of the two target fish species, *O. niloticus* and *C. carpio* in Lake Hashenge. The dashed lines are the 95% confidence interval of L_m and the solid lines (sigmoid curves) are the fitted lines. Open circles are the observed proportion of matured fish.

3.2 Gillnet selection

Using five different gillnet variants, a total of 2671 fish specimens were collected. The mean size of *O. niloticus* and *C. carpio* was not very different, despite a wider size ranges observed for *C. carpio* (Table 1). Using the collected catch data, the gillnet selectivity parameters of mesh sizes 60, 80, 100, 120 and 140 mm were estimated for both species (Fig. 2 and Table 2).

Table 1: Gillnets catch (n) of the two fish species using different stretched mesh in Lake Hashenge.

Species	n	Mesh sizes (mm)					Observed length (cm)*	
		60	80	100	120	140	Mean	Range
O. niloticus	1148	201	278	426	230	13	24.4	11 – 37
C. carpio	1523	255	587	352	260	69	24.2	12 – 64

***** The length measurement for *O. niloticus* and *C. carpio* refers to total length & fork length, respectively.

The mean length (± sd) of gillnet catches for 60, 80, 100, 120 and 140 mm mesh were 18.0 ± 3.8, 21.9 ± 1.9, 26.4 ± 1.7, 28.7 ± 1.9 and 32.3 ± 4.6 cm for *O. niloticus*, and 16.2 ± 4.9, 21.1 ± 3.3, 27.6 ± 5.2, 30.1 ± 4.5 and 44.8 ± 8.0 cm for *C. carpio*, respectively. The larger the mesh size of gillnets, the greater the mean size of fish capture. All size combination of mesh sizes caught wide size ranges of the species (Fig. 2).

The results of the SELECT method fitted for *O. niloticus* and *C. carpio* are given in Table 2. The Normal location (fixed spread) and the Log- normal model provided the best fit for *O. niloticus* and *C. carpio*, respectively, as they had the lowest deviance value. The Normal scale model provided the worst fit for both *O. niloticus* and *C. carpio*. The fitted selectivity curves and deviance residuals for the two species are shown in Fig. 2. The assumptions of proportional fishing power with mesh size didn't improve the fit as it had shown larger model deviance values (Table 2).

Table 2: Gillnet fitting parameters of the four models tested with the SELECT method by species (the best fitted models indicated in bold). Parameters 1 and 2 are k and σ for normal fixed model; k_1 and k_2 for normal scale (spread proportional to mesh size) model; α and k for gamma model; μ_1 and σ for lognormal model. Deviance (D) statistic measures the goodness of fit.

Species	model	Equal fishing power			Fishing power relative to mesh size			df
		Par.1	Par.2	D	Par.1	Par.2	D	
O. niloticus	Normal fixed	0.2696	3.4739	563.4	0.2747	3.5456	577.2	98
	Normal scale	0.2893	0.0021	952.5	0.279	0.001	958.2	98
	Gamma	43.6553	0.0066	749.0	44.6553	0.0066	749.0	98
	Lognormal	2.8355	0.1488	665.8	2.8576	0.1488	665.8	98
C. carpio	Normal fixed	0.293	3.136	114.3	0.297	3.151	110.5	206
	Normal scale	0.297	0.001	136.9	0.305	0.001	137.5	206
	Gamma	60.732	0.009	109.6	61.732	0.005	109.6	206
	Lognormal	2.878	0.129	100.3	2.895	0.129	100.3	206

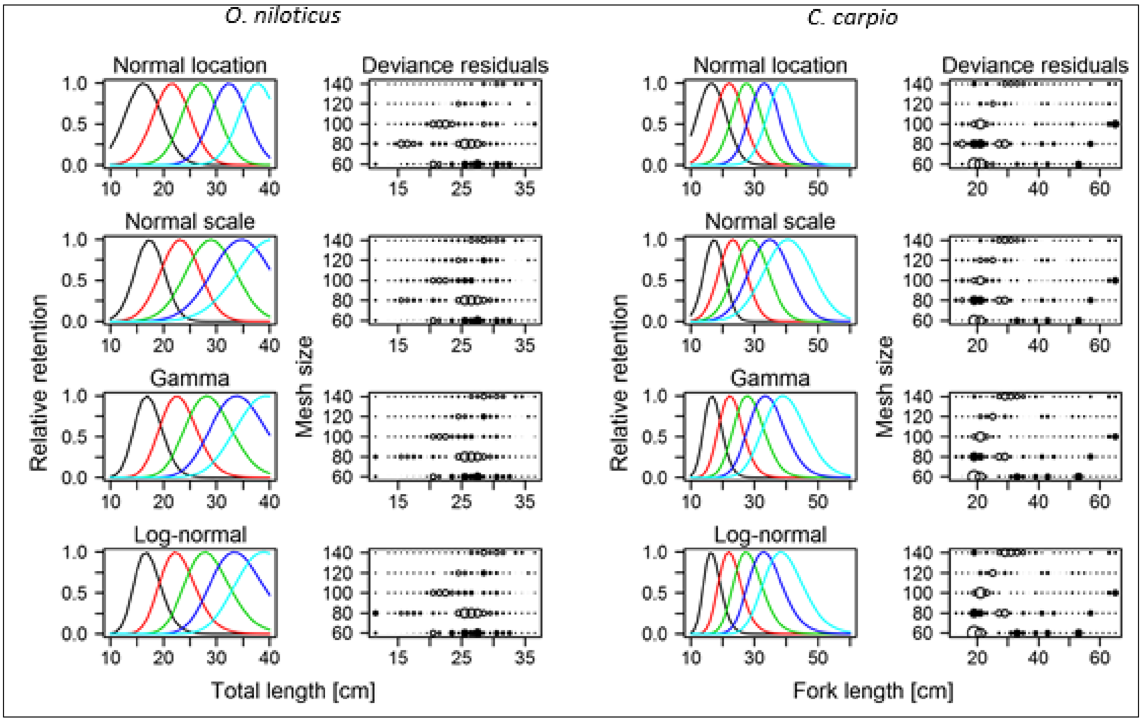

Fig 2: Gillnet selectivity curves and deviance residuals for target species in Lake Hashenge. The retention curves from left to right correspond to 60, 80, 100, 120- and 140-mm stretched mesh, respectively. Open and filled circles correspond to negative and positive residuals, respectively, and the size of the circle is proportional to the square of the residual.

The predicted modal lengths, which refers to the sizes with highest probability of capture of the both target species caught with different gillnets are given in Table 3. Gillnets with mesh size 100 mm selected fish sizes above the L_m value for *O. niloticus*, but it still selected below the L_m value for *C. carpio*. However, the predicated model lengths of gillnets with mesh size 120 mm and above fall either above or within the 95% confidence interval of the L_m value for both target species (Fig. 1 and Table 3).

Table 3: Predicted modal lengths (sizes with maximum probability of capture) with the best fitted model of the different gillnet mesh sizes for target species.

Species	Best fit model	Mesh sizes (mm)				
		60	80	100	120	140
O. niloticus	Normal location	16.2	21.6	27.0	32.4	37.7
C. carpio	Lognormal	16.4	21.9	27.4	32.9	38.4

4. Discussion

4.1 Size at first maturity

Nile tilapia (*O. niloticus*) is the most preferred fish species in Ethiopia [19]. It is also a highly appreciated and recommended species for aquaculture due to its fast growth and its capacity to easily adapt to different environmental conditions and management measures. The estimated size at first sexual maturity of 23.9 cm (Fig. 1) is similar (less than a cm difference) to the estimate for Lake Koka tilapia (24.6 cm) reported by Tesfaye *et al.* [3]. However, the estimate is much larger than the L_m value for the tilapia population in most of the intensively fished Rift valley lakes such as Lakes Ziway, Langano, and Awassa (Table 4). Although it needs further study on the state of tilapia population in Lake Hashenge, its estimated larger L_m value may suggest the existence of low fishing pressure for tilapia fishery compared to those Rift Valley lakes. Several studies already confirmed that high fishing pressure causes directional selection of genes resulting in earlier maturation and slower growth, setting the stage for fisheries-induced evolution of maturation at younger ages and smaller sizes [20-22].

Another possible reason for the higher L_m value of tilapia in Lake Hashenge could be the low mean water temperature of the lake (20.1°C) compared to the Rift Valley lakes (often above 23 °C). It has been known that as temperature increases, size or age of maturity decreases and vice versa. However, exceptionally larger L_m values were also reported for tilapia population in Lakes Turkana [23], Victoria [24] and Chamo [25] (Table 4). The different studies conducted had shown that L_m of *O. niloticus* could vary between lakes [24, 26]. It thus appears that the size at first maturity is very plastic trait that stocks can adjust depending on demographic conditions. Balarin and Hatton [27] and Teferi and Admassu [28] also noted that L_m relates to the condition of the fish and individuals that are in poor condition tend to breed at smaller sizes than those exposed to good conditions.

Common carp is one of the most frequently introduced fish species in different parts of the world due its great adaptability to a wide range of environmental conditions. It was introduced in Lake Hashenge in the early 2000s with the intention of boosting fish production and effective utilization of the lake ecosystem. It adapted to the new environment very well and established breeding populations [10]. Its size at first maturity in Lake Hashenge is comparable to the estimates for Lake Koka, Ethiopia, Lake Naivasha, Kenya and in Bermah Forest, Australia (Table 4). However, the estimate is much smaller than the value reported for Hartbeespoort Dam, South Africa (Table 4).

Table 4: Size at first maturity of *O. niloticus* and *C. carpio* from different water bodies in different countries

O. niloticus			
Lake/reservoir	**Country**	L_m *	**References**
Chamo	Ethiopia	42.0	Teferi *et al.* [29]
Awassa	Ethiopia	18.8 (f)	Admassu [26]
Langano	Ethiopia	19.5	Tesfaye and Tadesse [30]
Ziway	Ethiopia	18.1 (f)	Tesfaye and Tadesse [30]
Tana	Ethiopia	20.7 (m)	Wudneh [7]
Turkana	Kenya	29.6 (f)	Leveque [23]
Victoria	Kenya	30.8 (f)	Njiru *et al.* [24]
George	Uganda	20.0 (f)	Gwahaba [31]
Koka	Ethiopia	24.6	Tesfaye *et al.* [3]
Hashenge	Ethiopia	23.9	Present study
C. carpio			
Naivasha	Kenya	34 (m)	Oyugi *et al.* [32]
Hartbeespoort Dam	South Africa	40.3	Winker *et al.* [33]
Hashenge	Ethiopia	32.5	Present study
Koka	Ethiopia	30.6	Tesfaye *et al.* [3]
Bermah Forest	Australia	30.7 (f)	Brown *et al.* [34]

* The reported estimate in column 3 is from female and male, if "f" and "m" is given in parentheses, respectively, and those unspecified values indicate L_m values from unsexed specimen.

4.2 Gillnet selectivity

Different fishing gears harvest fish differently in fishing grounds with a mix of species and sizes. Gillnets are stationary gears, which take advantages of the swimming activity of the fish [5]. The selectivity of gillnets is affected by many factors, including the mesh characteristics (e.g. mesh size, twine size and type), and the morphometric features of fish species. Of these factors, Clarke [35] and Akongyuure *et al.* [36] isolated mesh size as the most influential factor in the capturing process of gillnets because of the fact that smaller individuals go through the mesh size unharmed, while the larger ones are not able to pass through the mesh at either end. Morphologically, both *O. niloticus* and *C. carpio* have laterally compressed deep body, but their gillnet selectivity could differ due to differences in girth circumferences and external body features such as spines and fin rays. For example, *C. carpio* has an anal fine with a bony ray which is serrated posteriorly. This structure often exposes the fish for entangling with gillnets and causing its selection curve to deviate from the common assumption of Normal distribution. As shown in Fig. 2 and Table 2, the best fitting gillnet selectivity model for common carp is the Log-normal model, which assumes Poisson distribution. Similar result was also reported for common carp from Lake Koka [3]. Contrary to this result, a gillnet selectivity study in Ebro Delta coastal lagoons reported the Normal Scale model which assumes Normal distribution as the best fitting model for common carp [37]. The size of the fish considered may attribute for this model variation. The size range of common carp samples for their study ranges from 8.1 – 33.1 cm (considered as smaller or young fishes), whereas this study considered sizes ranging from 12- 64 cm (Table 1). The external features like the anal fin ray may not be hard enough to entangle small common carps than the adult fish.

The selectivity analysis also revealed that *O. niloticus* on the other hand can best be described by the Normal location model which assumes Normal distribution (Fig. 2 and Table 2). This is due to lack of similar external morphological features like *C. carpio* in *O. niloticus* and resulted in more gilled, snagged and wedged than entangled tilapia. However, a similar study in Lake Koka confirmed that the Log-normal model and Normal location model equally described the gillnet selectivity of *O. niloticus* [3].

Visual inspection of the residual plots and comparing the model deviance values suggested that the four models included in SELECT provided an adequate fit to the data (Fig. 2 and Table 2). None of the models tested for *C. carpio* showed a lack of fit (deviance/ d.f. > 1), while the ratio of model deviance to degrees of freedom for *O. niloticus* was greater than 1 (Table 2), indicating over dispersion of data. However, over dispersion doesn't necessarily mean inaccurate result as it does not necessarily affect parameter estimation [38, 39]. The over dispersion of data for *O. niloticus* rather indicates that the species may not have behaved independently violating the assumption of independent catches due to their schooling behavior. Moreover, as seen from the higher or equal model deviance values for the best fit model (Table 2), the assumption of fishing power proportional to mesh size doesn't improve the fit.

The estimated L_{CAP} values for *C. carpio* is comparable to the reported estimates by Tesfaye *et al.* [3]. Comparable estimates of L_{CAP} for *O. niloticus* were also reported by Hailu [9] and Tesfaye *et al.* [3]. But, Wudneh [7] estimated lower L_{CAP} value (24.7 cm) for *O. niloticus* using the Holt [17] method for 100 mm mesh, which is smaller than the estimate of both the present study and the previous studies by Hailu [9] and Tesfaye *et al.* [3].

Based on classical fisheries theory [e.g. 40] and some current debates that favor minimum size limits [e.g. 41, 42] and minimum mesh sizes as technical management measures to optimize harvest and ensure sustainability, gillnets with 120 mm and above could safely be used for both tilapia and common carp fishery in Lake Hashenge. Notwithstanding the effect of 100 mm mesh gillnet on common carp, it could also be optimal for tilapia fishery in Lake Hashenge. Nevertheless, in multispecies fisheries, no single mesh size suits all species, and any change may favor one species at the expense of another [41]. However, contemporary fishery scientists argued against the above concept, and introduced a new concept called balanced harvest [43, 44]. The balanced harvest concept encourages exploiting all fishes according to their productivities along the size spectrum of the ecosystem. Using the balanced harvest concept, a recent study by Wolff *et al.* [45] also demonstrated that the use of small-meshed gillnets (even if it selects < L_m value) are not harmful for the stock sustainability as we often think; it rather promotes stock sustainability as they allowed the large adults (also called Mega-spawners by Froese) [42] to remain in the stock. However, the authors noted that the total yield would be suboptimal. It means that the use of small meshed gillnets is not a question of sustainability; rather it is a question of economics. Considering these facts, gillnets with mesh sizes ranging from 100 – 120 mm mesh could safely be applied in Lake Hashenge fishery as these nets allowed the fishermen to harvest maximum catch while maintaining the stock sustainability.

5. Conclusions

Gill net is one of the most widely used fishing gears for both subsistence and commercial fishery as well as for scientific purposes. As improper fishing practices have resulted in tremendous effect on fish populations and led to serious ecological consequences, gear selectivity evaluation is very essential to sustain the target fish stocks and maintain ecological integrity. Evaluation of the gillnet selectivity of the two commercially important fish species (tilapia and common carp) in Lake Hashenge showed that the best fitting statistical model differs between species mainly attributed to differences in morphological features and girth circumferences. Accordingly, Normal location model and Log-normal model has best described the gill net selectivity of tilapia and common carp in Lake Hashenge, respectively. Comparing the size at massive maturity (L_m) with the optimum length of capture (L_{CAP}) for both species, and considering the recent report by Wolff *et al.* [45], gillnets with mesh sizes ranging from 100 – 120 mm mesh could safely be applied in Lake Hashenge fishery as these nets allowed the fishermen to harvest maximum catch while maintaining the stock sustainability.

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