14(1): 001-013 (2020)

Journal of FisheriesSciences.com

E-ISSN 1307-234X

Research Article

Estimate of Gillnet Selectivity Parameters and True Relative Abundance of *Oreochromis niloticus* and *Sarotherodon galileus*, Using Four Indirect Methods, with Gillnets Principally of Three Different Meshes in Thevolta Lake, Ghana

Lawrence Issah Braimah

West Africa Regional Fisheries Program, P.O.Box AS 806, Ashaiman, Ghana

Received: 05.06.2020 / Accepted: 11.08.2020 / Published online: 18.08.2020

Abstract: The study was conducted from July to December, 2018, in the Volta Lake, with gillnets principally of mesh sizes, 7.62 cm, 8.89 cm and 10.16 cm, and an additional mesh size of 6.35 cm, using four indirect methods to investigate gillnet selectivity parameters for Oreochromis niloticus and Sarotherodon galileus and to estimate the true relative abundance of the fish populations from the gillnet catches. A total of 1,969 fish samples of both species was measured for standard length, and selectivity parameters determined by comparison of catches of length classes of successive pairs of gillnets. The study determined selection factors of 1.96 and 1.92 for Oreochromis niloticus and Saratherodon galileus respectively and being nearly equal was attributed to both species having similar body shape. The distribution of the selection curves was skewed, due to various factors, but the resultant asymmetry was corrected by the Beverton/Holt method which minimized the standard deviations of the curves to one-tenth of the normal Holt method for selectivity determination. The gillnet selectivity parameters assessed provided the bench mark for guidance for re-formulation ofthe fisheries regulations on mesh size restrictions for sustainable management of the two tilapiine fish species. Gillnet catches of the two species were significantly different from the true relative abundance of the fish populations due to the selectivity of gillnets. To reflect true abundance and be qualified for more advanced fisheries resources management work, the gillnet data should be adjusted using the probability of capture generated through the selectivity studies.

Keywords: *Oreochromis niloticus, Sarotherodon galileus*, Length frequency distribution, Optimum length, Selection factor, Probability of capture, True relative abundance

***Correspondence to:** **Braimah LI,** Senior Fisheries Consultant, West Africa Regional Fisheries Program, P.O.Box AS 806, Ashaiman, Ghana, Tel: +233 208149638; E-mail: l.i.braimah@gmail.com

Introduction

Gillnets are widely used in all artisanal fisheries in developing countries because they are efficient, relatively inexpensive (Carol and Garcia-Berthou, 2007,Faife andEinarsson, 2003,Hamley, 1975) and catch a higher amount of commercially valuable species than other fishing gear (Acosta andAppeldoorn, 1995).In Africa, and many tropical and sub-tropical countries where the tilapiine species have been of major importance in the artisanal fisheries,catches attributed to gillnets are significant. The most important of the tilapiine species are,*Oreochromis niloticus* and *Sarotherodon galileus*, total production of which amounts to nearly 750,000.00 t per year (FAO, 2007).

Gillnets are however among the most selective fishing gears in terms of both species caught and the size ranges retained (Gulland, 1983). Selectivity is defined as the proportion of fish available to the fishing gear in a given size or age group that is retained (Hunte and Mahon, 2001,Fridman, 1986). Lagler(1978) stated that selectivity is influenced by intrinsic and extrinsic factors. Intrinsic factors such as the fish behavior or habitat preferences, determine which fish encounter the gear. Extrinsic factors, including construction of the fishing gear and method of operation, determine if fish that encounter the gear are captured (Acosta and Appeldoorn, 1995,Fridman, 1981,Hamley, 1975).

The most reliable way of estimating gillnet selectivity is by directly fishing a known population, as selectivity is determined by the proportion of fish caught in each size class, but this is expensive therefore it is based mostly on indirect estimates (Winters and Wheeler, 1990,Hamley, 1975). Indirect estimates use comparisons of catches by two or more mesh sizes to determine gillnet selectivity based on a number of assumptions (Hamley, 1975,Hamley and Regier, 1973). Even though some authors criticize some of these assumptions, indirect methods for estimating gillnet selectivity still remain desirable because data needed are simple, easily obtainable and less expensive. Besides, gillnets are still being used for fisheries surveys as they have the virtue of being deplorable in areas with different bottoms which cannot be covered by most non selective gear. They are typically used as a survey gear in most fresh water lakes as well as at sea. Knowledge of selectivity enhances; managing of fish stocks on a sustainable basis by correcting the sampled size compositions to reflect the true relative composition of the populations; standardizing the catch per unit of effort for the various fishing gear as well as determining an optimum mesh size (Acosta andAppledoorn, 1995) to provide maximum yield,protect small fish; and minimize escapement of injured or dying fish (Queirolo*et al.*,2016,Carol and Garcia-Berthou, 2007,Santos *et al.*, 1998, 1995,Fijimori*et at.*, 1996, Acosta and Appeldoorn, 1995, Pet *et al.*, 1995,Hamley 1975).

Gillnets being the most important fishing gearin the artisanal fisheries worldwide, generate huge volumes of catch data which due to the concomitant selectivity issues are not utilized to the fullest, especially foradvanced assessment of stocks. Investigating the selectivity properties of gillnets and estimating relative abundance of the most dominant tilapiine fish species, *Oreochromis niloticus* and *Sarotherodon galileus* will boost prudent exploitation of the fish populations and improve the economies of the numerous artisanal gillnet fishermen worldwide who use this cheap fishing gear for the pursuit of livelihoods.

The objective of the study was to contribute to the sustainable management of the two most important tilapiine fish species (*Oreochromis niloticus* and *Sarotherodon galileus*), mostly caught by gillnets in the Volta Lake, by estimating the selectivity parameters of gillnets using four indirect means, and the true relative abundance of the fish populations, with gillnets, principally of three different mesh sizes.Study of the selectivity parameters will enable the assessment of the impact of gillnets in the exploitation of the fish resources while the true relative abundance will enable the treatment of gillnet data for more advanced stock assessment work for sustainable management of the fish species.

The main trust of the study was to compare successive pairs of the three most prevalent mesh sizes (7.62 cm, 8.89 cm and 10.16 cm) for the determination of gillnet selectivity parameters while using an additional mesh size of 6.35 cm for expansion of the net pair comparisons, for an acceptable application, in the Volta Lake, of the Holt's method for multiple mesh sizes to further the selectivity determination.

Materials and Methods

Fishing net materials

Two fishing nets, each of length 203 m and depth 1.94 m, were constructed from monofilament bundles of nets of 0.2 mm diameter and of stretched mesh sizes 7.62 cm, 8.89 cm and 10.16 cm, designated as net type *A*, *B* and *C* respectively, principally for determination of gillnet selectivity parameters.The three mesh sizes were selected because they were the most prevalently used on the lake by fishermen.

In addition, net type *D*, of stretched mesh size 6.35 cm, of similar material, number and dimension was included as supplementaryto provide additional data sets for application of the Holt's method for multiple mesh sizes for further assessment of gillnet selectivity.

The hanging ratio (E), top and bottom, was 0.5 for all nets used in the study. Extra nylon twine 210D/12, of half a meter length was attached to each head rope to assist in joining of adjacent nets.

Methods

Experimental fishing design

The study was conducted from July to December, 2018 on sixteen major fishing grounds characterized by large fishermen populations **(Figure 1)**. Although the fishing nets were rigged for bottom fishing they were operated within a depth range of 3-19 m and linked to each other as if they were a single net. The order in which the single gillnets was linked was not considered important as catching efficiency is not affected by order (Gulland 1980, Lagler 1978). The nets were set late in the evening and recovered early the next morning and, at all times, the immersion time was around 11 hours. Only fish which were meshed or gilled, that is, caught with the head in the mesh, with the net's twine retaining the fish by the operculum were considered and their standard lengths measured.

Indirect estimates of gillnet selectivity

Four methods were used to assess the selectivity of gillnets:

Holt's method for comparison of two mesh sizes (Pauly, 1984)

The Holt's method estimates the mean (optimum) selection length for each net, *LA* and *LB* with their common

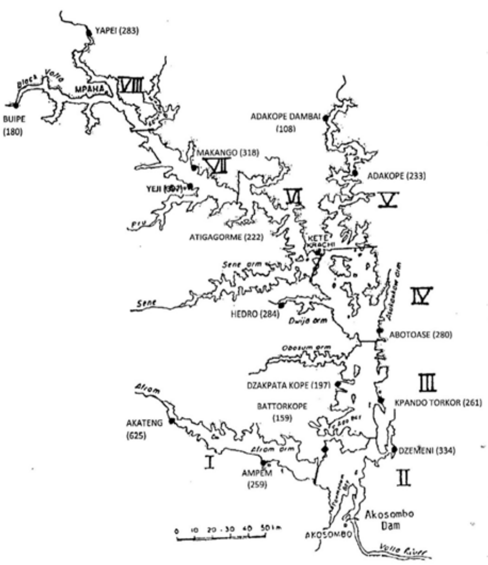

Figure 1: Map of the Volta Lake showing the sixteen fishing villages with high fishermen populations in the eight sub-strata of the Volta Lake, where the experimental fishing wasconducted from July to December, 2018. Numbers in bracket represent number of fishermen in the fishing village.

standard deviation (*SD*), through a linear regression of the form:

$$\ln (CB/CA) = a + bL \qquad \text{------------(1)}$$

Where *CA* is the number of fish within a given length, class caught by the smaller mesh size, *CB* is the number of fish within a given length class caught by the larger mesh size and *L* is the length–class midpoint. The intercept and slope were represented as *a*, and *b*, respectively.

The optimum lengths (*LA* and *LB*) of mesh sizes *A* and *B* were estimated by using:

$LA = -2\, a \times A/(b\,(A + B))$

$LB = -2\, a \times B/(b\,(A + B))$

The standard deviation (*SD*) was estimated as:

$SD = [2\, a\,(A-B)/b^2\,(A + B)]^{1/2}$

The probability of capture (*P*) was estimated for a given value of *L* from:

$PA = \exp\,[-\,(L - LA)^2/2{\times}SD^2]$

$PB = \exp\,[-\,(L - LB)^2/2{\times}SD^2]$

The selection factor *K*, was estimated as:

$K = Lm/M$

Where *Lm* is the optimum length (*LA* or *LB*) and *M* is the mesh size (*A* or *B*).

Beverton/Holt method for comparison of two mesh sizes (Pauly, 1984, Lelek and Wuddah, 1969)

To remove asymmetry so as to obtain a normal distribution curve, Holt's method adapted by Beverton was applied using the natural logarithm of length instead of the length as in Equation 1 and the standard deviation (*SD*), used for determining the selection curves.

Barenov's Coefficient (k) for estimating selection factor (Treschev, 1974)

The inverse of Baronov's coefficient (*k*) is also the selection factor for a given mesh size. Baronov's coefficient was determined using the formular:

$k = 2\,(M_A \times M_B)/l_o(M_A + M_B)$

Where,

M_A is mesh size of Net A

M_B is mesh size of Net B

l_o is length of fish appearing in equal numbers in the catches of both nets.

From the length distribution table, the percentage of fish caught was plotted against fish length and the l_o, values determined which were used in the calculation of *k*.

Holt's method for multiple mesh sizes (Hamley, 1975)

Estimates of selection factor *K*, and variance SD^2, were obtained from each pair of successive mesh sizes and the overall estimates K_T and SD_T^2 obtained by plotting $-2a/b$ against mesh sizes $M1+M2$, setting the intercept to zero (Pet *et al*., 1995, Hamley, 1975). The least square of its slope was the overall slope of K_T. The overall variance SD^2 was obtained by averaging the variance estimates from mesh pair comparisons. The modal lengths of the selectivity curves were:

$Lm = K_T \times M$

The selection curves were obtained by substituting *LmA* (or *LmB*) and SD_T^2 in the probability of capture equation:

$P = \exp[-(L - Lm)^2/2^* SD_T^2]$

With just the 3 main net types (*A*, *B*, and *C*) only 3 data points would be available for the plot of *-2ab* against mesh sizes *M1 + M2* which would render the determination unacceptable. It was therefore essential, for optimization of the method, to introduce net type *D* whose selectivity parameters would increase the data points from 3 to 6 to foster acceptability of the results of the multi mesh plot.

Determination of true relative abundance of fish populations

The length frequency distributions of the gillnet catches were divided by the probability of capture values *P*, to obtain the true relative abundance of the fish population in the Volta Lake.

Statistical analyses

The statistical differences in length frequencies of fish captured among the 3 principal gillnets (net types *A*, *B* and *C*) and differences between length frequency distribution (LFD) and the true relative abundance of the fish population were identified with Chi-square tests (Mead and Curnow, 1983, Bailey, 1981, Ricker, 1975).

Only lengths for which the 'Expected' catch was 5 or more number of fish were used in the analyses to meet the criteria for use of the Chi-square test. Therefore, considering the length frequency distribution of *O. niloticus*, to meet the Chi-square criteria, Class mid-point 13 cm was added to 14 cm and classes 21 cm, 22 cm, and 23 cm were added to Class 20 cm. For *S. galileus*,Class mid-points, 11 cm, 12 cm and 13 cm were combined for Class mid-point 14 cm. In addition, Class mid-points 21 cm, 22 cm, 23 cm were added to the Class mid-point 20 cm to bring the 'Expected' to 5 or more.

Interaction effects of the fish species with mesh size and with length class were evaluated by a two-way interaction variance analysis.

Results

Length frequency distribution (LFD) analyses of catches of the three principal mesh sizes

Size range and modal length of fish caught

The length frequency distribution of *O. niloticus* and *S. galileus* for the 3 principal mesh sizes, on the Volta Lake (7.62 cm, 8.89 cm and 10.16 cm) showed different size ranges and modal classes of fish caught **(Figures 2 and 3)**. The difference between the minimum and the maximum length of the selection ranges for mesh sizes, 7.6 cm, 8.89 cm and 10.16 cmfor *O. niloticus*was 6 cm, 6 cm and 7 cm respectively and for *S. galileus*, was8 cm, 6 cm, and 8 cm. The size range of fish caught was not related to mesh size. The modal lengths of both species caught for the mesh sizes, 7.6 cm, 8.89 cm and 10.16 cm were, 15 cm, 17 cm and 19 cm, respectively.Large meshes caught the largest fish and an increase by1.27 cm in mesh size was accompanied by an increase of 2 cm in modal length.

The length frequency distribution showed a significant

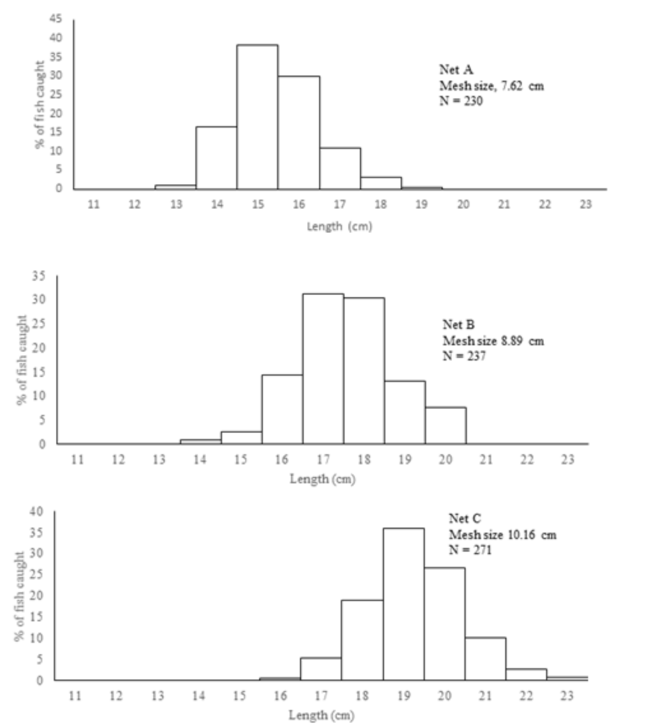

Figure 2: Length frequency distribution of *Oreochromisniloticus* for the three principal mesh size gillnets (A=7.62 cm, B=8.89 cm and C=10.16 cm) showing different size ranges and modal classes of fish caught.

difference between the mesh sizes (7.62 cm, 8.89 cm and 10.16 cm) for *O. niloticus* (P<0.01, df = 12, $\chi^2 = 670$) and for *S. galileus* (P<0.01, df = 12, $\chi^2 = 697$) indicating the 3 mesh sizes caught different sizes of both fish species **(Table 1)**.

Variance analyses

The two-way variance analyses conducted **(Table 2)** to determine possible interaction effects showed a significant interaction between *length classes* and *mesh sizes* at P<0.05 and P<0.01 (F = 22.2, df = 24 and 36) meaning that *length classes* were associated with *mesh sizes*.

The F-distribution for the interaction, *mesh size × species*, showed no significance (F=1.25, df=2 and 36) indicating no association of *mesh size* with s*pecies*.

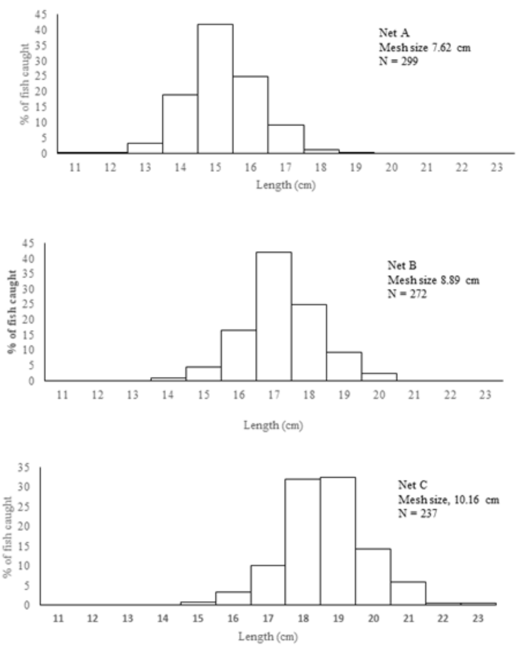

Figure 3: Length frequency distribution of *Saratherodongalileus* for the three principal mesh size gillnets (A=7.62 cm, B=8.89 cm and C=10.16 cm) showing different size ranges and modal classes of fish caught.

Gillnet selectivity

Holt and Beverton/Holt methods for comparison of two meshes (Pauly, 1984, Lelek and Wuddah, 1969)

Plots of *ln*(*catch ratio*) against *length* **(Figure 3)** (the Holt's method) and against *ln* (*length*) (the Beverton/ Holt method) **(Figure 4)** for *O. niloticus*and*S. galileus*, respectively, were compared for standard deviations **(Table 3)**.

The standard deviations of the *length* plot were approximately 10 times greater than those of the *ln*(*length*) plot for both *O. niloticus*and*S. galileus.* The use of the *ln*(*length*) plot therefore minimized asymmetry for the normal distribution curve.

Selection curves (probability of capture curves)

The selection curves, for both species, **(Figures 5-7)** were almost of the same height thus meeting the criteria of the Holt's method of equal efficiency for all meshes at their optimum lengths.

Estimation of optimum length and selection factor

From the parameters of the Holt's method, the (*length*) curve, optimum lengths were calculated for pair of mesh sizes and averages obtained for each mesh size **(Table 4)**.

Table 1: Chi-square test results of length frequency distributions of *Oreochromis niloticus*and *Saratherodon galileus* caught.

χ 2	*O. niloticus*	*S. galileus*
χ 2 – statistic	670	697
df	12	12
P	<0.01	<0.01
χ 2 -distribution	26.22	26.22
Difference	Significant	Significant

Table 2: Results of variance analyses showing significance of interactions (mesh size × species and class × mesh size) for *Oreochromis niloticus* and *Sarotherodon galileus.*

Source	Degrees of freedom (df)	Sum of squares (SS)	Mean of squares (SS)	Variance ratio (F)	5%	1%
Class	12	26600	2217.9	26.29		
Mesh size	2	10.756	5.3778	0.06		
Species	1	62.283	62.283	0.71		
Class× Mesh size	24	44580	1857.9	22.2	S	S
Meshsize × Species	2	211.61	105.81	1.25	NS	NS
Class × Meshsize × Species	36	3036.7	84.353			
Total	77	74530				

From the average optimum lengths, selection factors were estimated for each species as 1.96 for *O. niloticus* and 1.92 for *S. galileus* **(Table 5)**.

Determination of selection factor *K*, from the Barenov's coefficient *k*, for two mesh size comparisons

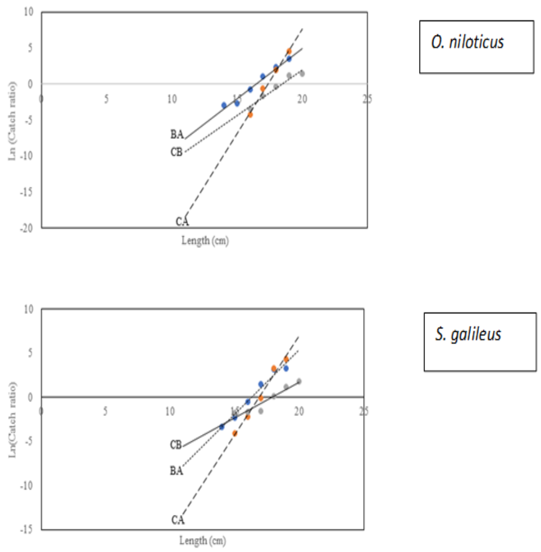

Figure 4: Plots of *Ln(catch ratio)* against *Length* (cm) (Holt's method) for estimation of standard deviation (*SD*), slope (*b*) and the intercept (*a*) for *Oreochromisniloticus* and *Sarotherodongalileus* for three pair of mesh sizes, BA, CA, and CB (AB=7.62 cm, B=8.89 cm and C=10.16 cm).

From plots of *percentage composition* against *length,* the length of fish appearing in equal numbers *lo*, for each pair of mesh sizes was obtained for the two species **(Figure 8 and 9)** and from the formula, the Barenov's coefficient *k*, determined **(Table 6)**.

The average coefficient *k*, was obtained for each species as 0.51 for *O. niloticus* and 0.52 for *S. galileus.*

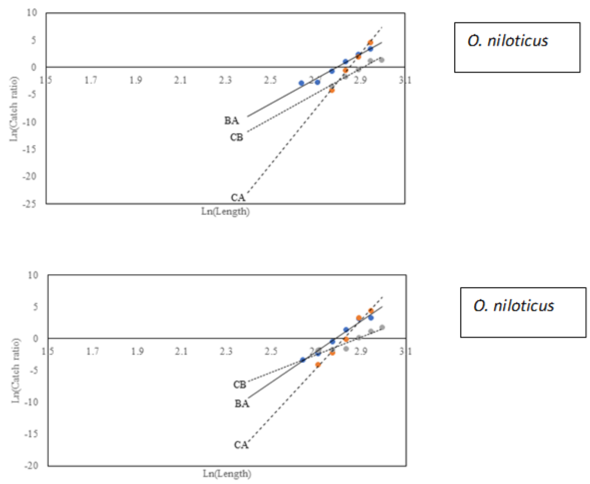

Figure 5: Plots of *Ln(catch ratio)* against *Ln(Length)*(cm) (Beverton/Holt's method) for estimation of standard deviation (*SD*), slope (*b*) and the intercept (*a*) for *Oreochromisniloticus* and *Sarotherodongalileus* for three pair of mesh sizes, BA, CA, and CB (AB=7.62 cm, B=8.89 cm and C =10.16 cm).

Table 3: Selectivity parameter comparison of plots of in (*Catch ratio*) against *length* (Holt's plot) and ln (*length*) (Beverton/Holt's plot) for *Oreochromis niloticus* and *Sarotherodon galileus* for pairs of mesh sizes, BA, CB and CA.

Net pair	Parameters from length plot (Holt's plot)			Parameters from ln(length) plot (Beverton/Holt's plot)		
	a	b	SD	a	b	SD
			O. niloticus			
BA	-22.89	1.392	1.347	-63.59	22.754	0.137
CB	-23.34	1.263	1.396	-66.39	22.783	0.13
CA	-50.3	2.899	1.307	-144.57	50.697	0.126
			S. galileus			
BA	-23.87	1.462	1.31	-66.94	24.017	0.133
CB	-14.28	0.795	1.733	-39.54	13.705	0.167
CA	-37.89	2.241	1.467	-107.09	37.92	0.145

Table 4: Average optimum lengths for mesh sizes; 7.62 cm, 8.89 cm and 10.16 cm, estimated from mesh size pair comparisons for *Oreochromis niloticus* and *Sarotherodon galileus* using parameters of the Holt's method.

Net type	Optimum lengths for *O. niloticus*			Optimum lengths for *S. galileus*		
	A=7.62	B=8.89	C=10.16	A=7.62	B=8.89	C=10.16
BA	15.17	17.7		15.06	17.56	
CB		17.23	19.7		16.73	19.12
CA	14.84		19.85	14.47		19.3
Average	15	17.47	19.78	14.77	17.14	19.21

Consequently, the selection factor *K*, calculated, being the inverse of the Barenov's coefficient *k,* was: 1.96 for *O. niloticus*; and 1.92 for *S. galileus*. The results were same as estimated via the optimum length determination **(Table 5)**.

Holt's method for multiple mesh sizes (Hamley 1975)

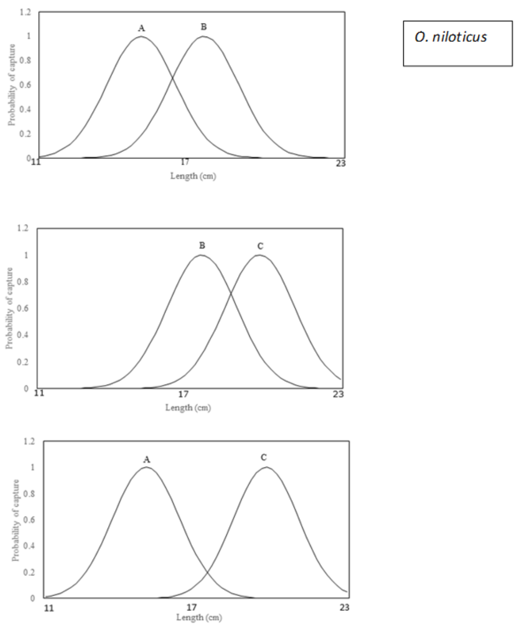

Figure 6: Selection curves produced by plotting the probability of capture against Length (cm) for *Oreochromisniloticus* with pair of mesh sizes; AB, BC and AC (A=7.62 cm, B=8.89 cm, C=10.16 cm).

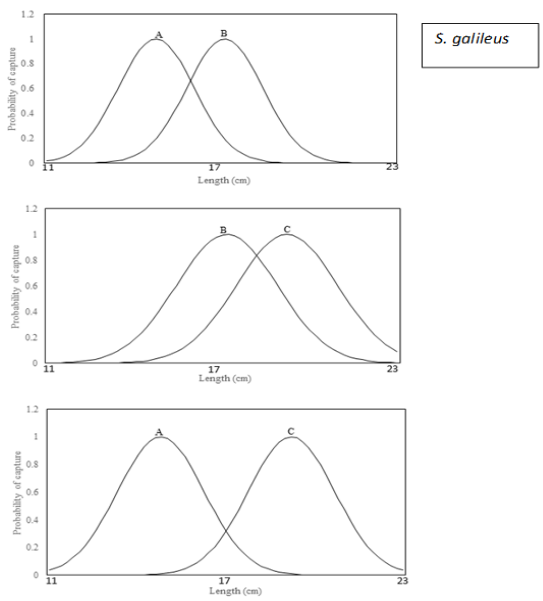

Figure 7: Selection curves produced by plotting the probability of capture against Length (cm) for *Sarotherodongalileus* with pair of mesh sizes; AB, BC and AC (A=7.62 cm, B=8.89 cm, C=10.16 cm).

A length plot (Holt's method) was prepared by pairing the LFD of the additional mesh size *D*, of 6.35 cm, with that of each of the 3 principal mesh sizes **(Figure 10)** and selection parameters obtained **(Table 7)**.

Combining the resultant selectivity parameters of **(Table 7)** and that of the Holt's *length* plot of Table 3, the plot of-2 *a*/*b* against *M*1+*M*2, with the intercept set at zero, was charted and the regression of the slope determined as 1.96 for *O. niloticus* and 1.92 for *S. galileus* **(Figure 7)**. The regression of the slope was referred to by Holt as the selection factor, K_T. The results were same as shown via the optimum length and the Baronov's coefficient determinations.

The initial Holt's multiple meshes plot for *O. niloticus*, showed that the point representing the pair of meshes *AD*, was an outlier and therefore eliminated to improve

Table 5: Selection factor (*K*) for 3 meshes (7.62 cm, 8.89 cm, and 10.16 cm) for *Oreochromis niloticus* and *Sarotherodon galileus*, estimated by dividing the average optimum length by mesh size.

Mesh size (cm)	Selection factor (K) for the two species	
	O. niloticus	*S. galileus*
Net A=7.62 cm	1.97	1.94
Net B=8.89 cm	1.97	1.93
Net C=10.16 cm	1.95	1.89
Average	1.96	1.92

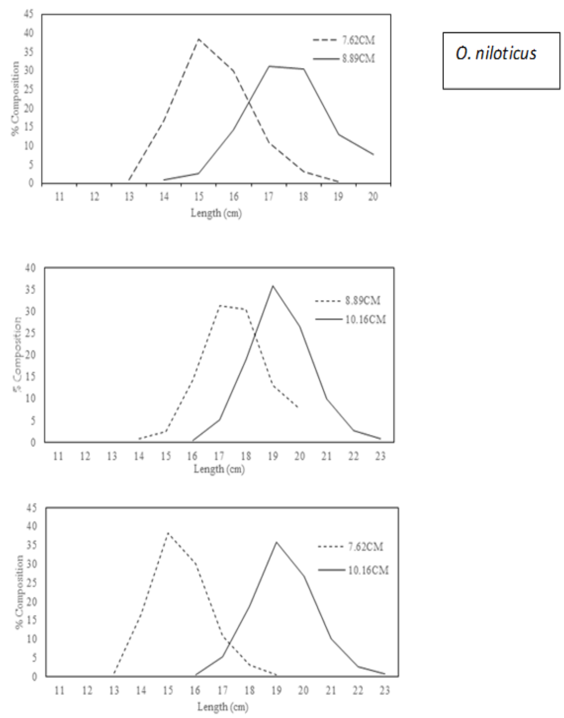

Figure 8: Percentage of fish caught plotted against length (cm) for determination of *lo*, length of fish appearing in equal numbers, for calculation of the Baronov's coefficient *k*, for *Oreochromisniloticus* for paired mesh sizes: (i) 7.62 cm and 8.89 cm; (ii) 7.62 cm and 10.16 cm; and (iii) 8.89 cm and 10.16 cm.

the regression coefficient (R^2=0.9493) of the general plot **(Figure 11)**. This consequently reduced the data points from 6 to 5. So also, due to insufficient data for the plot *CD*, **(Table 7)** it was eliminated in the Holt's multiple mesh size plot for *S. galileus* **(Figure 11)**.

The average of the variances (SD_T^2) of the remaining mesh pair comparisons, in the Holt's multiple meshes plot was obtained and with the selection factor K_T determined, the optimum lengths of the mesh sizes were calculated **(Table 8)**.

Probability of capture

Substituting the average variance (S_T^2) and the optimum length calculated, the probability of capture (selection curves) for each length class was plotted for the mesh sizes, 6.35 cm, 7.62 cm, 8.89 cm and 10.16 cm **(Figure 12)**. It was shown that all 4 curves for the two species were of equal height in conformity with the Holt's criteria of equal efficiency for all meshes at their optimum lengths.

Estimate of true relative abundance of the fish populations

Using the probability of capture figures generated for length classes in **(Figure 12)**, the true relative abundance was estimated for the twospecies and compared as histograms with the corresponding catch length frequencies **(Figures 13 and 14)**.

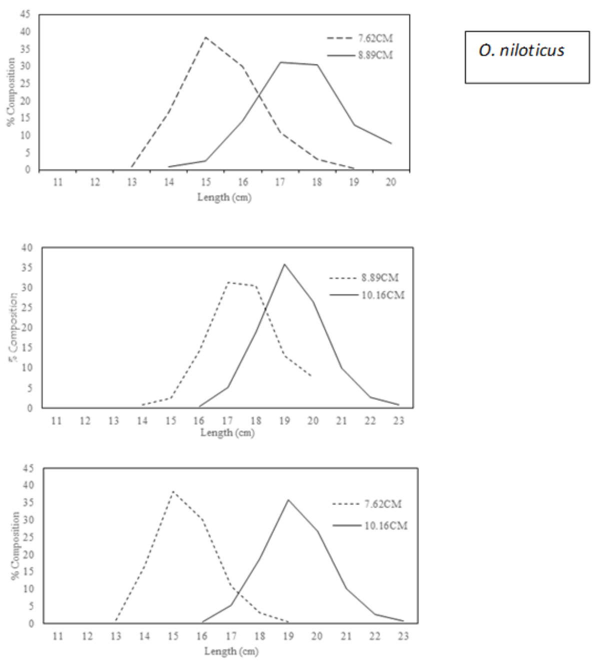

Figure 9: Percentage of fish caught plotted against length for determination of *lo*, length of fish appearing in equal numbers, for calculation of the Baronov's coefficient *k*, for *Sarotherodongalileus*, for paired mesh sizes: (i) 7.62 cm and 8.89 cm; (ii) 7.62 cm and 10.16 cm; and (iii) 8.89 cm and 10.16 cm.

Table 6: The Baronov's coefficient *k*, calculated using the Baronov'sformular, and determining *lo*, the length of fish appearing in equal numbers, from mesh pairs of 3 mesh sizes (A=7.62 cm; B=8.89 cm; and C=10.16 cm) for *Oreochromis niloticus* and *Saratherodon galileus*.

Mesh size comparison	*O. niloticus*		*S. galileus*	
	lo	k	lo	k
BA	16.3	0.40946	16.2	0.50624
CB	17.3	0.50339	16.9	0.51429
CA	18.4	0.51649	17.8	0.53213
		Average 0.51		Average 0.52

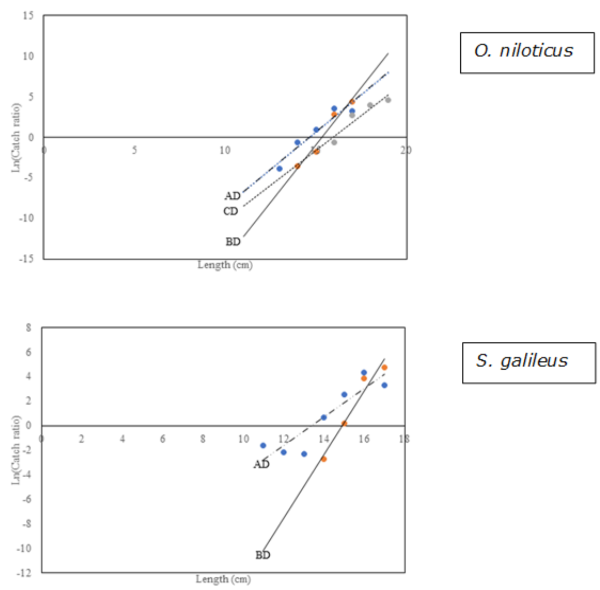

Figure 10: Plots of ln(catch ratio) against length (cm) (Holt's method) for estimation of standard deviation (SD), slope (b) and intercept (a), pairing the additional mesh size (D) of 6.35 cm with the three principal mesh sizes: AD, BD, and CD (A=7.62 cm, B=8.89 cm and C=10.16 cm) for Oreochromisniloticus and Saratherodongalileus. The 18 cm and 19 cm length class data for Oreochromisniloticus for the pair of mesh sizes AD and BD were outliers and not used for the plot. Also the pair of mesh sizes CD, for Saratherodongalileus was discarded due to availability of only 3 data sets.

Table 7: Selectivity parameters determined, using outputs of Figure 6, for the pair of mesh sizes, *AD*, *BD* and *CD* for *O. niloticus* and *S. galileus.* Parameters for the paired mesh size *CD* for *S. galileus* were not computed due to only 3 data sets available.

Paired mesh size	a	b	SD	a	b	SD
	O. niloticus			*S. galileus*		
AD	-26.989	1.8414	1.203	-15.601	1.162	1.449
BD	-43.217	2.8175	1.347	-38.729	2.5957	1.384
CD	-27.305	1.7096	2.076			

Comparison of fish populations

While the total *O. niloticus* catch for the gillnets

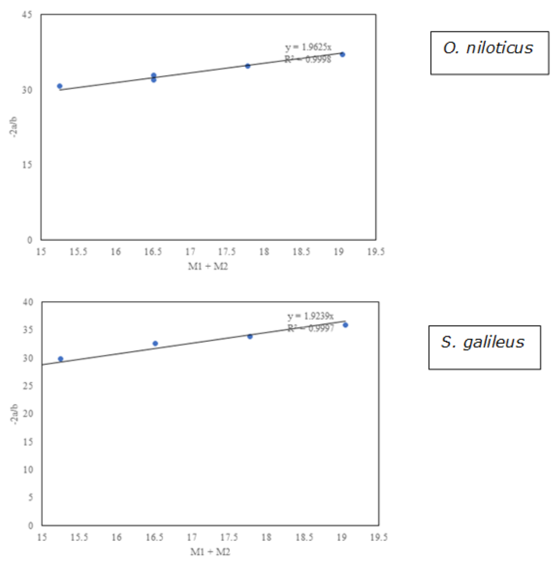

Figure 11: Holt's multiple mesh size plot, *-2a/b* against *M1 + M2*, where *a*, is the intercept, *b* the slope (using the Holt's plot parameters in Table 5 and 9) and *M1* and *M2* are the two meshes being compared. The regression of the multiple mesh size plot, setting the intercept at zero, is the selection factor K_T, and is 1.96 for *Oreochromisniloticus* and 1.92 for *Sarotherodongalileus*.

Table 8: Summary of selectivity parameters: selection factor (K_T); average variance (SD_T^2); and optimum lengths (*Lm*) for 3 mesh sizes, estimated by Holt's method for multiple meshes for *Oreochromis niloticus* and *Sarotherodon galileus*.

Parameters	*O. niloticus*	*S. galileus*
Selection factor (KT)	1.96	1.92
Average variance (SDT2)	2.3201	2.1786
Optimum length, cm Lm, (D=6.35 cm)	12.45	12.19
Optimum length, cm Lm, (A =7.62 cm)	14.94	14.63
Optimum length, cm Lm, (B=8.89 cm)	17.42	17.07
Optimum length, cm Lm, (C=10.16 cm)	19.91	19.51

combined was 1,007 the estimatedtotal true relative abundance of the fish population was 12,870 signifying that the true population was 12.8 times under-represented by the gillnet catch. For *S. galileus*, the total gillnet catch was 963 while the relative abundance was 4,515 expressing a 4.7 times under-representation by the gillnet catch.

Analyses of difference of LFD of the gillnet catches and estimates of true relative abundance of the fish populations

Using the combined length frequency distribution and the estimated true relative abundance of the fish populations for a Chi-square test it was established that significant difference existed between the two entities: for *O. niloticus* ($P<0.01$, df=11, $\chi^2=3277$); and for *S. galileus*($P<0.01$, df=10, $\chi^2=642$) **(Table 9)**.

Since the χ^2- statistic was greater than the χ^2- distribution it showed that the gillnet catch distribution could not be used to represent the true relative abundance of the fish

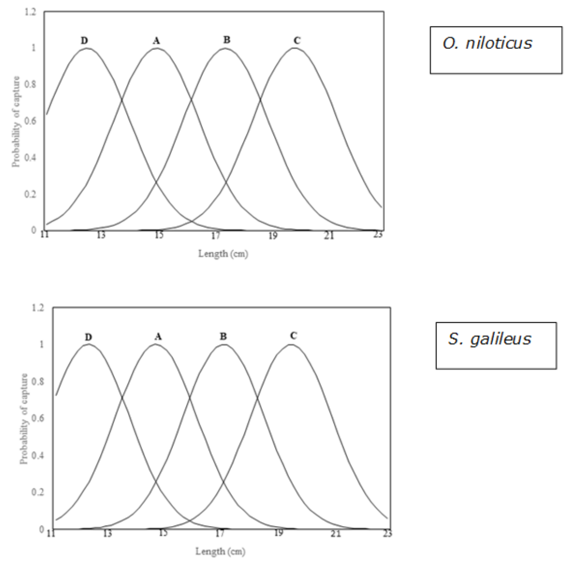

Figure 12: Selection curves plotted using the probability of capture against length (cm) for gillnets D, A, B, C, and D of mesh sizes 6.35 cm, 7.62 cm, 8.89 cm and 10.16 cm for *Oreochromisniloticus* and *Sarotherodongalileus*. Gillnet D of mesh size 6.35 cm is an additional net to the 3 principal nets (A, B, and C).

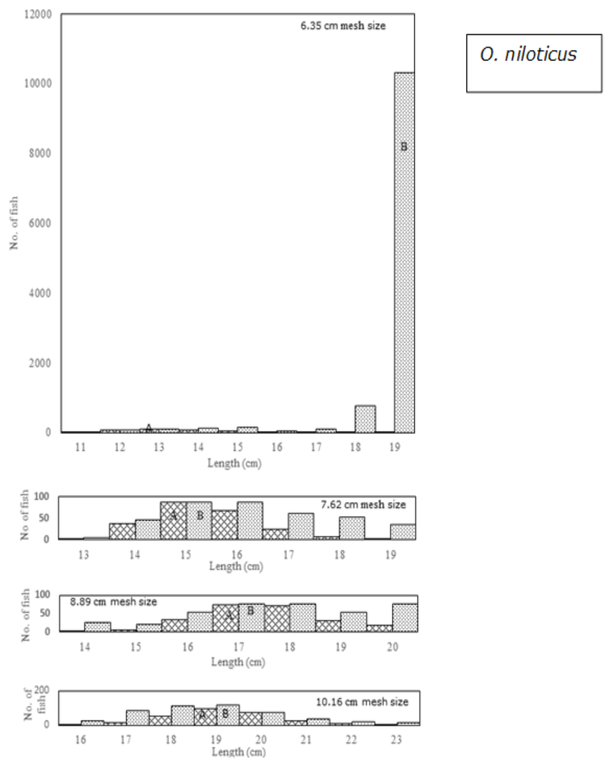

Figure 13: Comparison of length frequency distribution (A) of catch and estimated true relative abundance (B) of *Oreochromisniloticus*for the four mesh sizes (6.35 cm, 7.62 cm, 8.89 cm and 10.16 cm.).

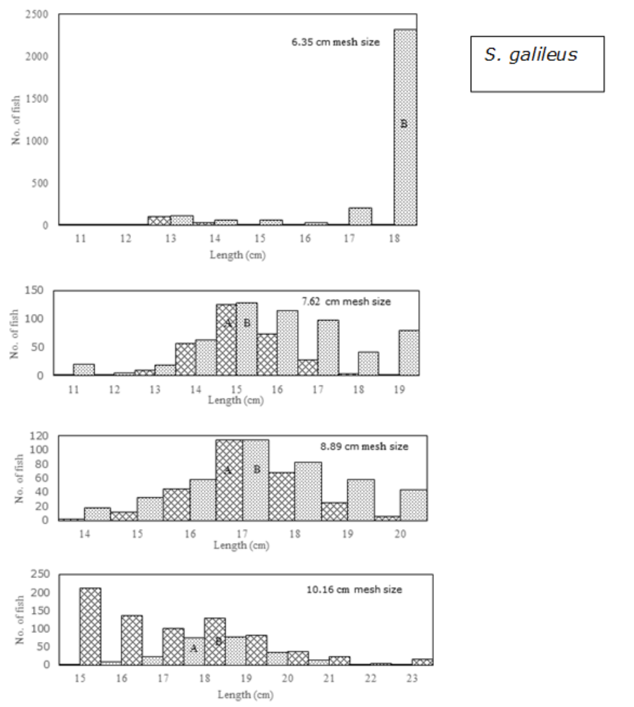

Figure 14: Comparison of length frequency distribution (A) of catch and estimated true relative abundance (B) of *Saratherodongalileus* for the four mesh sizes (6.35 cm, 7.62 cm, 8.89 cm and 10.16 cm.)

Table 9: Chi-square test results of differences between catch length frequency distribution and true relative abundance of fish populations of *Oreochromis niloticus*and *Saratherodon galileus.*

χ 2	***O. niloticus***	***S. galileus***
χ 2 -statistic	3277	642
df	11	10
P	<0.01	<0.01
χ 2 -distribution	24.7	23.21
Difference	Significant	Significant

populations. The difference which is due to the selectivity properties of gillnets necessitates the treatment of the gillnet catch data with the corresponding probability of capture values before acceptable for application for stock assessment analyses and subsequent basis for decisions of sustainability of fish stocks.

Discussion

Results show no preference or association of species with mesh size but mesh size is associated with length indicating that a mesh size catches fish of a certain size (optimum or modal length) the most. This finding collaborates Hamley's (1975), that few fish are caught more than 20% outside the optimum. Gillnets are therefore selective and will seldom capture fish small enough to swim through the meshes (Thompson and Ben-Yami, 2019) and is influenced by the selection factor which is a function of optimum length and mesh size. The selection factors determined for both species (1.96 for *O. niloticus*; 1.92 for *S. galileus*) are nearly equal and this can be attributed to the species having similar body shape. Species which have similar maximum girth in the available length range are liable to be caught most effectively by a net of a particular mesh size, provided that enmeshing is the main mode of capture (Hovgaård and Lassen, 2018, Reis andPawson 1999). In this regard, gillnets are said to be girth specific and accords the opportunity to predict the selection factors of species with similar body shapes. In the Volta Lake, for instance, it can be concluded that the following species fall in the same bracket of selection factors due to their similar shape: *Tilapia dageti*; *Tilapia zilli*; *Chromidotilapiaguentheri*; *Leptotilapiairvinea*; *Hemichromisfasciatus*; *Hemichromisbimaculatus*; and *Steatocranus*species.

Normal distribution of the selection curves, shown by the comparison of two mesh sizes, is restored, when certain factors have acted to cause asymmetry, by application of the Beverton/Holt's method (the plot against logarithm of length). By this method the standard deviation of the curves is reduced to one-tenth of that of the usual Holt method for selectivity which requires a plot against length. This is usually the case when selection curves for a given species are asymmetrical and drawn to the right (Pauly, 1984). The right slope of a gillnet selectivity curve represents large fish usually caught by their heads, its shape is determined by the characteristics of the head and its skew increases with the proportion of tangled fish (Hamley, 1975). Since tangled fish were excluded in the study, skewness to the right is attributed only to the characteristics of the head and the behaviour of the large Tilapiine fish which affects the probability of capture (Winter and Wheeler, 1990). Fish in the tributaries of the lake, which are part of the sampled population, have streamline characteristics (Entsua-Mensah, 1995) hence fish of the same girth will be longer in the tributaries and may develop greater swimming thrusts and therefore penetrate deeper into the mesh to be wedged. It is for this reason large fish of up to 18 – 19 cm, standard length are found wedged even in the small mesh size (6.35 cm) net.The presence of these large fish, particularly *O. niloticus* in the small mesh nets (6.35 cm and 7.62 cm mesh size) have brought about outliers in the length curve which had to be disregarded in order to improve the regression coefficient of the Holt curve. Whenever behaviour varies with fish size, there is bound to be a disturbance in the selectivity curve. Larger fish move about more and are likely to encounter nets and therefore be caught (Hamley, 1975, Hamley and Regier, 1973). A size dependent habitat preference will have major effects on the length frequency distribution when only a limited part of the avoidable habitat is covered in the sampling program (Pet *et al.*, 1995). The differential distribution in area (and depth) of different sizes of *O. niloticus* and *S. galileus* in the Volta Lake delineate breeding areas in the near inshore area from the adult stock in the deeper inshore area where submerged trees are found (Vanderpuye, 1982).

Considering the period of the study, which coincides with the rainy season (i.e. flood period) various factors may have affected the selectivity of the gillnets both to the right and left sides of the curve. Tilapiine species of the lake are deep bodied fish, and the shape, especially for females, varies in relation to the several spawning periods. Variation of shape in spawning composition can act to confound selectivity curves when length and not girth is used as a measure of body size (Winters and Wheeler, 1990, Hamley and Regier, 1973, and Hamley, 1975). Pet *et al*. (1995) expressed that condition may be of greater importance in systems where food availability is more variable. In the Volta Lake, they reported that food availability is linked with the rainy season and the upwelling period from December-January, hence, the condition factor is at its highest and fish become much plumber and is bound to introduce a measure of asymmetry. Kurkilahti*et al.* (2000) have shown with the Eurasian perch (*Percafluviatilis*) that the simple selectivity model derived from one population is not applicable to another if there are differences in fish condition unless the Fulton's condition (K) model is applied to correct the error demonstrating the influence of the condition factor on selectivity.

Comparing the results of the present study, using monofilament nylon nets, to that of Lelek and Wuddah (1969), with multi-filament nylon nets (Pauly, 1984), for the two mesh sizes (7.62 cm and 10.16 cm) catching *S. galileus*, the modal length for the smaller mesh size (7.62 cm) for both monofilament and multifilament nets is same (15 cm) while for the larger mesh size (10.16 cm), the monofilament net is 19 cm and the multifilament net, 17 cm. It would appear then that the difference in the modal length of the larger mesh size is due to the type of net twine used and that the larger the mesh size, the larger the difference between monofilament and multifilament twines. Selectivity is then affected by the elasticity and flexibility of the net twines (Pet *et al*., 1995). Generally, an increased elasticity should result in the capture of a larger average size and a wider selection range (Pet *et al*., 1995, Hamley, 1975). Meshes of the more elastic monofilament twine are stretched to a larger size by struggling larger fish. This makes monofilament nets nearly 2 - 3 times more efficient than multifilament nets (Faife and Einarsson, 2003, Hamley, 1975). Commercial multifilament nets were estimated to select 10% smaller fish than monofilament nets which can be explained by the lower elasticity of multifilament nets (Pet *et al*., 1995).

The net twine through its visibility (color and thinness) can affect the avoidance behavior of fish and probability of catching fish that swim into the net. Reports of the erstwhile Volta Lake Research Project, 1990-1996, an FAO/UNDP project, show that after introduction of several net colors in the lake, only white and light green were acceptable to fishermen. In the Danish fisheries, orange colored nets dominate in the Baltic Sea whereas grey or green nets are preferred for the North Sea fisheries. In addition, the dimension of the netting material affects selectivity of gillnets (Hovgaård and Lassen, 2018). The new multifilament nets being introduced in the Volta Lake have reduced twine sizes, made possible by reducing the number of threads in the yarn from 3 to 2. The data for gill nets show that the common multifilament net is now 21OD/2 and not 21OD/3 as was previously. Faife and Einarsson (2000) mention that an increase in number of filaments in multifilament twine from 4 to 6 decreases numbers by about a third. Similarly, monofilament twines sizes have reduced, the common twine size currently is 0.16 mm and no longer 0.23 mm. Nets of thinner twine are less visible, easier to stretch and more flexible therefore they should catch large fish as long as the twine can hold (Hamley, 1975) and likely to compound selectivity curves.Hovgaård and Lassen (2018) state that multi-monofilament (MM) nets are the most efficient nets as the use of thin parallel threads make the nets more 'soft' than the monofilament (MO) or multifilament and can affect selection curves even more.

By the Fisheries Law of Ghana, (Fisheries Act 625), the minimum stretched mesh size allowed for inland waters is 5.08 cm for multifilament nets and 7.62 cm for monofilament nets. As far as the selection factors of *O. niloticus* (1.96) and *S. galileus*(1.92) are concerned, the minimum mesh size of 5.08 cm permitted by Law should target fish of length around 10.00 cm. However, considering the length at first maturity of *O. niloticus* and *S. galileus* to be 13.6 cm and 11.5 cm (Braimah, 2001) respectively, the law is seen to encourage the exploitation of fish below the size at first maturity and promoting growth over fishing. This requires an express amendment to adjust upwards the minimum mesh size for all gillnets to be at least 7.62 cm to achieve the objective of fisheries management. Queirolo*et al.* (2016) observed similar constraining mesh size restrictions in Brazil where a lot of white croach were caught below the length at maturity and increased the quantities of fish that must be discarded which increases the risk of punishment for fishermen. The impact of gillnet selectivity parameters on fish populations is therefore important in fisheries management and species conservation (Petriki*et al.,* 2014).

Gillnet catches have been shown not to be representative or reflective of the true relative abundance of fish populations (Gulland, 1975, Hamley, 1975) as a result of the significant difference in the length frequency distributions due to selectivity. As gillnet catches are a major constituent of the artisanal fisheries, the need to treat data for selectivity to enable utilization for prudent fisheries management has never become more imperative. In this regard, correction should be done to the gillnet catch size composition, to reflect true relative abundance (Pauly, 1984, Hamley, 1975), to qualifyfor use for such advanced research studies as yield per recruit, and spawning biomass models, for the attainment of the wellbeing of the resources as well as for the numerous artisanal fishermen all over the world.Shoup and Ryswyk (2016) have also noted that by correcting for selectivity, the data are improved, as at times, the adjustment can be large enough to alter management decisions.

Conclusions

The selection factors of, 1.96 and 1.92, determined for *O. niloticus* and *S. galileus* respectively were consistent, from application of the four selectivity assessment methods, and being nearly equal was attributed to both species having similar body shape.

The normal distribution of the selection curves was skewed to the right or left by various factors including; the characteristics of the head, the behavior of the fish, the condition of the fish, and twine elasticity, flexibility and visibility but the resultant asymmetry was corrected by the Beverton/Holt's method which minimized the standard deviation of the curves to one-tenth of the usual Holt's method used for determination of selectivity.

The gillnet selectivity parameters assessed provided the bench mark for guidance for re-formulation of fisheries regulations on mesh size restrictions for the sustainable management of the two tilapiine fisheries species.

Gillnet catches of the two fish species were significantly different from the true relative abundance of the fish populations due to the selectivity of gillnets. Therefore, to reflect true abundance and be qualified for more advanced management work, such as yield per recruit and spawning biomass models, gillnet data should be adjusted using the probability of capture generated through the selectivity studies.

Acknowledgements

The dedicated effort put in the fishing expeditions and collection of catches by the team of five fishermen of the Fisheries Commission at the Yeji Station, led by Augustin Teye is very much appreciated. In addition, the staff of the Commission at Yeji who engaged in the measurement of fish and storage of data for collation are acknowledged.

References

Acosta, A.R., Appeldoorn, R.S. (1995) Catching efficiency and selectivity of gillnets and trammel nets in coral reefs from south-western Puerto Rico. Fisheries Research 22:175-196.

Barley, N.T.J. (1981) Statistical methods in biology. Second edition. Cambridge: Cambridge university press pp: 216.

Braimah, L.I. (2001) Management of fisheries resources on a sustainable basis. A report as part fulfilment of Doctor of Philosophy Degree, University of Hull, UK. ISN: 0000 000134766301.

Carol, J., Garcia-Berthou, E. (2007) Gillnet selectivity and its relationship with body shape for eight freshwater fish species. Journal of Applied Ichthyology 23:654-660.

Denyoh, F.M.K. (1969) Changes in fish population and gear selectivity in the Volta Lake. In L. E. Obeng (ed.). Man-made lakes, the Accra symposium:206-219.

Entsua-Mensah, M. (1995) Length-weight relationships of fishes from tributaries of the Volta River, (Ghana): Part I Analysis of pooled data sets. In: NAGA, The ICLARM quarterly. January 1995:36-38.

Faife, J.R., Einarsson, H.A. (2003) Effect of mesh size and twine type on gillnet selectivity of cod (Gadusmorhua) in Icelandic coastal waters. United Nations University. Fisheries Training Program, Final Project pp: 23.

FAO. (2007) Fisheries and Aquaculture department statistics.

Fridman, A.L. (1981) Calculations for fishing gear designs. London: Fishing news books Ltd pp: 241.

Fujimori, Y., Tokai, T., Hiyama S., Matida, K. (1996) Selectivity and gear efficiency of trammel nets for Kuruma prawn (Penaeus japonicas). Fisheries Research 26:113-124.

Gulland, J.A. (1980) General concepts of sampling fish. EIFAC (European Inland Fisheries Advisory Commission) Technical paper 33:7-12.

Hamley, J.M., Regier, H.A. (1973) Direct estimates of selectivity to walleye (Stizostedionvitreumvitreum). Journal of the Fisheries Research Board of Canada 30:817-830.

Hamley, J.M. (1975) Review of gillnet selectivity. Journal of the Fisheries Research Board of Canada 32:1943-1969.

Hovgaård, H., Lassen, H. (2018) Manual on estimation of selectivity for gillnet and longline gears in abundance surveys. FAO Fisheries Technical Paper 397.

Hunte, W., Mahon, R. (2001) Trap mesh selectivity and management of reef fishes. Blackwell-Synergy Science Ltd. 2: 356-375.

Kurkilahti, M., Appelberg, M., Hesthagen, T., Rask, M. (2002) Effect of fish shape on gillnetselectivity: a study with Fulton's condition factor. Fisheries Research 54:153-170.

Lagler, K.F. (1978) Capture, sampling and examination of fishes. International Biological Programme Handbook 3 (3rd edition).

Lelek, A., Wuddah, A.A. (1969) A note on the occurrence and length frequency distribution of Tilapia species caught in gillnets in the Volta Lake. In: L. E. Obeng (ed). Man-made lakes, the Accra symposium: 186-189.

Mead, R., Curnow, R.N. (1983) Statistical methods in Agriculture and experimental biology. London: Chapman and Hall Ltd pp: 33.

Pauly, D. (1984) Fish population dynamics in tropical waters: A manual for use with programable calculators. ICLARM studies reviews 8: 325.

Pet, J.S. (1995) Comparison of methods for the estimation of gillnet selectivity to tilapia, cyprinids and other fish species in a Sri Lankan reservoir. Fisheries Research 24:141-164.

Petriki, O., Erzini, K., Moutopoulous, D.K., Bobori, D.C. (2014) Gillnet selectivity for freshwater fish species in three lentic systems of Greece. Journal of Applied Ichthyology. 30:1016-1027.

Queirolo, D., Pio, V.P., Pezzuto, P.R., Avila-da-Silva, A.O., Haimovici, H. et al. (2016) Gillnet selectivity for white mouth croaker (Micropogoniasfurnieri) from southeastern and southern Brazil. Latin America Journal of Aquatic Research 44:975-984.

Reis, E.G., Pawson, M.0G. (1999) Fish morphology and estimating selectivity by gillnets. Fisheries Research 39:263-374.

Ricker, W.E. (1975) Computations and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada. Bulletin 191.

Santos, M.N., Monteiro, C.J., Erzini. K. (1995) Aspects of the biology and gillnet selectivity of the anxillaryseabream (Pagellusacarne, Rissa) and common pandona (Pagelluserythrinus, Linnaeus) from the Algave (South) Portugal. Fisheries Research 23:223-236.

Santos, M.N., Monteiro, C.C., Erzini. K., Lasserre. G. (1998) Maturation and gillnet selectivity of two small breams (genus Diplodus) from the Algave (South) Portugal. Fisheries Research 23:185-194.

Shoup, D.E., Ryswk, R.G. (2016) Length selectivity and size-bias correction for the North American standard gillent. North America Journal of Fisheries Management 36:485-496.

Thompson, D.B., Ben-Yami, M. (2019) Fishing gear selectivity and performance. Papers presented at the expert consultation on the regulation of fishing effort (fishing mortality). ISBN 92-5-104461-9.

Treschev, A.T. (1974) Scientific principles of selective fishing. Pishchepromizdat, Moscow pp: 44.

Vanderpuye, C.J. (1982) Further observations of the distribution and abundance of fish stocks in Volta Lake, Ghana. Fisheries Research 1:319-343.

Winters, G.H., Wheeler, J.P. (1990) Direct and indirect estimation of gillnet selection curves of Atlantic Herring (Clupeaharengusharengus). Canadian Journal of Fisheries and Aquaculture Sciences 47:460-470.