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RESEARCH PAPER

Gillnet Selectivity for *Ethmalosa fimbriata* in Saloum Delta and Joal (Senegal)

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Abstract

In this study, a total of 64 fishing attempts was performed and a total of 17775 specimens was caught. The indirect method of Holt (1963) was used to estimate the selectivity parameters. The optimum selection lengths for *E. fimbriata* in 30, 32, 36 and 40 mm mesh size were 17.32, 18.48, 20.79 and 21.10 cm, respectively. Estimated values of common selection factor and standard deviation were 5.77 and 1.48, respectively. Results indicated that using monofilament gillnets with 30 and 32 mm mesh size could have an increasing fishing pressure on juvenile population of *E. fimbriata* but also the use of 40 mm mesh size could affect most fertile females. For the sustainable conservation of *E. fimbriata* fishery, it can be suggested to use monofilament gillnet with 36 mm mesh size in Senegalese coastal and estuarine waters.

Keywords: Monofilament, fishery, mesh sizes, standard deviation, selection factor.

Introduction

Ethmalosa fimbriata is the most common clupeid in the brackish waters of the West African coast and it is very abundant from Mauritania to Angola (Albaret & Gerlotto, 1976). Among the small coastal pelagics in the Northwest African zone, *E. fimbriata* represents 5.5% of the official reported landings in 2013 (FAO, 2015). Spatially *E. fimbriata* are frequently found in Senegal, Gambia, Guinea, Sierra Leone, Nigeria and Cameroon. Since 2008, the high importance of this species in each of the above countries has been raised because: (a) in Mauritania, it has become one of the main sources of supply for new fish flour factories in Nouakchott (FAO, 2015), (b) in Nigeria, it occupies a very important place, as well as in Côte d'Ivoire and Cameroon (Charles-Dominique, 1982; Ama-Abasi, Holzloehner, & Enin, 2004), and (c) in Senegal it is one of the small pelagics that represent the main supply channel for the local markets.

Due to the importance of this species in the landings of artisanal fisheries in the West African sub-region, *E. fimbriata* has been the subject of many studies focused on its growth and reproductive biology in Senegal (Boëly & Elwertowski, 1970; Scheffers, Conand, & Reizer, 1972; Scheffers, 1973; Scheffers & Conand, 1976; Panfili *et al*., 2004a; Faye *et al*., 2014a; 2014b). However, no studies on fishing gear selectivity, particularly gillnets, have been conducted in Senegal, whereas the results of stock assessment of this species in the sub-region, demonstrated an overfishing situation and perhaps a recruitment overfishing due to targeting juvenile fish using small mesh sizes (FAO, 2015). While in Senegal, the primary gear used for the *E fimbriata* is the gillnet (62% of the total landings) but the species is also caught by the purse seine (35%). Other types of gear provide only 3% of the catches (Anonyme, 2014).

The objective of this study is to estimate the selectivity of gillnets for *E. fimbriata* in order to reduce the catch of undersized juvenile fish of this species and to maximize the yields of the fishermen. Knowledge of the selectivity of commercial fishing gear is essential to fisheries management in order to get the maximum sustainable yields and protect undersized juvenile fish (Millar & Holst, 1997; Cochrane & Garcia, 2009; Huse, Lokkeborg, & Soldal, 2000). The study of gillnets selectivity is a very important and decisive approach to fisheries management. Good fisheries management requires that fishing gears should catch the large adult fish while small juveniles are allowed to escape. This implies that the capture efficiency of the fishing gear should change with the size of fish.

Materials and Methods

Study Area

This study was carried out in estuarine waters of the Saloum Estuary (13° 35' et 14° 10' north and 16° 50' et 17° 00') and in coastal marine waters of Joal (14°13'30'' and 14° 08' 30'' North and longitude 16° 52' 30'' and 16° 47' 00''). These sites are both located at the south of Senegal. The Saloum estuary belongs to the category of inverse estuaries (Barusseau, Diop, & Saos, 1985; Pages & Citeau, 1990; Diouf, 1996). The locality of Joal is characterized by sea water omnipresence with its Atlantic coastline that stretches over more than 10 km (Anonyme, 2010). The fishery operations were carried out in nine fishing areas which were located in the sea (Joal 1, Joal 2 and Bacao), in the mouth (Sangomar, Fandiongue and Banc rouge) and in the estuary (Djiffoda, Balgane and Bakhalou) (Figure 1). The bottom structure of the fishing area was sandy and muddy (Domain, 1980). The fishing grounds (3.2-10.5 m depth) were selected once and then kept constant during the experimental fishing operations.

Sampling Strategy

Experiments were conducted every three months from September 2014 to Jun 2016 (Table1) and a total of 64 fishing trips was performed on board artisanal pirogues in collaboration with fishers. Samples were collected using gill nets (monofilament polyamide) with 30, 32, 36 and 40 mm of mesh size (Knot to knot). Local fishers usually used gillnet with 32, 36 mm mesh size and the minimum landing size for *E. fimbriata* was 15 cm. The length of each gillnet was 160 m and the number of mesh in depth was 133. The colour of the gillnet was light green. The four different mesh sizes were vertically connected to each other from small to large mesh size with hanging ratio of 0.5. The design of the nets used in the study was similar to those used by local fishers in terms of number of meshes deep, hanging ratios, lead lines and floats. Gillnets were set at sunset for three hours. After hauling, fish were removed from the nets and separated according to the mesh size. Fork length was measured to the nearest millimetre. Sex and sexual maturity stage of fish determined.

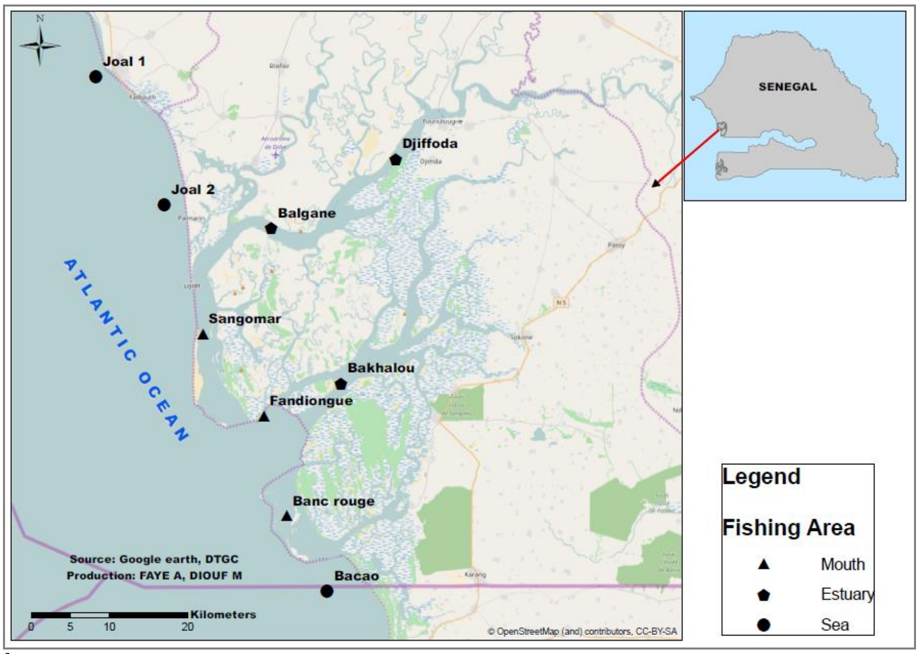

Figure 1. Study area.

Table 1. Calendar of mission trips for studying gillnets selectivity of *E. fimbriata*

Mission trips	Periods
1st Mission	September, 2014
2nd Mission	December, 2014
3rd Mission	March, 2015
4th Mission	June, 2015
5th Mission	September, 2015
6th Mission	December, 2015
7th Mission	March, 2016
8th Mission	June, 2016

Selectivity Estimation

There are two main experimental methods used for selectivity analyses: the direct method and the indirect method (Millar & Fryer 1999). If the length distribution of the fished population is ''known'' then selectivity can be estimated directly. Good knowledge about the population length distribution is rare and in practice one might consider an experiment that used only the recaptures of a tagged sub-population of Fish (Hamley & Regier, 1973; Millar & Holst, 1997). The indirect methods involve estimation from catches taken by nets of slightly different mesh size (Sparre, Ursin, & Venema, 1989).

The indirect method proposed by Holt (1963) was used in this study to estimate the selectivity parameters of gillnets for *E. fimbriata*. This method allows the estimation of the selectivity parameters by comparing the catches in terms of quantity of two slightly different meshes, m_1 and m_2, for the same length. Holt (1963) demonstrated that the natural logarithms of the number caught by two slightly different mesh sizes, m_1 and m_2, are linearly related to fish lengths:

$$\mathrm{Ln}(C_2/C_1) = a+bL$$

Where, C_1 is the catch of mesh size m_1, C_2 is the catch of mesh size m_2, L is the length class, a and b are the intercept and slope of the linear regression, respectively.

The optimal lengths (Lm_1 and Lm_2) for mesh sizes m_1 and m_2, the selection factor (SF) and the standard deviation (SD) were then estimated from the following equations:

$$Lm_1 = -2[am_1/b(m_1+m_2)]$$

$$Lm_2 = -2[am_2/b(m_1+m_2)]$$

$$\mathrm{SF} = -2a/b(m_1+m_2)$$

$$\mathrm{SD} = \{-2a(m_2-m_1)/\mathrm{b}(m_1+m_2)\}^{1/2}$$

The common selectivity factor was calculated with the following formula because the number of meshes used was more than two (Sparre *et al*., 1989):

$$SF = -2\Sigma[(a_i/b_i)(m_i+m_{i+1})]/\Sigma[(m_i+m_{i+1})^2] \text{ for } i=1 \text{ to } n-1$$

The common standard deviation (SD) was calculated as the mean value of the individual estimates for each consecutive pair of meshes (Sparre *et al*., 1989):

$$SD = \{1/(n-1)\Sigma[2a_i(m_{i+1}-m_i)]/[b_i^2(m_i+m_{i+1})]\}^{1/2}$$

The optimal length (Lm) (corresponding to a retention probability of 100%) for each mesh of size m was obtained as:

$$Lm = SF \times m$$

The probability of capture (P) for a given length in a gill net having a mesh size m was determined from the following equation (Holt, 1963):

$$P = \mathrm{Exp}[-(L-Lm)/(2SD^2)]$$

Size of First Sexual Maturity

The size at first maturity can be defined as the length at which 50% of all individuals within a population are sexually mature (L_{50}) where the mature individuals are characterized by the presence of spermatophores or ova in gonads (Ozyurt, Kiyaga, Mavruk, & Akamca, 2011). Sex and maturity stages of the fish were determined. Maturity was recorded on the basis of visual inspection of the gonads (males and females) on a scale from 1 to 5 and individuals with stage 3, 4 and 5 in the gonad development stage were considered to be mature (Faye *et al*., 2014a). A logistic function linking the percentage of mature fish and the mean length (Ghorbel, Jarboui, Bradai, & Bouain, 1996) was used to estimate the L_{50}:

$$\%M = \frac{100}{1+e^{-\sigma(LF-L_{50})}}$$

Where, $\%M$ is the percentage of mature fish, LF is the fish fork length, and σ and L_{50} are estimated parameters.

Sex-ratio

The sex ratio was calculated for each mesh size considered. It is defined as the percentage of male or female individuals in relation to the total sampled population. The sex ratio was calculated according to the following formula (Kartas & Quignard, 1984):

$$SR = F \times 100 \times \frac{1}{(M+F)}$$

Where, SR is the sex ratio, F are the females and M the males.

Statistical Analysis

Statistical analysis and graphs were performed with Microsoft Office Excel and R softwares. To compare the mean fork length and the sex ratio of the sampled fish One-Way Anova and Chi-square tests were used Statistical significance was determined at P<0.05.

Results

Estimation of Selectivity

In 64 fishing trips a total of 17775 *E. fimbriata* were sampled from which 6013 (33.83%), 5981 (33.65%), 4394 (24.72%) and 1387 (7.80%) individuals were caught by 30, 32, 36 and 40 mm mesh sizes, respectively. The number of individuals caught gradually decreased with the increase of the mesh size. The result from the Anova analysis revealed that the mean fork lengths increased with the mesh size ($P<0.05$).

The use of larger mesh sizes resulted in increased in modal length of caught fish (Figure 2). The length-frequency distributions were unimodal for each mesh size. The modal lengths caught in the smallest mesh size 30 mm was 17 cm and this increased with mesh size to 18, 19 and 21 cm in 32, 36 and 40 mm mesh sizes, respectively.

The calculation of selectivity parameters was based on the net pairs of mesh sizes; 30-32, 32-36 and 36-40. The regression slope, intercept, coefficients for optimum lengths, selection factors and standard deviation were assessed from length-frequency distributions for each mesh size combination (Table 2).

The common selection factor, standard deviation and optimum selection lengths for each mesh size were given in Table 3. The optimum selection lengths increased gradually with increasing mesh size and for mesh sizes 30, 32, 36 and 40 mm were found to be 17.32, 18.48, 20.79 and 23.10 cm, respectively. The selection curves of each mesh size followed a normal distribution and each mesh retained a specific size range for *E. fimbriata*. The heights of the selection curves for different mesh sizes were uniform (Figure 3).

The estimated selection curves were compared with the observed length-frequency distributions of fish caught in the different mesh sizes. It appears from this figure that the probability of retention of small individuals *of E. fimbriata* decreased progressively with increasing mesh size. The modes of the observed length-frequency distributions and calculated optimum selection lengths showed deviation in 36 and 40 mm mesh size. The optimum selectivity lengths were 8.61% and 9.01% higher than the modes of observed length-frequencies in 36 and 40 mm mesh sizes, respectively.

Size of First Sexual Maturity

A total of 8533 *E. fimbriata* of which 4385 females and 4148 males was used to establish the size at first sexual maturity. The results obtained indicated that for both sexes (males and females); *E. fimbriata* reached the size at first sexual maturity at 18.5 cm with males (18.2 cm) reached their maturity earlier than females (18.9 cm) (Figure 4).

The percentage of juveniles decreased progressively with increasing mesh size (Figure 2). The percentage of individuals with length smaller or greater than the size at first sexual maturity showed that 78%, 55%, 30% and 7% of the immature individuals were caught by 30, 32, 36 and 40 mm mesh sizes, respectively.

The analysis of the sex ratio showed no significant difference (χ^2-test; $P<0.05$) between the percentage of males and females by mesh size. A slight dominance of males in the small mesh sizes (30 and 32 mm) was observed while the opposite was noted for the largest mesh size all within the range of sampling errors (Table 4).

Discussion

In Senegal, *E. fimbriata* is mainly caught using with gill nets by artisanal fishery. However, selectivity for this gear is poorly described and no research has been done in Senegal prior to this study. Fisheries regulation pertaining to mesh sizes of the fishing gear has been part of the technical conservation measures to protect undersized juvenile fish and get the maximum sustainable yields across the world (Gulland, 1983; Wileman, Ferro, Fonteyne, & Millar, 1996; Cochrane & Garcia, 2009).

In the present study, selectivity parameters of gillnets with 30, 32, 36 and 40 mm mesh sizes used to catch *E. fimbrita* in the Saloum estuary and Joal (Senegal) were determined. The observed length-frequencies were unimodal for all mesh sizes and modal length increases with the increase of mesh size. The optimum fork length of *E. fimbriata* for the varying mesh sizes were 17.32, 18.48, 20.79 and 23.10 cm, respectively. It showed a sequential increment of 1 cm for each 2 mm increase in mesh sizes. This was in accordance with previous studies on gillnet selectivity for *Ethmalosa fimbrita and Sardinella aurita* (Chindah & Tawari, 2001), *Mullus barbatus*, *Pagellus erythrimus*, *Pagellus acarne* and *Spicara flexuousa* (Petrakis & Stergious, 1996), for *Abramis brama* (Psuty & Borrowski, 1997) and for *Carangoides ferdau* and *Caranx papuensis* (Balasubramanian, Meenakumari, Erzini, Boopendranath, & Pravin, 2011). The unimodal length-frequency distributions in all mesh sizes meant that most of fish were wedged or gilled on its operculum and dorsal fin (Holst, Madsen, Poulsen, Fonseca, & Campos, 1994).

The selection curves of the different mesh sizes were been shaped with uniform height, a fact that is also found in other studies (Baranov, 1914; Amarasinghe, 1988; Karakulak & Erk, 2008). This was in accordance with the present study. The selectivity estimates for *E. fimbriata* in the present study showed that individual selection factors range between 5.73 and 5.81 (Table 2). These results are consistent with the findings of Andreev (1962), who maintained that selection factors generally range between 5 and 10.

The modes of the observed length-frequency distributions and calculated optimum selection lengths showed deviation in mesh size of 36 and 40 mm.

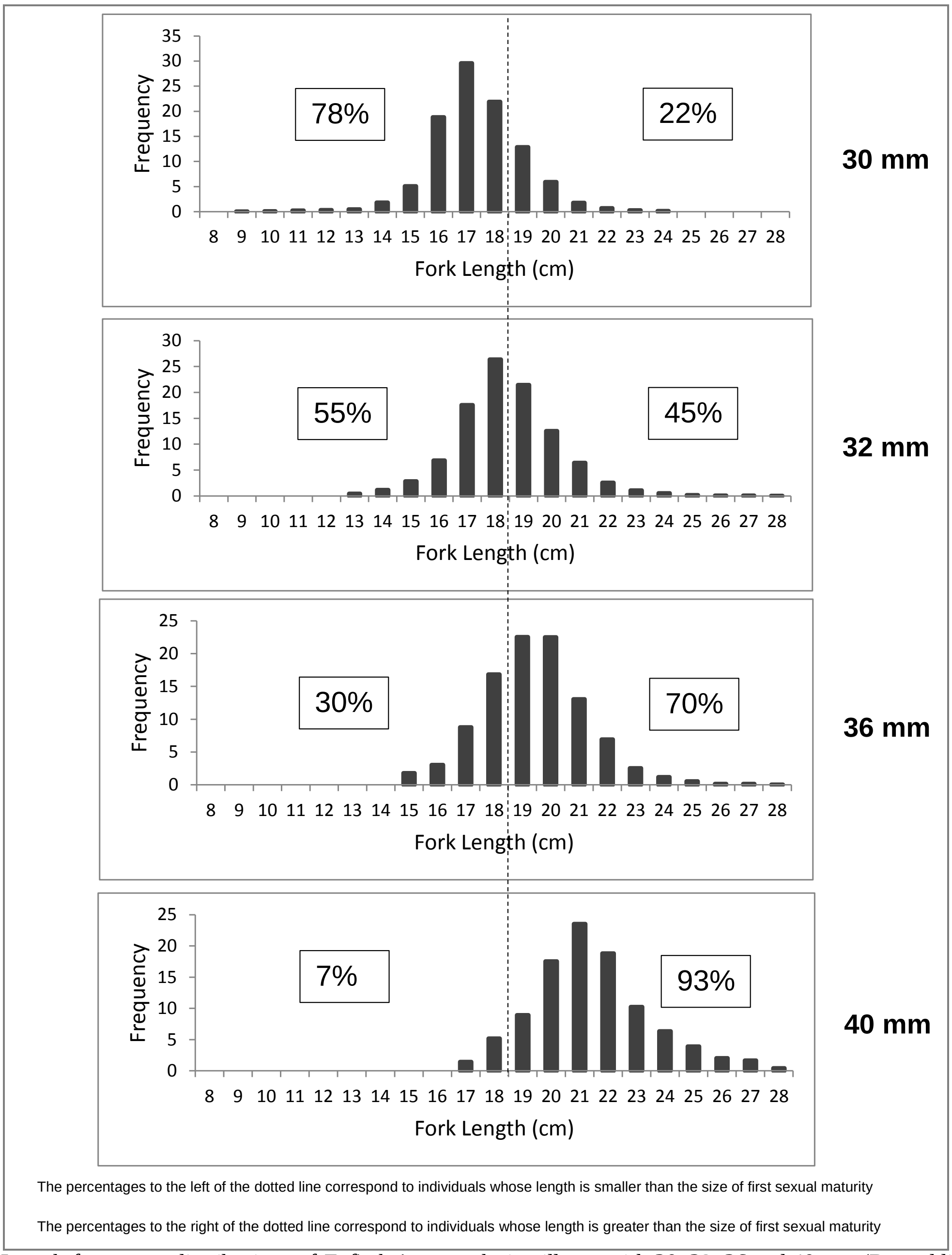

Figure 2. Length-frequency distributions of *E. fimbriata* caught in gillnets with 30, 32, 36 and 40 mm (Dotted line: Size at first maturity for both sexes).

Table 2. Parameters of the regressions of log-transformed *E. fimbriata* catch ratios on length class for various gillnet combinations (mesh sizes 30, 32, 36 and 40 mm)

Mesh size		Parameters							
m_1(1)	m_2(2)	a(3)	b(4)	R^2(5)	N(6)	L_1(7)	L_2(8)	SF(9)	SD(10)
3	3.2	-9.27	0.52	0.957	3	17.32	18.48	5.77	1.49
3.2	3.6	-10.07	0.52	0.9990	3	18.33	20.62	5.73	2.10
3.6	4	-14.60	0.66	0.985	4	20.92	23.25	5.81	1.87

(1), (2) m_1 and m_2 are mesh sizes of two gillnets.
(3), (4) a and b are respectively the intercept and slope of the linear regression.
(5) R^2 is the correlation coefficient.
(6) N is the number of points used in the regressions.
(7), (8) L_1 and L_2 are the estimated optimum lengths for nets of mesh sizes m_1 and m_2 respectively.
(9) SF is the selection factor.
(10) SD is the standard deviation.

Table 3. Common selection factor (SF), common standard deviation (SD) and estimated optimum lengths L30, L32, L36, and L40, of *E. fimbriata* for gill nets of 30, 32, 36 and 40 mm mesh sizes, respectively

SF	SD	L30	L32	L36	L40
5.77	1.84	17.32	18.48	20.79	23.10

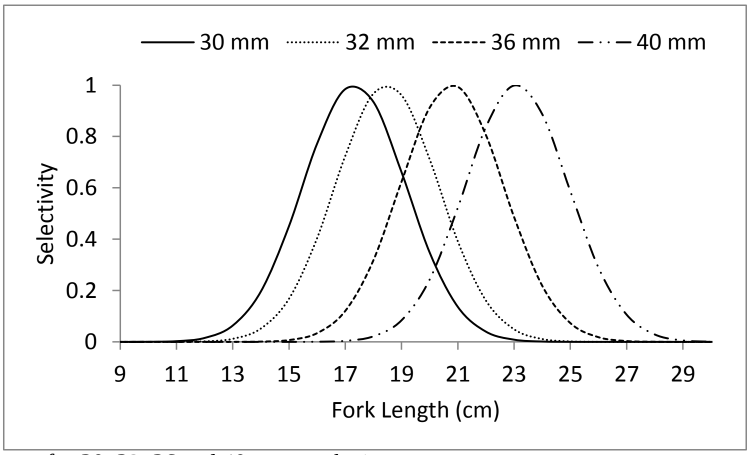

Figure 3. Selection curves for 30, 32, 36 and 40 mm mesh sizes.

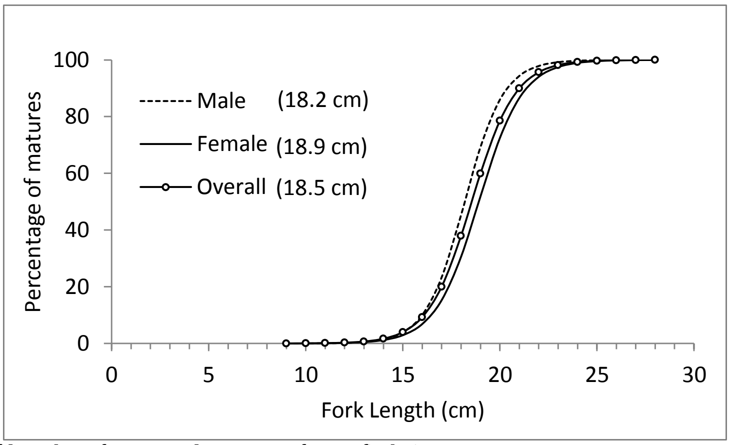

Figure 4. Estimation of length at first sexual maturity for *E. fimbriata.*

Table 4. Percentage of females and males caught in 30, 32, 36 and 40 mm mesh sizes

Mesh size	Sex-ratio		Chi-square	P-value
	Female	Male		
30 mm	44.97%	55.03%	0.24	0.621 (Not significant)
32 mm	45.48%	54.52%	0.82	0.366 (Not significant)
36 mm	50.44%	49.56%	0.01	0.930 (Not significant)
40 mm	61.29%	38.71%	5.10	0.024 (Significant)

Similar results with large-mesh selectivity curves were reported for Atlantic herring *Clupea harengus harengus* (Clarke and King, 1986) and for Pacific herring *Clupea harengus pallasi* (Kawamura, 1972). The apparent non-compatibility of the length frequency distributions and probability of capture of the samples in 36 and 40 mm mesh sizes might be due to the absence of larger size class in the fishing area (De Croos, 2009) or to the avoidance of the fishing gear by the larger size samples (Grégoire, Huard, Croteau, & Lévesque, 1995). Gillnets selectivity can be affected by many factors such as visibility (Hamley, 1975). The visibility of the net in the water varies according to the time of day but also increases with fish age (Grégoire *et al*., 1995).

On the other hand, the deviation of the

selectivity curves compared to the size frequencies in the 36 and 40 mm meshes would be due to the capture effect by entanglement (or snagging). Indeed, the small fish are wrapped in the net and attached to the net by teeth, fins, or other projections. According to Hamley (1975) that catches associated with the left side of a selectivity curve are small fish retained by the body and those associated with the right side are the larger fish that are captured by the head.

Length at first maturity has been considered as a criteria to fix the optimum length of capture (Amarasinghe & Pushpalatha, 1997; Jude, Neethiselvan, Gopalakrishnam, & Sugumar, 2002; Santos, Monteiro, & Erzini, 2005; Ozyurt e al., 2011). The knowledge of the length at first sexual maturity allows to assign an appropriate mesh size for the capture of a given species. In the present study, selectivity and size at maturity were estimated independently for *E. fimbriata* to provide guidance for fisheries management. It is often desirable to set a legal size limit greater than the length at first sexual maturity of the fish. Somvanshi (1980) estimated that knowledge of the length at first sexual maturity is useful for adjusting the mesh size of fishing gear to maintain sustainability by allowing undersized juveniles fish to escape. The size at first sexual maturity for both sexes combined (18.5 cm) was greater than the optimal selection lengths in 30 and 32 mm mesh sizes. Moreover, catch analysis by mesh size indicates that 78% and 55% of the individuals caught respectively by 30 and 32 mm mesh sizes have not yet had a chance to spawn at least once in their life cycle. So the use of gillnets with 30 and 32 mm mesh sizes should be banned in order to avoid the catch of a large quantity of immature individuals. The use of gillnets with 40 mm mesh could also result in a significant decrease in the most productive females (the larger sized females) of *E. fimbriata*. Indeed, the sex ratio calculated in this study showed that females outnumbered males significantly in 40 mesh size. Previous study on sex ratio of *E. fimbriata* in Senegal (Faye *et al*., 2014a) showed a predominance of males in smaller size class with females became increasingly numerous in large size class until reaching 100%. The study on fecundity of *E. fimbriata* according to size class showed that the large individuals had a higher fecundity (N'goran, 1991). In addition, recent studies also demonstrate that for some species the eggs from older females had much higher survival probability than those produced by smaller females (Hislop, 1984; Berkeley, Chapman, & Sogard, 2004a; Sbrana, Belcari, De Ranier, Sartor, & Viva, 2007) and larger females were notably more productive than the small ones (Palombi, 2004).

In view of the recommendations for responsible fisheries, we can conclude that the appropriate legal minimum size for *E. fimbriata* is 19 cm. The corresponding gillnet mesh size must be greater than or equal to 36 mm and strictly less than 40 mm to prevent the capture of the undersized juvenile fish, increase the spawning stock and realize the maximum sustainable yields and economic benefits in this fishery. The present study showed that the use of the appropriate mesh could improve the size of the spawning stock and increase recruitment of *E. fimbriata*. These results would enable the Ministry of Fisheries and Maritime Affairs of Senegalese to adopt and disseminate to fishermen a mesh size larger than the size at first maturity of *E. fimbriata*.

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