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Mortality, recruitment pattern and exploitation rates of two *Schilbe* Oken, 1817 populations: *Schilbe mandibularis* and *Schilbe intermedius* from the Aghien Lagoon; estuarine system of West Africa

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In Côte d'Ivoire, the Aghien Lagoon is under heavy fishing pressure. Mortality, recruitment pattern and exploitation rate of *Schilbe mandibularis* and *Schilbe intermedius* were investigated in this lagoon. Fish samples of both sexes (N = 575) were collected monthly between June 2014 and May 2015 from artisanal and experimental captures. Natural mortality was higher in *S. intermedius* (M = 0.89 years^{-1}) than in *S. mandibularis* (M = 0.58 years^{-1}). The population of *S. intermedius* was more vulnerable to fishing (F = 2.90 years^{-1}) than *S. mandibularis* (F = 0.51 years^{-1}). The Z/K ratio (Z/K = 2.65 for *S. mandibularis*; Z/K = 4.85 for *S. intermedius*) indicated that mortality was predominant over growth for the two species. The recruitment pattern showed one Gauss curve translates was continuous for each species. For *S. mandibularis*, the exploitation rate (E = 0.47) was close to $E_{0.1}$ ($E_{0.1}$ = 0.46), indicating that *S. mandibularis*'s stock was in an optimum state of exploitation. However, for *S. intermedius*, E_{max} was lower (E_{max} = 0.57) than the exploitation rate (E = 0.77). This result reflected overexploitation of this species.

Key words: *Schilbe mandibularis*, *Schilbe intermedius*, mortality, recruitment, exploitation, Aghien Lagoon.

INTRODUCTION

Fish stocks directly threatened by exploitation are especially those of economic interest. These stocks are under heavy fishing pressure, which is often beyond their level of viability. Stock collapse associated with intensive exploitation has been observed in many fisheries around the world. Some examples are the collapse of the cod stock (*Gadus morhua*) (Bundy, 2005), or that of sharks (*Carcharhinus amblyrhynchos*, *Carcharhinus galapagensis* and *Triaenodon obesus*) in the main Hawaiian Islands (Friedlander and DeMartini, 2002).

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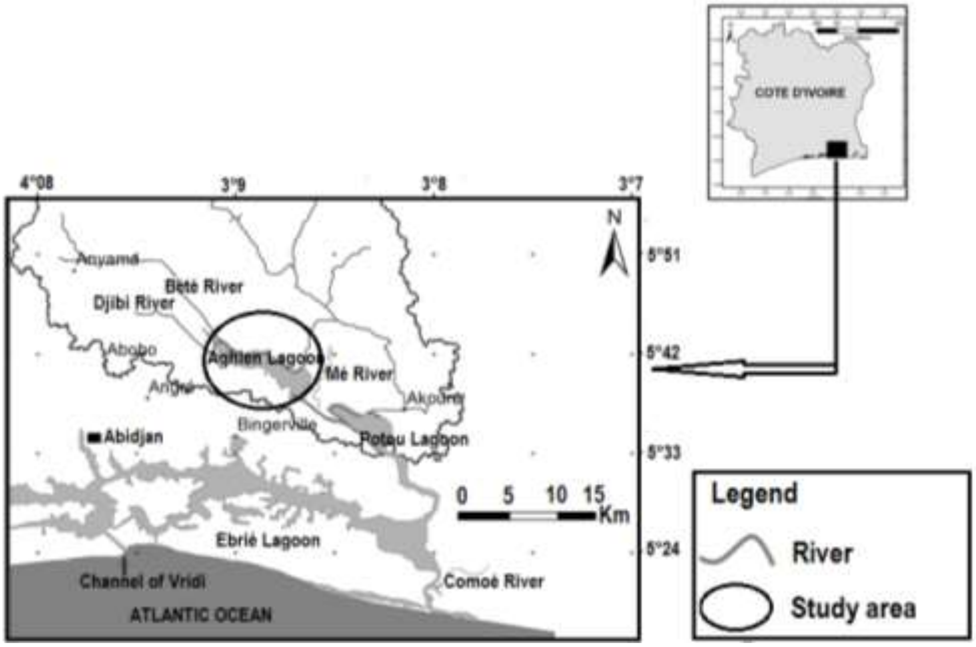


Figure 1. Location of Aghien Lagoon.

In Côte d'Ivoire, the Aghien Lagoon is under heavy fishing pressure. *Schilbe mandibularis and Schilbe intermedius*, belonging to the family Schilbeidae are among the fish most targeted by the artisanal fishing in this freshwater lagoon. In addition, Tossavi et al. (2015) reported that fish belonging to the Schilbeidae family are highly consumed by humans in West Africa. Fish belonging to the Schilbeidae family are classified as catfish and they are characterized by a dorso-ventrally flattened head, a rather short abdomen, a laterally compressed caudal region, and an elongate anal fin. Dorsal fin short, sometimes absent; pectoral fins provided with a spine (as also the dorsal fin of most species) (De Vos, 2007). Schilbeidae is a family of fish found in Africa and Asia (De Vos, 2007).

Population dynamics of fishes are generally studied with the major objective of rational management and conservation of the resource (Tia et al., 2017). Indeed, knowledge of population's parameters such as mortalities (natural and fishing) rate and exploitation level (E) are necessary for planning and management of fish resources (Abowei et al., 2010). Consequently, the knowledge of mortality and exploitation rates of *S. mandibularis* and *S. intermedius* at the Aghien Lagoon will serve as a basis for planning and management of the stocks of these two species. Previous studies had focused on growth and mortality parameters *S. mandibularis* and *S. intermedius* in different environments. For example, Assi et al. (2017) studied growth parameters of these in the Aghien Lagoon. The mortality parameters of *S. mandibularis* and *S. intermedius* had been assessed, respectively in the Ayamé Lake of Côte d'Ivoire (Tah et al., 2010) and in the Pendjari River of Benin (Ahouanssou, 2011).

This study aimed to compare the mortality parameters and the exploitation level of these two sympatric fish species in the Aghien Lagoon.

MATERIALS AND METHODS

Study site and samples collection

The Aghien Lagoon is located in the Southeastern region of Côte d'Ivoire, between latitudes 5°22'N and 5°26'N and longitudes 3°49'W and 3°55'W (Figure 1). This lagoon is located to the north of the Ebrié Lagoon from which it is separated by the Potou Lagoon. The Aghien and Potou Lagoons communicate through a natural channel (Koffi et al., 2014). The Aghien Lagoon could reach a depth of 11 m (Guiral and Ferhi, 1989). This lagoon covers an area of 20 km² for a perimeter of 40.72 km. It is supplied by two main tributaries, Djibi and Bété Rivers, and is almost exclusively continental all year long. This gives to the hydrosystem a fluvial character (Koffi et al., 2014). Located in an estuarine zone, the ichthyological diversity of this lagoon is strongly influenced by species of marine and continental origin. The result is a very diverse fish community with intense fishing activity (Bedia et al., 2009; Traoré et al., 2014).

Both sexed samples were randomly collected monthly between June 2014 and May 2015 from artisanal (n = 34 for *S. mandibularis* and n = 58 for *S. intermedius*) and experimental (n = 101 for *S. mandibularis* and n = 382 for *S. intermedius*) captures in Aghien Lagoon, with *S. mandibularis* (n = 135) and *S. intermedius* (n = 440). Fishes (n = 575) were collected using gill nets (10 to 40 mm stretch mesh). Fish specimens were identified following Paugy et al. (2003a, b), Sonnenberg and Busch (2009), Eschmeyer et al. (2014), as well as Froese and Pauly (2014). For all individuals caught, the standard length (SL) was measured to the nearest millimeter and the total weight (W) was recorded to the nearest gram. Standard length (SL) was used to avoid errors due to tail fins accidentally damaged during intra or interspecific fighting during capture and specimen conservation (Chikou, 2006).

Estimation of mortality rates and exploitation ratio

The total mortality coefficient (Z) was estimated using the length-converted catch curve method (Gayanilo et al., 2002), using the final estimates of L∞ and K and the length distribution data for the species. The linearized length-converted catch curve (Pauly, 1984) was constructed using the formula:

$$\text{Ln}\,(Ni/\ \Delta ti) = a + bti$$

where Ni is the number of individuals in length class i, Δti is the time needed for the fish to grow through length class i, t is the relative age corresponding to the mid-length of class i. The total mortality (Z) was obtained from the slope (b) of the descending limb of the catch curve with the sign changed.

The natural mortality (M), for each species was estimated using Pauly's (1980) empirical equation:

$$\text{Log}\,(M) = -\ 0.0066 - 0.279\text{Log}\,(L\infty) + 0.6543\text{Log}\,(K) + 0.4634\ \text{Log}\,(T)$$

where T is the annual mean of habitat temperature (°C). The indicated value is equal here to 27.90°C.

The values of L∞, K and t_0 is given by Assi et al. (2017). These authors calculated the values of L∞ and K using the FiSAT II package (Gayanilo et al., 2002) from experimental and artisanal fisheries data. The parameter was calculated using the Pauly (1979) equation:

$$\text{Log}_{10}(-t_0) = -0.392 - 0.275\text{Log}_{10}L\infty - 1.038\text{Log}_{10}K.$$

The temperature used for this study was measured *in-situ* monthly during the period from June 2014 to May 2015.

Fishing mortality (F) was derived as the difference between total mortality coefficient (Z) and natural mortality (M) (Dadzie et al., 2007; Abowei et al., 2010):

$$F = Z - M$$

Following the estimations of Z, M and F, the exploitation ratio (E), was obtained from Pauly (1985):

$$E = F / Z = F / (F+M)$$

Probabilities of capture

The catch-curve analysis was extended to an estimation of probabilities of capture by backward projection of the number (N) that would be expected if no selectivity had taken place, according to Sparre (1987). From the analysis, the size at which 50% of a fish population is likely to be caught by fishing gear (L_{50} or Lc) was estimated. By analogy, L_{25} and L_{75} were estimated.

Recruitment pattern

The number of recruitment peaks for each species was examined using "recruitment patterns". Recruitment patterns were generated from the estimated growth parameters by backward projection of length frequency data, as done in ELEFAN I incorporated in the FiSAT software, onto the time axis (Moreau and Cuende, 1991). This type of back-calculation usually allows identification of the number of seasonal pulses of recruitment that have been generated by the population represented in the length frequency data (Gayanilo et al., 2002).

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R)

Beverton and Holt (1966) method as modified by Pauly and Soriano (1986) were used to predict the relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) of the species to the fisheries. Y'/R was computed following this formula

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

where U = 1 - (Lc / L∞) is the fraction of growth to be completed by the fish after entry into the exploitation phase; m = (1- E) / (M / K) = (K / Z) and E = F / Z is the fraction of mortality of the fish caused by the fishermen.

The predicted values were obtained by substituting the input parameters of Lc/ L∞ and M/K in the FiSAT II package.

The relative biomass per recruit (B'/R) was estimated from the relationship:

$$B'/R = (Y'/R) / F$$

Then we computed E_{max} (the value of exploitation rate E giving the maximum relative yield per recruit), $E_{0.1}$ (the value of E at which marginal increase in Y'/R is 10% of its value at E = 0) and $E_{0.5}$ (the value of E at 50% of the unexploited relative biomass per recruit) through the first derivative of the function according to Beverton and Holt (1966). All these methods were provided by the FiSAT II package.

All the parameters evaluated during this study are made using the FiSAT II package. This software is the most frequently used to estimate fish population parameters (Al-Barwani et al., 2007), because of relatively simple application, requiring only length frequency data. In addition, the only necessary and sufficient condition for the use of the FiSAT II package, for a species, is to have data of frequency distributions of lengths of at least 100 fish distributed over 10 to 20 length classes (Ahouanssou, 2011).

RESULTS

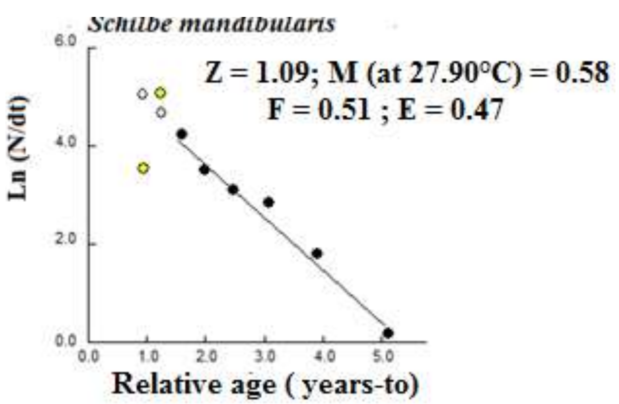
Descriptive statistics of sizes

Total number of fish sampled each month and length ranges are shown in Table 1. At the end of the 12 sampling campaigns in the Aghien Lagoon, a total of 575 specimens were recorded including 135 specimens of *S. mandibularis* and 440 specimens of *S. intermedius*. The large numbers of *S. mandibularis* recorded were 37, 22, 14 and 12, respectively for the months of October, November, August, and September 2014. However the large numbers of *S. intermedius* obtained were 107, 58, 55 and 39, respectively for the months of August, October, November, and September 2014. The size of specimens of *S. mandibularis* varied from 68 and 204 mm SL with a mean of 113.93 ± 29.86 mm SL. For *S. intermedius*, the size varied from 50 to 174 mm SL with a mean of 102.36 ± 21.34 mm SL. For both species, mean size varied significantly from one month to another (Anova, $p < 0.05$). The largest average size is obtained in

Table 1. *Schilbe mandibularis* and *Schilbe intermedius* monthly samples indicating total number of fish sampled each month and length ranges observed.

Month	*Schilbe mandibularis*			*Schilbe intermedius*		
	N	SL range (mm)	Mean ± SD	N	SL range (mm)	Mean ± SD
June 2014	5	143-204	165.6 ± 22.75	10	118-174	132.6 ± 16.61
July 2014	7	87-183	121.33 ± 53.51	23	107-155	127.26 ± 14.87
August 2014	14	68-175	111.5 ± 39.01	107	50-117	90.68 ± 12.99
September 2014	12	70-145	99.33 ± 25.27	39	52-112	83.23 ± 13.05
October 2014	37	70-163	107.80 ± 24.53	58	64-117	89.70 ± 10.29
November 2014	22	85-200	116.72 ± 33.97	55	69-106	92.63 ± 8.20
December 2014	6	108-165	136.5 ± 40.30	41	79-118	99.60 ± 9.40
January 2015	7	102-173	132 ± 24.83	15	99-123	113.66 ± 7.67
February 2015	6	95-154	112.75 ± 27.65	11	91-125	110.54 ± 11.75
March 2015	5	101-146	122 ± 18.17	13	88-152	125.76 ± 17.09
April 2015	8	95-136	111.3 ± 13.11	50	100-157	131.26 ± 14.60
May 2015	6	95-125	107.5 ± 13.22	18	99-163	129.94 ± 19.74
Total	135	68-204	113.93 ± 29.86	440	50-174	102.36 ± 21.34

N: Number of fish sampled, SL: standard length, SD: standard deviation.



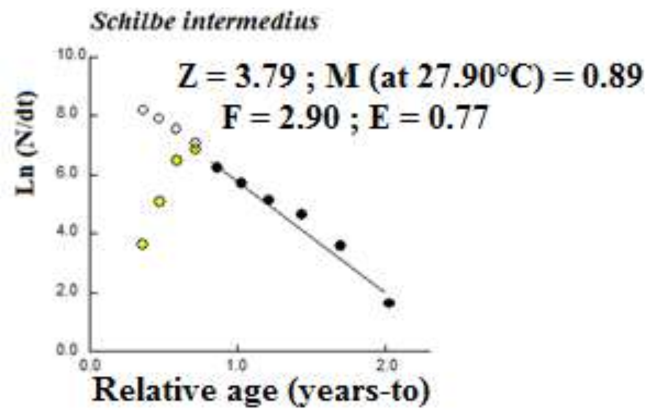


Figure 2. Length-converted catch curve for *S. mandibularis* and *S. intermedius* from the Aghien Lagoon.

June 2014 for *S. mandibularis* (SL = 165.6 ± 22.75 mm) and *S. intermedius* (SL = 132.6 ± 16.61 mm). In contrast, the smallest average size is observed in September 2014 for both species. (SL = 99.33 ± 25.27 mm for *S. mandibularis* and SL = 83.23 ± 13.05 mm for *S. intermedius*).

Mortality rates and exploitation ratios

Total mortality (Z) derived from length-converted catch curve method (Figure 2) was higher in *S. intermedius* (Z = 3.79 years^{-1}) and lower in *S. mandibularis* (Z = 1.09 years^{-1}). As for natural mortality (M), it is also higher in *S. intermedius* (M = 0.89 years^{-1}) than in *S. mandibularis* (M = 0.58 years^{-1}). The population of *S. intermedius* was more vulnerable to fishing (F = 2.90 years^{-1}) than *S. mandibularis* (F = 0.51 years^{-1}).

The exploitation rate corresponding to the range of fishing mortality in *S. mandibularis* estimated at 47%, while the exploitation rate was 77% in *S. intermedius* (Table 2).

Probabilities of capture

The size of fish at various probabilities of capture is presented in Figure 3. The length at first capture of *S. intermedius* (L_{50} or Lc = 78.53 mm SL) was greater than that of *S. mandibularis* (L_{50} or Lc = 69.65 mm SL). In addition, the sizes at 25 and 75% probabilities of capture were higher in *S. intermedius* (L_{25} = 71.78 mm SL and L_{75}

Table 2. Estimate of mortality parameters and exploitation rate of *S. mandibularis* and *S. intermedius* from the Aghien Lagoon.

Species	Z ($Year^{-1}$)	M ($Year^{-1}$)	F ($Year^{-1}$)	E
S. mandibularis	1.09	0.58	0.51	0.47
S. intermedius	3.79	0.89	2.90	0.77

Z: Coefficient of total mortality, M: coefficient of natural mortality, F: coefficient of fishing mortality. E: exploitation rate.

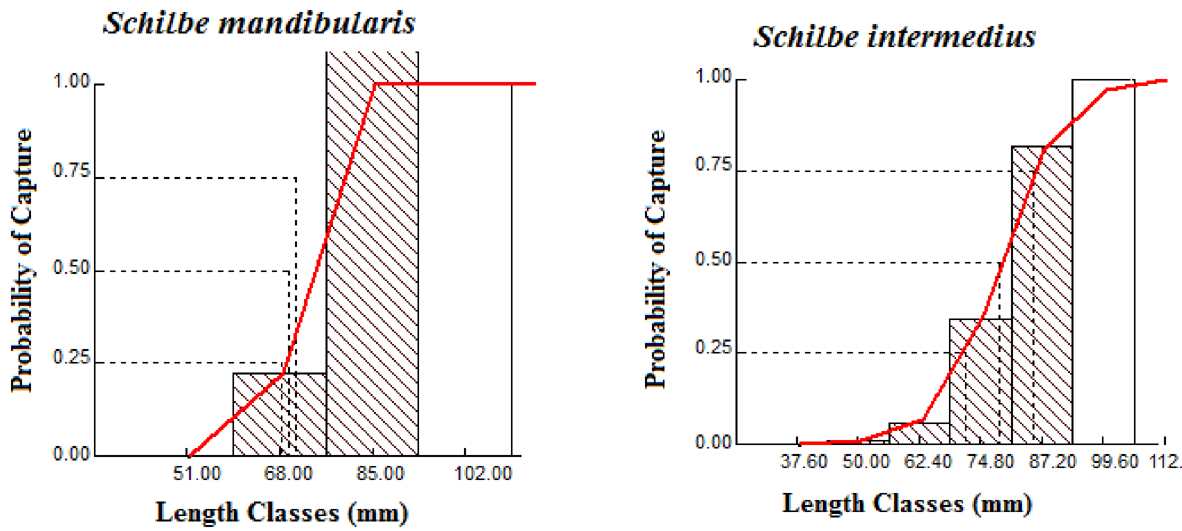


Figure 3. Logistic selection curve for probability of capture, showing 25, 50 and 75% selection length of *S. mandibularis* and *S. intermedius* from the Aghien Lagoon.

= 85.28 mm SL). For *S. mandibularis*, L_{25} = 68.18 mm SL and L_{75} = 71.11 mm SL.

Recruitment pattern

The recruitment pattern of *S. mandibularis* and *S. intermedius* are presented in Figure 4. This recruitment has one Gauss curve for both fish populations. Monthly values of recruitment percentages for both *Schilbe* species are shown in Table 3. In general, the period of intense recruitment varied from one species to another. For *S. mandibularis*, the period of intense recruitment lasted from May to July, with a maximum of recruitment in the month of May. On the other hand, for *S. intermedius*, this period is between June and August. Maximum of recruit was observed in July.

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R)

Table 4 shows the estimated optimum exploitation rates and related coefficient rates of *S. mandibularis* and *S. intermedius* from Lagoon Aghien. The relative yield per recruit and relative biomass per recruit is presented in Figure 5.

In both species, the relative yield per recruit (Y'/B) increases to a maximum then decreases while the curve of the relative biomass gradually decreases with the increase of the level of exploitation. For the *S. mandibularis* population, the current exploitation rate (E = 0.47) is identical to the value of E at which marginal increase in Y'/R is 10% of its value at E = 0 ($E_{0.1}$ = 0.46). However, the exploitation rate with a maximum productive yield (E_{max} = 0.57) is lower than the exploitation rate (E = 0.77) for the population of *S. intermedius.*

DISCUSSION

Descriptive statistics of sizes

The monthly distribution of fish abundances showed important variation. The high abundances of *S. mandibularis* and *S. intermedius* were recorded in September, August October, and November. These months corresponded to the rainy and flood season at the Aghien Lagoon (Ettien, 2010). According to Ouattara

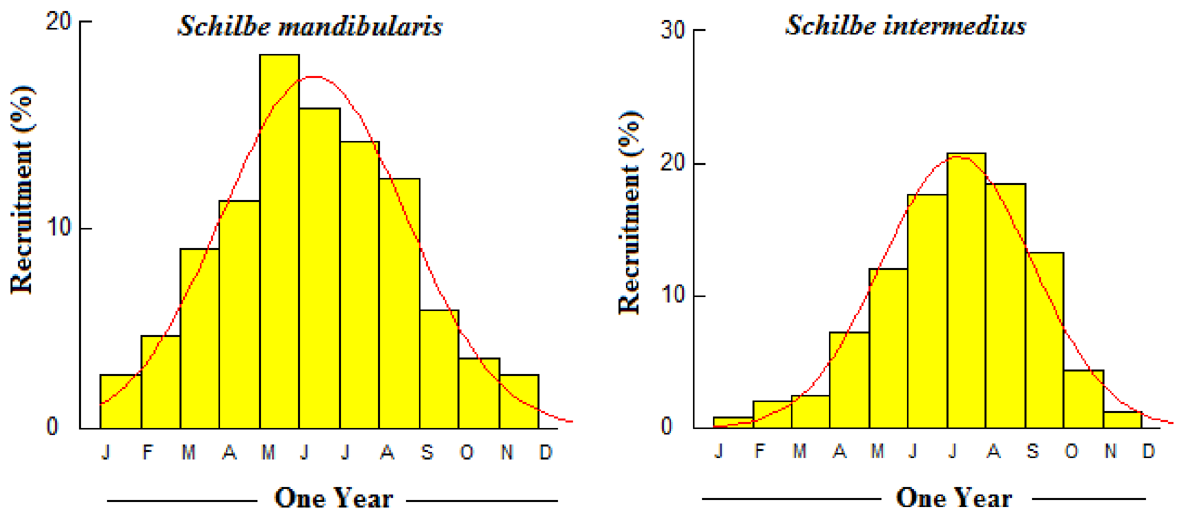


Figure 4. Recruitment patterns of *S. mandibularis* and *S. Intermedius* from the Aghien Lagoon.

Table 3. Monthly values of recruitment percentages for *S. mandibularis* and *S. intermedius* from the Aghien Lagoon.

Species	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
S. mandibularis	2.66	4.57	8.90	11.19	18.42	15.74	14.22	12.21	5.75	3.57	2.76	0.00
S. intermedius	0.79	2.08	2.46	7.15	12.01	17.52	20.72	18.29	13.20	4.56	1.22	0.00

Jan: January; Feb: February; Mar: March; Jun: June; Aug: August; Sept: September; Oct: October; Nov: November; Dec: December.

Table 4. Estimated optimum exploitation rates and related coefficient rates.

Species	E_{max}	$E_{0.1}$	$E_{0.5}$	$Lc/L\infty$	M/K	Z/K
S. mandibularis	0.53	0.46	0.17	0.32	1.41	2.65
S. intermedius	0.57	0.45	0.33	0.38	1.14	4.85

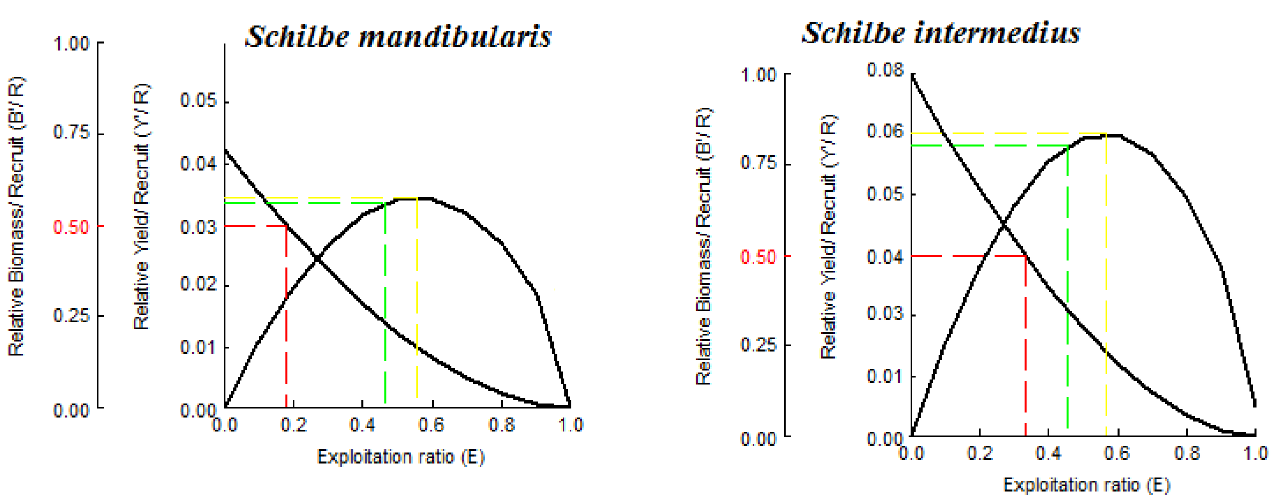


Figure 5. Relative yield per recruit and relative biomass per recruit for *S. mandibularis* and *S. intermedius* from the Aghien Lagoon, as computed using Ogive selection method.

(2000), Ahouanssou et al. (2011) and Tossavi et al. (2015), the period of the rainy and flood season coincided with the reproduction of *S. mandibularis* and S. *intermedius.* In addition, Ouattara (2000) indicated that periods of rainfall and breeding would stimulate fish aggregation, which could explain the high abundance of *S. mandibularis* and *S. intermedius* in catches during this period. Size is a relevant parameter for analyzing trends in a farmed fish community (Enin et al., 2004). In this study, the maximum size recorded for *S. mandibularis* (204 mm SL) was smaller than that recorded by Doumbia (2003) in the Bia River (500 mm SL). Concerning *S. intermedius*, the maximum size (174 mm SL) was smaller than that obtained by Ahouanssou (2011) in the Pendjari River (269 mm SL). For *S. mandibularis* and *S. intermedius*, most of the catches at the Aghien Lagoon were composed of small individuals that could be juveniles. This observation could be explained by the fishing pressure that could modify the size spectrum of the target fish populations in favor of small individuals (Shin et al., 2005).

Mortality rates and exploitation ratios

Analysis of the Z/K ratio (Z/K = 2.65 for *S. mandibularis*; Z/K = 4.85 for *S. intermedius*) indicated that mortality was predominant over growth for the two species (Barry and Tegner, 1989). Several studies have shown the predominance of mortality on the growth of *S. mandibulais* and *S. intermedius* stocks in some West African waters. Tah et al. (2010) reported a predominance of mortality (Z/K = 5.71) in the *S. mandibularis* population of Ayamé Lake. With regard to *S. intermedius*, the predominance of mortality was also reported by Etim et al. (1999) and Ahouanssou (2011), respectively in the Cross River of Nigeria (Z/K = 6.37) and Pendjari River of Benin (Z/K = 3.74). However, total mortality (Z) was higher in *S. intermedius* during this study. According to Laevastu and Favori (1998), the intense mortality suffered by these two species could be due to predation and high fishing pressure. Otherwise, for the population of *S. mandibularis*, the fishing mortality rate (F= 0.51 $year^{-1}$) was close to the natural mortality rate (M = 0.58 $year^{-1}$), indicating that the stock of *S. mandibularis* was in an optimum state of exploitation. According to Gulland (1971), the stock of a fish species reaches its optimal exploitation level when the fishing mortality is equal to the natural mortality. The optimum exploitation status recorded for *S. mandibularis* differed from that of Tah et al. (2010), which reported overexploitation in the Ayamé Lake of E = 0.59. In contrast, for *S. intermedius* stock, the exploitation rate recorded (E = 0.77) was higher than the optimum exploitation rate (E_{opt} = 0.50) recommended by Gulland (1971). This result indicated overexploitation for this species in the Aghien Lagoon. Our results differed from that of Ahouanssou (2011) which reported a state of under exploitation for *S. intermedius* in the Pendjari River with an exploitation rate of 0.40.

Probabilities of capture

The length at first capture (Lc) (that is, the length at which 50% of fish population is vulnerable to capture) of *S. mandibularis* species (Lc = 69.65 mm SL) was lower than the first maturity size reported by Ouattara et al. (2008) in the Bia River (L_{50} = 154.33 mm SL for females and L_{50} = 135.5 mm SL for males). For *S. intermedius*, the first capture size (Lc = 78.53 mm SL) was lower than those reported by Merron and Mann (1995) in Okavango Delta in Botswana (Lc = 173 mm SL for females and Lc = 143 mm SL for males). For a population of *S. mandibularis* and *S. intermedius*, these results indicated that the fishing gears used in the Aghien Lagoon targeted mainly individuals that had not yet made their first breeding. These results could also be explained by their economic interest for fishermen. In all cases, the fact that the first capture size of the two species was lower than the first maturity sizes recorded in the literature may not ensure a constant renewal of their stocks in the Aghien Lagoon. The diagnosis of fishing through analysis of the $Lc/L\infty$ ratio ($Lc/L\infty$ = 0.32 for *S. mandibularis*; $Lc/L\infty$ = 0.38 for *S. intermedius*) revealed that this ratio was less than 0.5 in both species. This result, according to Moreau and Cuende (1991), this observation indicated that catches in *S. mandibularis* and *S. intermedius* were dominated by small individuals.

Recruitment pattern

The studied fish exhibited a single annual recruitment peak. This result reflected a single breeding season for the two species. Tah et al. (2010) reported that *S. mandibularis* had two annual recruitment peaks in the Lake Ayamé. This observation is consistent with Pauly's (1982) assertion that tropical fish exhibit annual double recruitment. The periods of intense recruitment of *S. mandibularis* and *S. intermedius* coincided with the rainy season, when trophic conditions become better for juvenile's growth. This situation had been reported by some studies on the reproduction of tropical fish in Africa (Tedesco and Hugueny, 2006; Ahouanssou et al., 2011).

Relative yield per recruit and relative biomass per recruit

Analysis of the relative yield per recruit based on the model of Beverton and Holt (1966) using the Ogive selection revealed that the exploitation rate for *S. mandibularis* (E = 0.47) was quite equal to the rate exploitation of $E_{0.1}$ ($E_{0.1}$ = 0.46), showing an optimum state of exploitation. Concerning *S. intermedius*, the relative yield per recruit analysis showed that the exploitation rate (E = 0.77) was higher than the maximum exploitation rate (E_{max} = 0.57). These results indicated overexploitation for this species in the Aghien Lagoon. As shown in our results, the theoretical exploitation rate of E_{50} that maximises surplus production using relative biomass per recruit was equal to 0.17 and 0.33, respectively for *S. mandibularis* and *S. intermedius*. Both values were lower than the exploitation rate recorded for each species. This result indicated that the relative biomass per recruit for both species in the Aghien Lagoon were below the required value recruits. It can be concluded that the renewal of the stocks of the two species were compromised in the Aghien Lagoon.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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