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Full Length Research Paper

Stochastic modelling of Lake Malawi *Engraulicypris sardella* (Gunther, 1868) catch fluctuation

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Lake Malawi continues experiencing serious depletion of most valuable fish species. Presently, commercial and artisanal fishery are forced to target less valuable fish species. Evidently, economic importance of *Engraulicypris sardella* in Malawi cannot be negated as it currently contributes over 70% of the total annual landings. However, such highest contribution could be a sign of harvesting pressure. Therefore, as the species continues being increasingly exploited, the development of scientific understanding through application of stochastic models is particularly relevant for present and future policy making and formulation of strategies to sustain the resource in the lake. Thus, the study was designed to forecast the annual catch trend of *E. sardella* from Lake Malawi. The study used time series data from 1976 to 2015 period obtained from Monkey Bay Fisheries Research Station of the Malawi Fisheries Department. The study adopted Box-Jenkins procedures to identify appropriate Autoregressive Integrated Moving Average (ARIMA) model, estimate parameters in ARIMA model and conducting diagnostic check. The study findings showed that ARIMA (2,1,1) model had least *Normalized Bayesian Information Criterion* (NBIC) value making it a appropriate model for the study. ARIMA (2,1,1) model showed that *E. sardella* annual catches are positively fluctuating. Again, the model predicted that *E. sardella* annual catches from Lake Malawi will increase from the annual total landings of 71,778.47 metric tons to 104,261.20 metric tons in the next 10 years (*ceteris paribus*).

Key words: Box-Jenkins, *Engraulicypris sardella*, Lake Malawi, autoregressive integrated moving average (ARIMA), Modelling, Usipa, Stochastic.

INTRODUCTION

Engraulicypris sardella locally known as Usipa is one of the endemic fish species in Lake Malawi. The species

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belongs to the Cyprinid family. Literature suggests that the biology of *E. sardella* is very contentious. In early 1960s, Iles (1960) noted that the life cycle of *E. sardella* can normally be completed within 1 year. However, Morioka and Kaunda, (2004) argued that the species has an extended breeding periods. Morioka and Kaunda, (2004) further claimed that the fact that the species has an extended breeding periods is a strong evidence of the existence of plural stocks meaning that different stocks of *E. sardella* may adapt to the different optimum temperature for reproduction. However, because fisheries scientists, ecologists and managers have not yet found a substantial evidence on this contentious biology and life span of *E. sardella*, it has been difficult to set management recommendations and strategies to sustain *E. sardella* stocks in Lake Malawi. Similar observation was made by Allison et al (1996). Unfortunately, the economic importance of *Engraulicypris sardella* in Malawi cannot be negated as it currently contributes over 70% of the total annual landings (Department of Fisheries, 2017). Furthermore, it has been noted that fish catches in the past two years have shown a positive catch fluctuation with estimated annual catch of 30,000 metric tonnes to 80,000 metric tonnes as of 2010 and a significant catch contribution has been from *E. sardella* and *Haplochromine species* (GoM, 2015). On the other hand, it has also been noted that Lake Malawi continues experiencing serious depletion of most valuable fish species. Presently, both commercial and artisanal fishery have been forced to target less valuable fish species such as *E. sardella* and *Haplochromine species* (Hara and Njaya, 2016). It is very apparent that the shifting will consequently increase harvesting pressure on the resource. Therefore, as the species continues being increasingly exploited, the development of scientific understanding through application of stochastic models is relevant for present and future policy making and formulation of strategies to sustain the resource in the lake (Cohen and Stone, 1978). Thus, the study was designed to forecast the annual catch trend of Lake Malawi *E. sardella* using stochastic models.

MATERIALS AND METHODS

Data collection

Figure 1 shows *E. sardella* data collection points. Literature shows that Malawi Department of Fisheries started collecting *E. sardella* catch data in early 1970s from beach recorders using a random sampling technique introduced by FAO (Bazigos, 1972). However, it was noted that data collected from the beach recorders during 1970s to 1975 were not tested for its statistical realiability (Bazigos, 1972). Because of such suspicions, the study used the time series data of *E. sardella* total landings from 1976 to 2015 period. The data was obtained from Monkey Bay Fisheries Research Station of the Malawi Fisheries Department. The unit of measurement referred to the weight of fish at the time of removal from water was expressed in metric tons. For the purpose of data collection, Lake Malawi is coded into several sections also known as strata (refer to Figure 1). *E. sardella* data is collected by employing random selection of a series of landing sites within each established sampling frame taking into consideration the mobility patterns among the fishermen within the fishing community.

The actual survey at each sampling site includes all crafts/fishing gears or in the case of larger fishing communities sub-sampling of the crafts/fishing gears. It is very important to note that Mangochi district only uses gear based sampling called Malawi Traditional Fishery (MTF) and the rest of the districts use craft based sampling known as Catch Assessment Survey (CAS). The survey is conducted by the actual weighing of the catch of the selected landings and interviewing the fishermen especially on the effort exerted to produce the landed catch.

Stationarity test

To check whether *E. sardella* time series data needed to be differenced to make it stationary or not, Dickey-Fuller t-statistics test was carried out. The mathematical model of -Dickey- Fuller test is given below (Dickey and Fuller, 1976):

$$DF_{\tau} = \frac{\hat{\gamma}}{SE(\hat{\gamma})} \qquad (1)$$

The Dickey-Fuller t-test was based on the fact that accepting null hypothesis implies that the data needs to be differenced to make it stationary.

Derivative of stochastic models

Autoregressive (AR) *model*

As suggested by Box and Jenkins, the *(AR)* which is a component of ARIMA model was mathematically expressed as (Box and Jenkins, 1970):

$$X_t = c + \sum_{i=1}^{p} \emptyset_i X_{t-i} + \varepsilon_t \qquad (2)$$

$\emptyset_1, \ldots, \emptyset_p$ are *autoregressive* parameters, c is given as constant and the random variable and ε_t is the white noise error.

Moving average (MA) model

The MA model was defined as (Box et al. 2015):

$$X_t = \mu + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} + \varepsilon_t \qquad (3)$$

$\theta_1 \ldots \theta_q$ are the *moving average* parameters of the model, μ is the expectation of X_t (often assumed to be equal to 0), and ε_t, ε_{t-i} are again white noise error terms.

The Autoregressive Moving Average (ARMA) Model

Autoregressive (AR) and *Moving Average* (MA) models were combined to form ARMA (p, q) model mathematically expressed as (Cochrane, 1997):

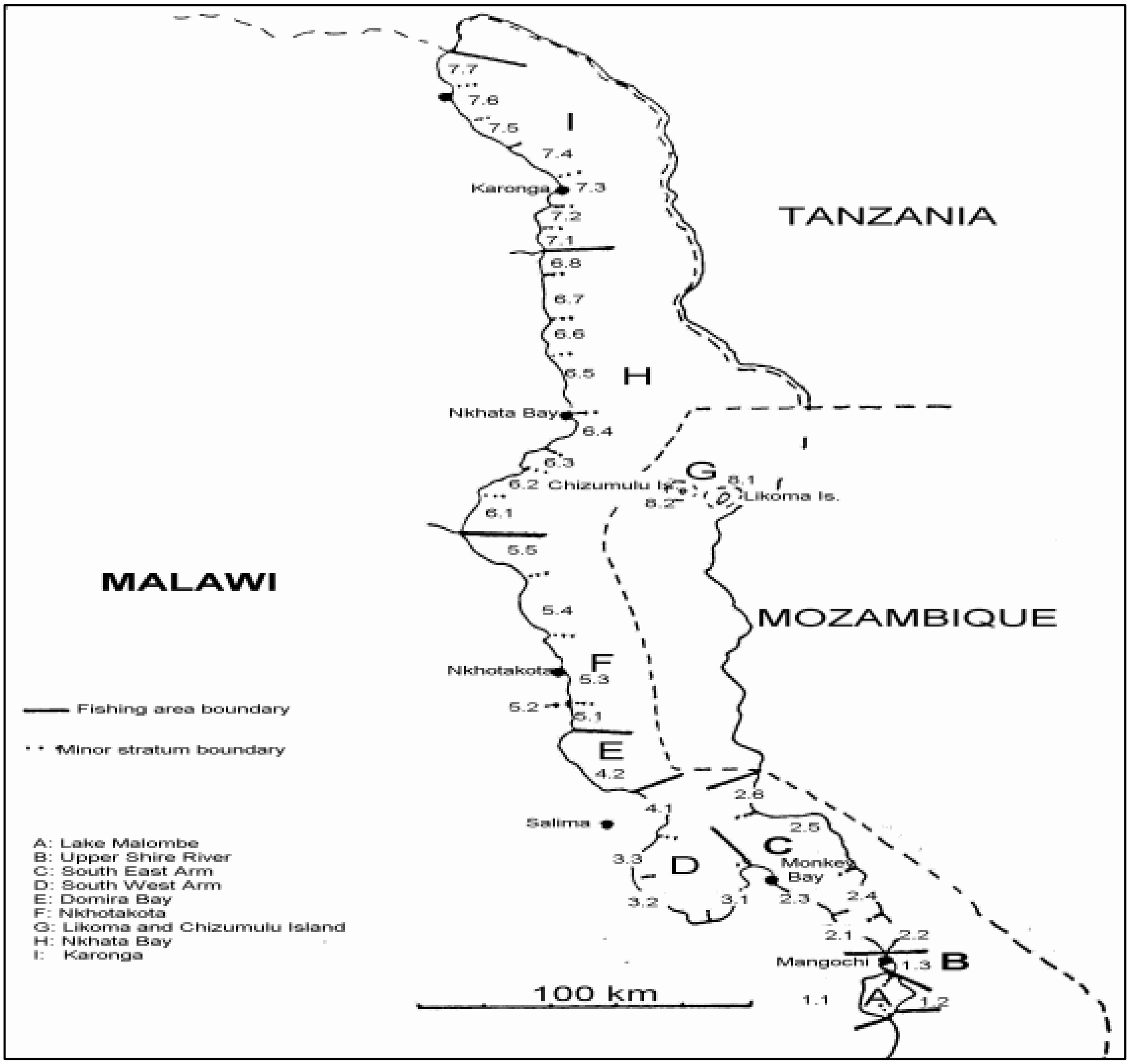

Figure 1. Lake Malawi *E. sardella* data collection points (Kanyerere et al., 2001).

$$Y_t = c + e_t \sum_{i=1}^{p} \varnothing_i Y_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} \dots\dots\dots\dots \quad (4)$$

here *p, d* and *q* are integers greater than or equal to zero and refer to the order of the autoregressive, integrated and moving average parts of the model respectively. The integer *d* controls the level of differencing.

The Autoregressive Integrated Moving Average (ARIMA) Model

In ARIMA models, a non stationary data is made stationary by applying log-difference transformation (Minović, 2008) or finite differencing which transforms non stationary time series data into stationary (Stoffer and Dhumway, 2010). The general mathematical expression of ARIMA (*p, d, q*) model is (Lombardo and Flaherty, 2000):

$$\left(1 - \sum_{i=1}^{p} \varphi_i L^i\right)(1 - L)^d Y_t = \left(1 + \sum_{j=1}^{q} \theta_j L^i\right) \varepsilon_t \dots \quad (5)$$

Model Identification

This procedure employs Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots (Stoffer and Dhumway, 2010). These plots helped to determine the order of AR and MA terms (Makwinja et al. 2017). The autocovariance of a time series $x_1, x_2 \dots\dots\dots\dots x_n$ is defined for $v < n$ as:

$$\hat{R}(v) = \frac{1}{n} \sum_{i=1}^{n-v} (x_i - \bar{x})(x_{i-v} - \bar{x}) \quad (6)$$

where $\bar{x}$ is the sample mean. The autocorrelation function is then defined as:

Table 1. Augmented Dickey-Fuller test for unit root.

Variable	Test statistics	1% Critical value	5% critical value	10% critical value	
Z(t)	1.901	-2.639	-1.950	-1.915	
		MacKinnon approximate p-value for Z(t) = 0.0000			
D.catch (tons)	**Coef**	**Std. Err**	**t**	**p>|t|**	**[95% CI]**
L1	0.1244081	0.0654558	1.9	0.065[ns]	-0.0083426, 0.2571587
LD	-0.1047851	0.1449183	-0.86	0.340[ns]	-0.9986931, -0.4108771

$$\hat{\rho}_{\gamma} = \frac{\hat{R}_{\cdot\gamma}}{\hat{R}_{\cdot 0}} \quad (7)$$

Another measure, *Partial Autocorrelation Function* (PACF) is presented in form of plot of $\emptyset_{kk}\ vs\ k$.

Parameters estimation

The Maximum Likelihood test (ML), least square estimation method and Yule-Walker statistical procedures were used to estimate the parameters and the corresponding standard errors.

Diagnostic checking

Box and Jenkins (1970) developed a practical approach to build ARIMA model, which best fit a given time series and also satisfy the parsimony principle. Generally, this step involved the analysis of the residuals as well as model comparisons (Chang et al., 2012). The Ljung-Box Q was used in the diagnostic test. Mathematically, the Ljung-Box Q was expressed as (Box et al. 2015)

$$Q^{*} = n(n-2)\sum_{k=1}^{m}\frac{\hat{\rho}^{2}_{k}}{n-k} \quad (8)$$

where $\hat{\rho}_k$ is the estimated autocorrelation of the series at lag k and m is the number of lags being tested.
The hypothesis of Ljung-Box test was:

H_0: Residual is white noise
H_1: Residual is not white noise

If the sample value Q exceeds the critical value of X^2 distribution with m degree of freedom, then at least one value of ρ is statistically different from zero at the specified level of significance.

Again, Bayesian Information Criterion (BIC) was employed to evaluate the adequacy of AR, MA and ARIMA processes. Bayesian Information Criterion (BIC) developed by Gideon Schwarz (Schwarz, 1978) was used to select the model among a finite set of models. BIC model was computed as

$$\boldsymbol{BIC(p)} = n\ln\left(\hat{\sigma}_e^2/n\right) + P + P\ln(n) \quad (9)$$

where, n is the number of effective observations used to fit the model, p is the number of parameters in the model and $\hat{\sigma}_e^2$ is the sum of sample squared residuals. Given the estimated models, the model with lower value of BIC is preferred (Clement, 2014).

Model fitting and Prediction

Upon identification of optimum model and estimating all parameters, the forecast of *E. sardella* catch landing from 2015 to 2025 was made. All inferential and descriptive statistics were performed using STATA 14 (StataCorp, 2015)

RESULTS AND DISCUSSION

Stationarity test

The stationarity test was done by applying Dickey-Fuller statistical test. The test was done to determine whether time series data had a unit root or not (Hamilton, 1994). The results are presented in Table 1.

The basic null hypothesis of Dickey-Fuller statistical test was that *E. sardella* time series data had a unit root. According to Dickey and Fuller (1976), if unit root is found in a series, it implies that more than one trend is present in the series. As seen from Table 1, the Z-score yielded by the Dickey-Fuller statistical test showed that *E. sardella* time series data had a unit root. The Z(t) test statistics fell within the range of acceptance interval $-2.639 > -1.915$ which explained that the data had to be differenced to make it stationary. Furthermore, Figure 2 shows that the mean of the series appears to be non-stationary with an average return not equal to zero.

To transform the data from non stationary to stationary, first order differencing of the data was conducted using natural logarithms (Box et al. 1978). The results are presented in Figure 3. Enders (2004) noted that the first-differencing of the time series data mitigates the effects of the trend and controls seasonarity. Figure 2, shows that the mean of the series were stationary with an average return of approximately zero. The autoregressive model of order p(AR (q)) was stationary and moving average model of order q(MA (q)) was perfect.

Model Identification

As seen from Figure 2, the autocorrelation and partial

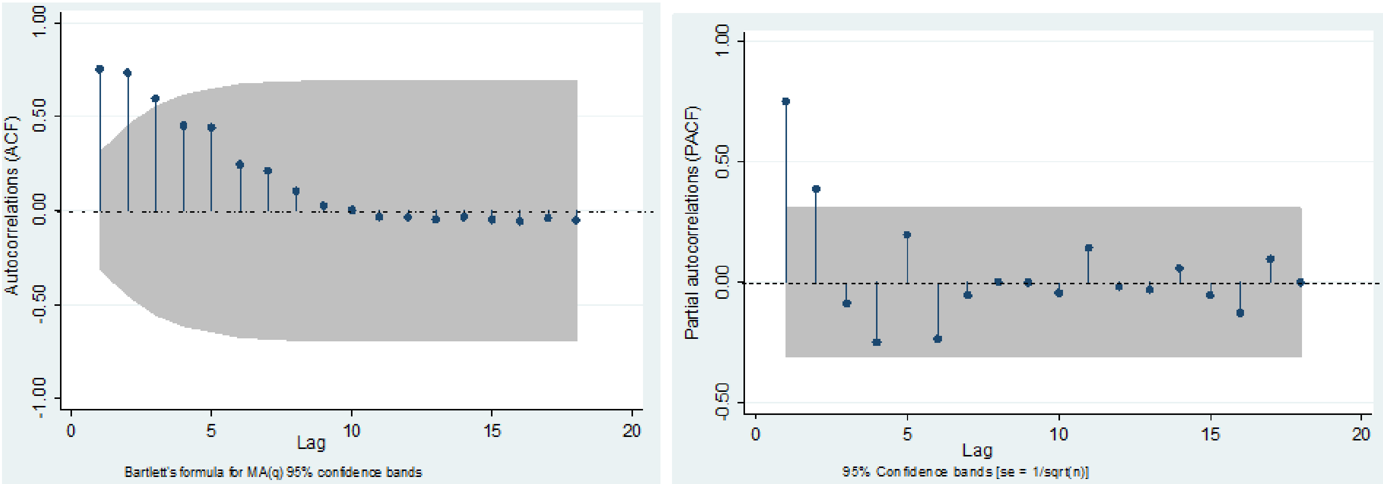

Figure 2. Autocorrelograms and partial autocorrelograms of undifferenced *E. sardella* time series data.

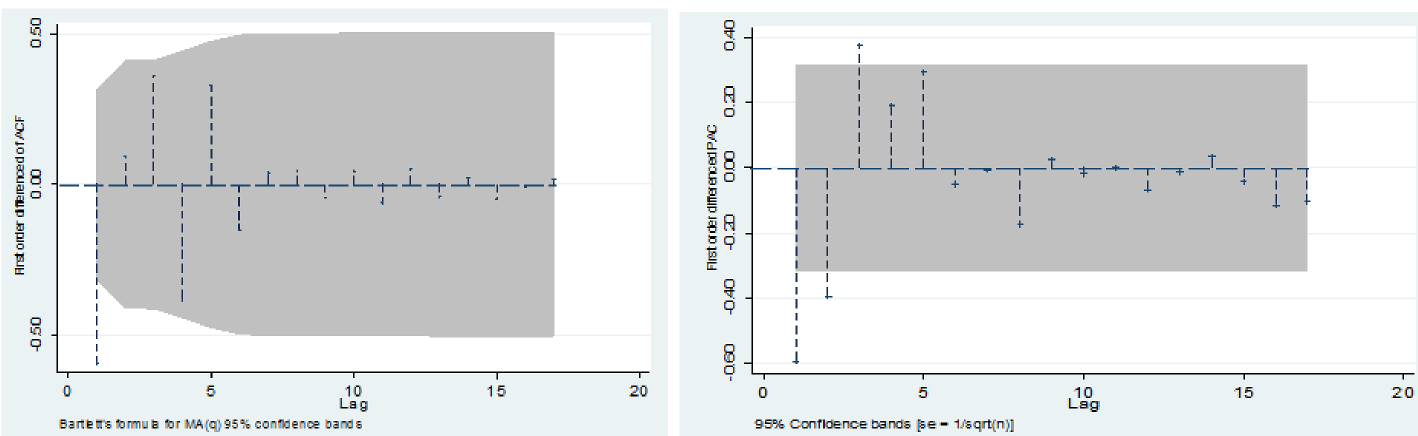

Figure 3. Autocorrelograms and partial Autocorrelograms of first order differenced data.

autocorrelation coefficients (ACF and PACF) were ploted and the type and order of the adequate model required to fit the series was determined. Table 2 shows the autocorrelation and partial autocorrelation coefficients (ACF and PACF) of various orders of differenced series of data.

The coefficients presented in Table 2 were used to identify various ARIMA models together with their corresponding fit statistics. Table 3 shows the results of various competing ARIMA models. It was very interesting to note that ARIMA (2,1,1) model in Table 3 was the best model among all other competing models.

Table 4 shows the estimated values of the ARIMA (2,1,1) model. The Ljung-Box Statistic test of ARIMA (2,1,1) model was not signficantly (p>0.05) different from zero. The P. value was significantly higher (**0.985)** comparing to the critical value (0.05). This implied that the null hypothesis of white noise, had to be rejected. Rejecting the null hypothesis of white noise implied that the ARIMA (2,1,1) model was capable of adquately capturing the correlation in the time series. According to Czerwinski et al (2007), the residuals were independently distributed in the population from which sample size was taken. It was further noted that the coefficients of parameters of ARIMA (2,1,1) model were all significant (p<0.05) and had least Normalised BIC value. Czerwinski et al (2007) suggested that the best ARIMA model with accurate forecasts must have lowest Normalised BIC and model parameters must be significant (p<0.05). This presents a substantial justification why the ARIMA (2,1,1) model was mostly prefered in the study.

Model Diagnostic Check

The ARIMA (2,1,1) model was further subjected to

Table 2. ACF and PACF for time series data of Lake Malawi *E. sardella* annual catch fluctuation.

LAG	AC	PAC	Q	Prob>Q	[Autocorrelation] -1 0 1	[Partial Autocor] -1 0 1
1	-0.5914	-0.5914	14.719	0.0001		
2	0.0928	-0.3953	15.091	0.0005		
3	0.3619	0.3731	20.909	0.0001		
4	-0.3838	0.1911	27.638	0.0000		
5	0.3303	0.2963	32.769	0.0000		
6	-0.1503	-0.0507	33.863	0.0000		
7	0.0384	-0.0067	33.937	0.0000		
8	0.0446	-0.1745	34.04	0.0000		
9	-0.0432	0.0250	34.139	0.0001		
10	0.0434	-0.0172	34.243	0.0002		
11	-0.0606	0.0013	34.452	0.0003		
12	0.0544	-0.0684	34.627	0.0005		
13	-0.0400	-0.0138	34.726	0.0009		
14	0.0214	0.0346	34.755	0.0016		
15	-0.0467	-0.0424	34.9	0.0025		
16	-0.0064	-0.1148	34.903	0.0041		
17	0.0180	-0.1038	34.927	0.0064		

Table 3. Various competing ARIMA models

ARIMA (p, d, q)	NBIC	Ljung-Box Q (P-value)
ARIMA (1,1,1)	18.39	0.962^{ns}
ARIMA (2,1,1)	**18.34**	**0.985^{ns}**
ARIMA (3,1,1)	18.43	0.985*
ARIMA (1,2,1)	19.89	0.019**
ARIMA (2,1,2)	18.47	0.017**

^{ns}Non-significant, *significant at P<0.01.

Table 4. Lake Malawi *E. sardella* estimated ARIMA (2,1,1) model paramters.

Variable	Estimate	Std Error	t.value	p.value
Constant	5.73	2.39	2.39	0.020*
AR				
Lag 1	-0.81	0.38	-2.10	0.045
Lag 2	0.47	0.21	2.14	0.039
Difference	1			
MA	0.396	0.44	2.15	0.034*

^{ns}Non-significant, *significant at P<0.01.

autocorrelations and partial autocorrelations of residuals of various orders. Figure 4 shows the various autocorrelations of up to 24 lags. From the plots of the residual ACF and PACF, it was very apparent that, the ARIMA (2,1,1) model was confirmed to be adequate in the sense that the points below and above were all uneven suggesting that the model was fit. Also, the individual residual autocorrelations were very small and generally within 95% level of confidence suggesting that the selected model was fit.

Forecasting

The ARIMA (2,1,1) model forecasted *E. sardella* total landings from 1976 to 2025. For the preciseness and accurateness sake, observations only from 2013 to 2025 have been presented in Table 5.

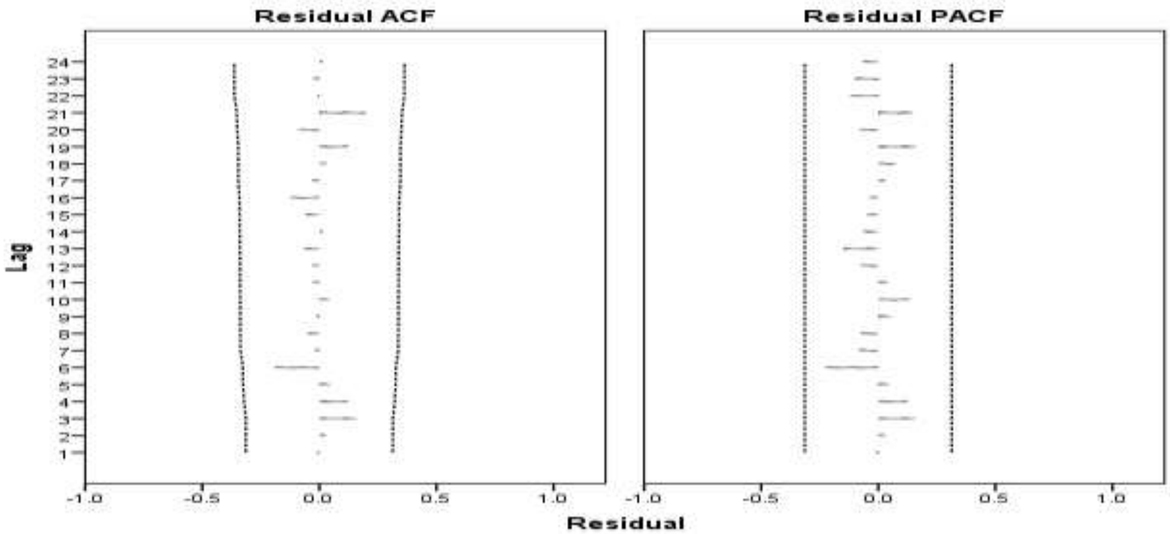

Figure 4. ACF and PACF residual.

Table 5. *E. sardella* total catch forecasted values (metric tons).

Date (Year)	Predicted values	95% Confidence interval
2013	76627.75	(0.31, -0.31)
2014	52305.19	(1.28, -1.09)
2015	71778.47	(0.84, -0.79)
2016	76351.72	(0.18, -0.08)
2017	70586.10	(1.62, -1.55)
2018	80946.38	(0.16, -0.83)
2019	82983.03	(1.86, -0.96)
2020	84256.27	(0.22, -0.23)
2021	90384.81	(0.77, -0.84)
2022	92995.75	(0.32, -0.39)
2023	96321.19	(0.58, -0.67)
2024	100914.39	(0.44, -0.59)
2025	104261.20	(0.25, -0.38)

Figure 5 shows the forecasted value from 1976 to 2025. Figure 5 further shows that *E. sardella* total landing is fluctuating with positive trend as it decreases and increases at some point. The model (2,1,1) in Figure 5 further predicted that there is high probability that *E.sardella* catches from Lake Malawi will increase up to 104261.20 metric tons by 2025. The positive annual catch trend depicted by the model could be a sign of harvesting pressure exerted upon the species by the fishers. Figure 6 shows that there has been stability in total annual landings from 1993 to 2004. The lowest *E. sardella* total annual landing was recorded in the year 1993 and the highest in the year 2015. Generally, E. *sardella* total annual landings fluctuation has been showing positive trend from 2004 to 2015 with some troughs in 2011 and 2012 and then another drop two years later. It has been noted that low efficiency to harvest the field was reported from 1993 and lasted for11 years. As observed by Hara and Njaya (2016), the positive trend of *E.sardella* total landings among other reasons could be attributed to the fact that many fishers are currently targeting usipa much more than utaka because of the far much better catches of the former compared to the latter for similar effort.

In fisheries and conservation biology, the catch per unit effort is an indirect measure of how abundant a targeted species is (Puertas and Bodmer, 2004). In other words, the fishing efficiency which is known as catch per unit effort (CPUE) is an index of abundance which to some extent provide relevant information on how much fish is in

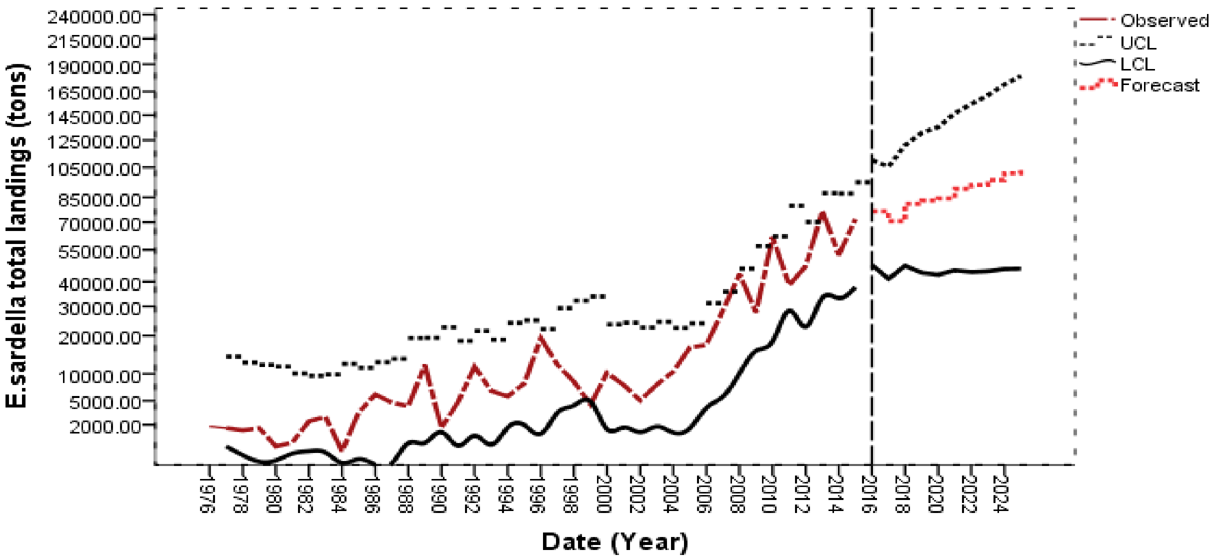

Figure 5. Predicted *E.sardela* catch trend from 1976 to 2025.

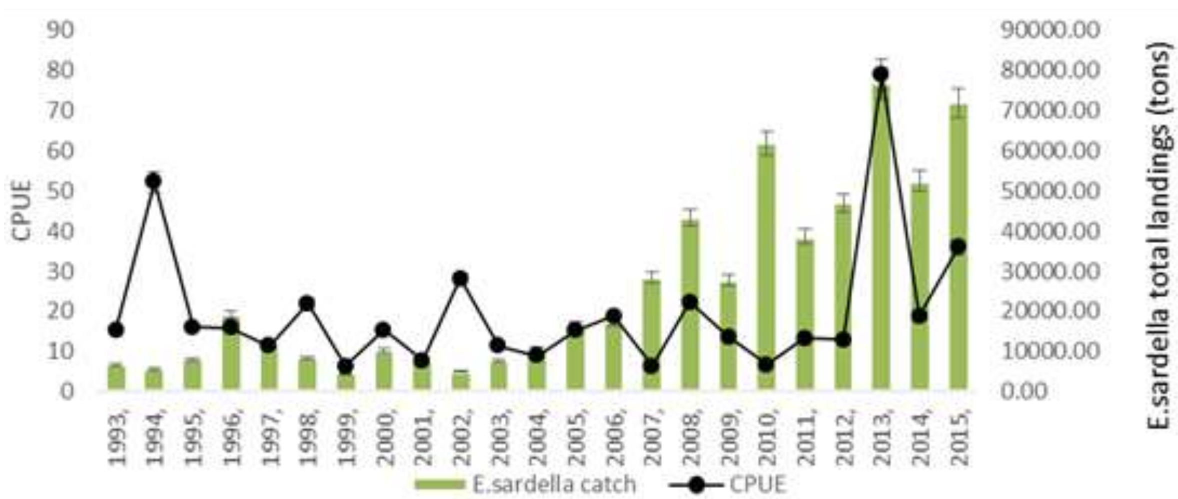

Figure 6. *E. sardella* catch (tons) and CPUE relationship.

the water. As seen from Figure 6, the CPUE of *E. sardella* has been fluctuating throughout. Such fluctuation indicates that *E.sardella* population diversity is unstable. As seen from Figure 5, CPUE fluctuated positively from 1993 to 1994 and from 1994 to 1995, the CPUE trend decreased rapidly and since then, there has been a slight fluctuation up to 2012 despite increasing in *E. sardella* catches from 2007 to 2012. From 2012 to 2013, the CPUE trend increased and recorded highest in 2013 and also corresponded to the highest *E.sardella* total landings. The general increasing trend of CPUE in 2013 indicated that *E. sardella* fishery was in good health and the fishery was yet to reach its maximum sustainable yield (MSY).

From 2013 to 2014, the CPUE decreased sharply while *E.sardella* catch trend remained high. According to Puertas and Bodmer, (2004), deceasing in CPUE indicated overexploitation while increasing CPUE indicated underexploitation. However, if the CPUE were to register stable, then it could indicate sustainable harvesting. Since CPUE is unstable, it means that *E.sardella* fishery requires proper management plans because human population will obviously surpus (Malthus, 1798) the capacity at which *E. sardella* can reproduce and when that happens, such positive trend may likely collapse in the near future especially in the years of low recruitment.

Conclusion

The study findings showed that ARIMA (2,1,1) model had least *Normalized Bayesian Information Criterion* (NBIC) value making it a appropriate model for the study. ARIMA (2,1,1) model showed that *E. sardella* annual catches are positively fluctuating. Again, the model predicted that *E. sardella* annual catches from Lake Malawi will increase from the annual average level of 71,778.47 metric tons to an average of 104,261.20 metric tons in the next 10 years (*ceteris paribus*). However, regardless of the model projecting future positive fluctuation of *E. sardella* total landings, the catch per unit effort (CPUE) has been fluctuating throughout. Such fluctuation indicates that *E.sardella* population diversity is unstable and requires proper management plans because human population will obviously surpass the capacity at which *E. sardella* can reproduce and when that happens, such positive trend will likely collapse in the near future especially in the years of low recruitment.

RECOMMENDATIONS

Despite the fact that the ARIMA (2,1,1) model predicted that *E. sardella* total landings will increase for the next 10 years, the CPUE shows to be unstable, which means that *E. sardella* fishery requires proper management plans to ensure its sustainability.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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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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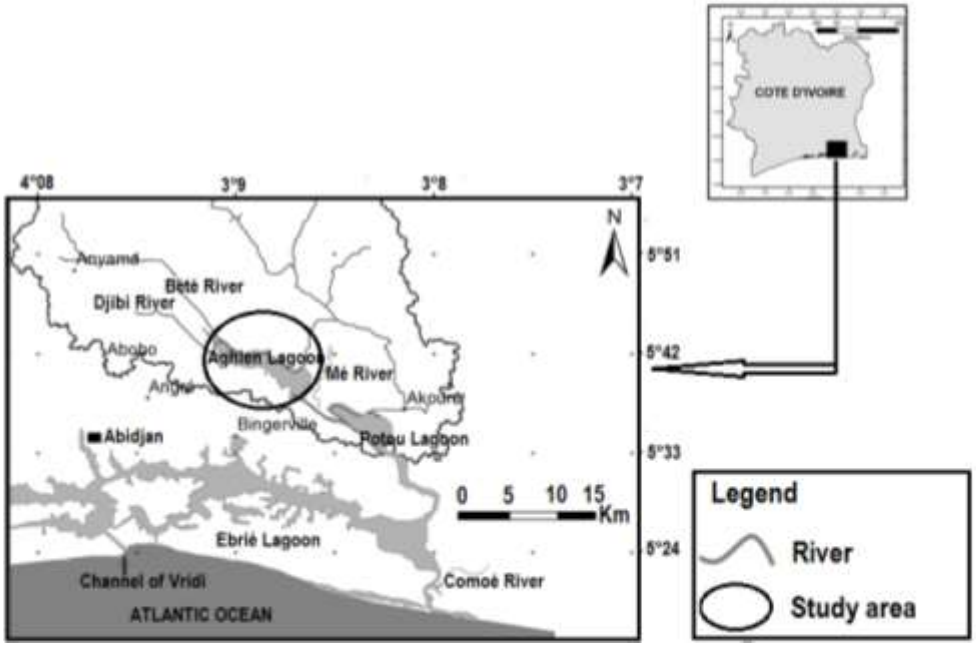

Figure 1. Location of Aghien Lagoon.

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.

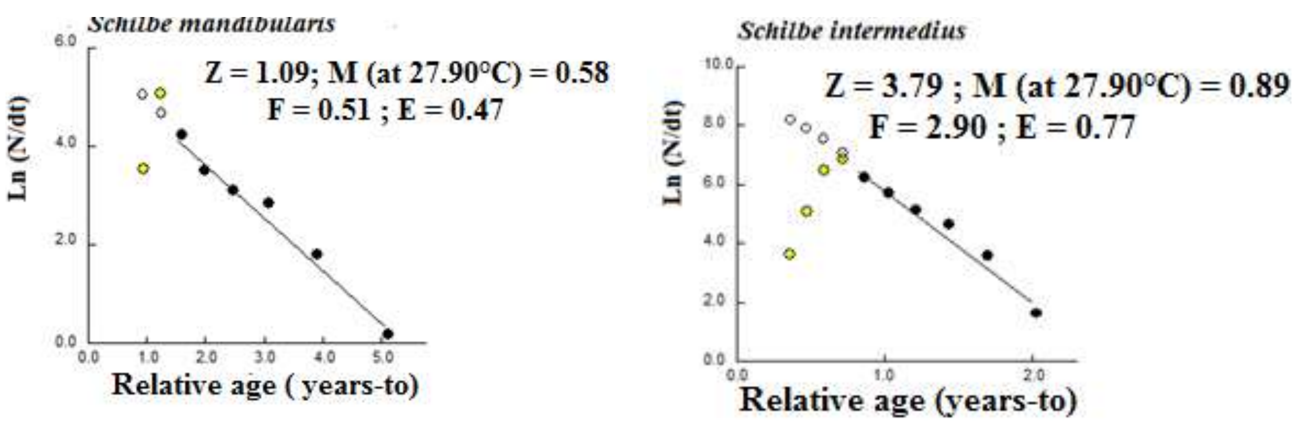

Figure 2. Length-converted catch curve for *S. mandibularis* and *S. intermedius* from the Aghien Lagoon.

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.

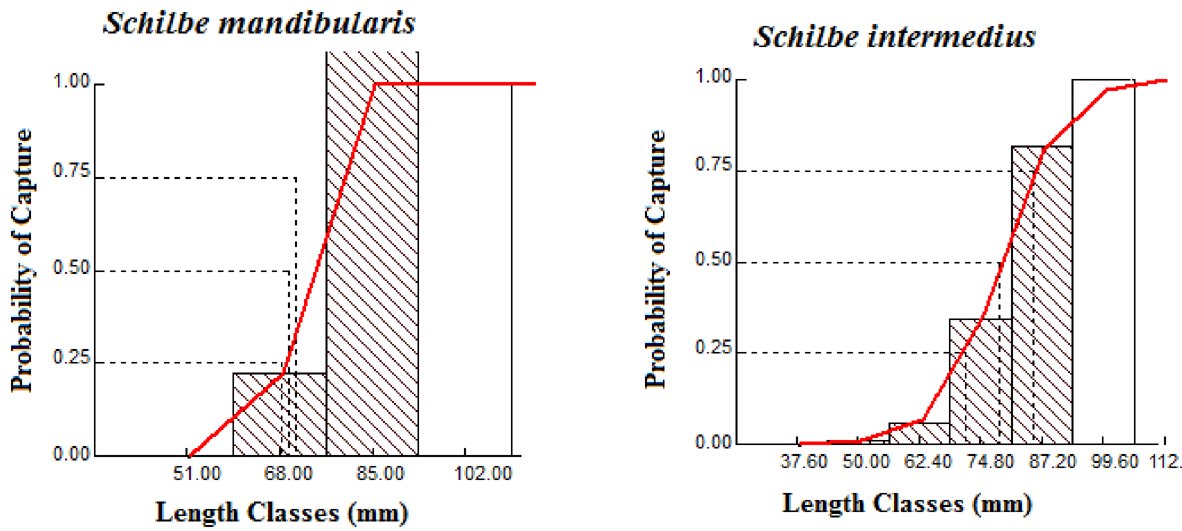

Figure 3. Logistic selection curve for probability of capture, showing 25, 50 and 75% selection length of *S. mandibularis* and *S. intermedius* from the Aghien Lagoon.

= 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

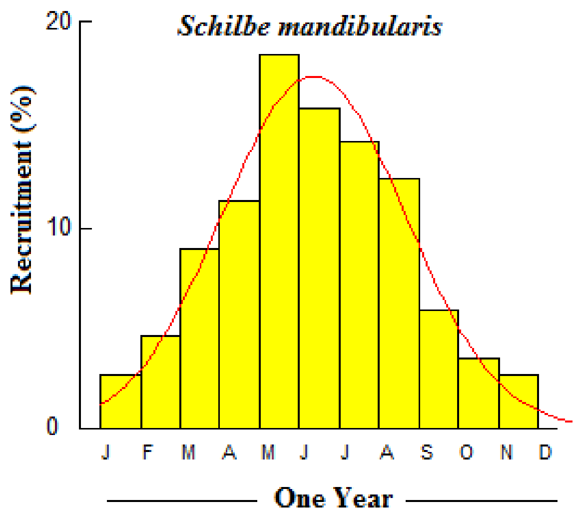

Figure 4. Recruitment patterns of *S. mandibularis* and *S. Intermedius* from the Aghien Lagoon.

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

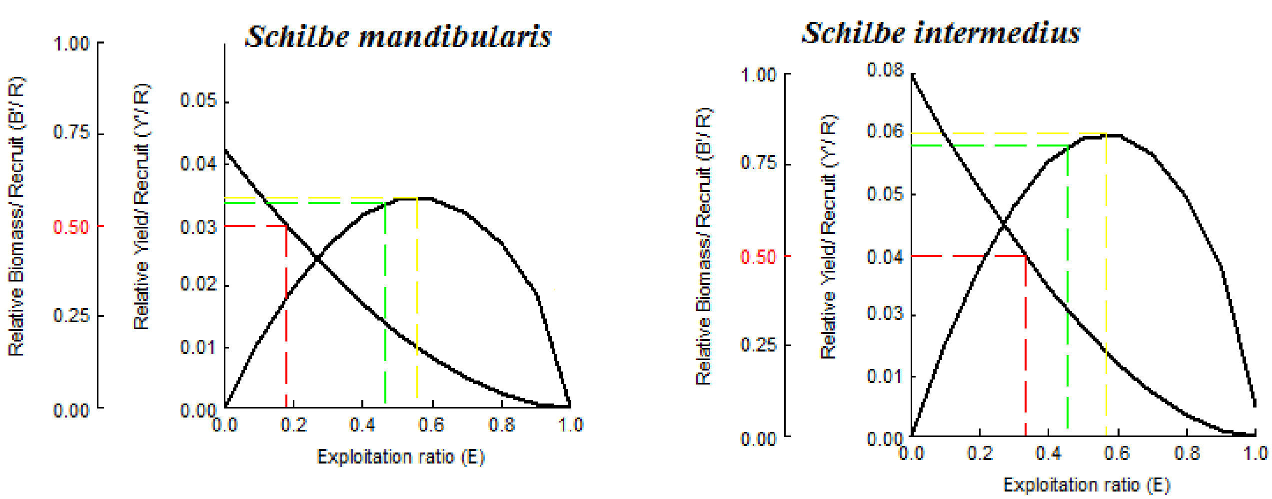

Figure 5. Relative yield per recruit and relative biomass per recruit for *S. mandibularis* and *S. intermedius* from the Aghien Lagoon, as computed using Ogive selection method.

(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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