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Growth Pattern, Mortality and Exploitation Rate of the Giant African Threadfin, *Polydactylus quadrifilis* (Cuvier, 1829) from Ebrié Lagoon (Potou Sector, Côte d'Ivoire)

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Authors' contributions

This work was carried out in collaboration among all authors. Author TAB designed the study and wrote the protocol. Author BC wrote the first draft of the manuscript and managed the literature research with author YAK. Authors EPK and VN managed the revision of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The study evaluated some population parameters of *Polydactylus quadrifilis* within Ebrié lagoon (Potou sector). Samples were obtained using artisanal gillnet fishery from April 2004 to March 2006. A total of 741 individuals of *P. quadrifilis* ranged from 11 to 70 cm were examined. Population parameters were estimated where asymptotic length ($L\infty$) was found 60 cm, growth rate (K) 0.33 per year, the longevity (T max) 9.09 years, and growth performance index (Φ′) 3.06. The length at first capture (Lc50 = 10.60 cm) was lower than the length at first maturity (Lm50 = 40 cm). Total mortality rate (Z) was calculated as 1.10 per year including natural mortality and fishing mortality. The exploitation rate (E=0.36) was found to be less than the maximum exploitation rate (E_{max} = 0.44) and indicated that *P. quadrifilis* is not overexploited. The current exploitation rate should be maintained by sustainable fisheries measures including monitoring of fishing effort.

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1. INTRODUCTION

Fisheries are important contributors to food security, livelihoods and employment, export earning and economic growth across the globe [1]. In West-Africa, the fishing industry is not only an important source of employment, revenue and social well-being [2] but it also represents an important source of food as fish constituted 53% of the animal protein intake on an average of the West African population [3]. In Côte d'Ivoire, the fisheries sectors contributed a lot in the national economy [4] through the production which has decreased since some years [5]. In fact, most of major commercial fish stocks are (or are close to being overfished) presently. Such observation was noticed in Côte d'Ivoire continental fisheries by [6]. This is expressed by a strong regression of catches in spite of increasing of fishing efforts and gears performance [7]. Polynemidae family which includes the giant African threadfin *P. quadrifilis* is constitutes by shallow water fishes of tropical waters. *P. quadrifilis* is known to occur in the tropical Eastern Atlantic from Senegal to Angola. It enters estuaries and occasionally can be caught in fresh water [8]. In Côte d'Ivoire, the current production of inland fisheries was stabilized around 7,800 tons/year with some main species among which *P. quadrifilis* [9]. The species is highly regarded for its delicacy and forms important commercial, recreational and subsistence fisheries. The challenge is to increase the production by using management plans. However the execution of such plans requires data on biology, growth and species mortalities and there is dearth of information on the *P. quadrifilis*, especially on this aspects in Ebrié lagoon (Potou sector). Therefore, the aim of this work was to investigate growth patterns, mortality parameters and exploitation rate of the giant African threadfin *P. quadrifilis* in Ebrié lagoon (Potou sector) for conservation and management measures.

2. MATERIALS AND METHODS

2.1 Study Area

The Ebrié Lagoon system comprises the Ebrié lagoon itself (523 km^2) and the Potou lagoon system (43 km^2), located between 5°15-5°27 N and 3°43-3°56 W [10] (Fig. 1). The climate of the study zone is an equatorial type and interannual precipitations rank above 1500 mm. This zone contains a significant hydrographic network, composed of the Bété, Djibi and Mé Rivers [11]. The most significant depths are recorded on the level of the channels connecting the Aghien lagoons and Potou (5 to 7 m) on the one hand and the Potou lagoon with the remainder of the lagoon Ebrié (7 m) [12].

2.2 Fish Sampling

Samples were collected between April 2004 and March 2006 during 3 to 4 days continuously per month in Ebrié Lagoon (Potou Sector). Moreover, monthly fish samples were collected from commercial landings at random using gillnets and beach seines. Fishermen were chosen by random and fishes in their catches were analyzed. Each specimen was identified to the species level by using [8-13] manual. Then each individual collected was measured for its standard length (LS) to the nearest 0.1 cm by using a fish measuring board. The fish specimens were individually weighed to the nearest 0.01g using an electronic weighing balance model FEL-500S. Length data were pooled monthly and converted into length frequencies with a constant class interval of 2 cm. The mean lengths and weights of the classes were used for data analysis using the format accepted by FiSAT [14].

2.3 Data Collection

2.3.1 Population structure

The size frequency was analyzed at a 2 cm interval total length class using a histogram to determine the type of distribution which characterizes the fish population.

2.3.2 Length –Weight Relationship (LWR)

The LWR of *P. quadrifilis* was estimated by using the equation:

$$BW=a\ SL^{b},$$

Where BW= body weight, SL=standard length, a is the intercept and b is the slop (growth coefficient). After logarithmic transformation of this relation ($\log_{10} BW=\log_{10} a + b \log_{10} SL$), parameters (*a)* and (*b)* were determined via least squares linear regression [15]. The 95% confidence limits for *b* (CL 95%) were computed

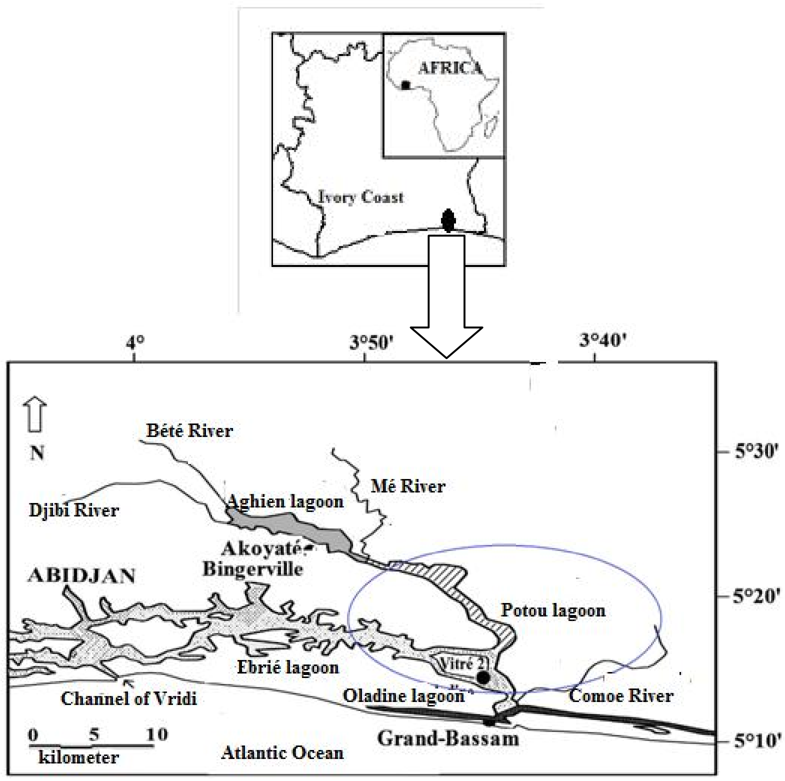

Fig. 1. Map of Ebrie lagoon showing sampling zone (Potou Sector)

using the equation: CL= $b \pm (1.96 \times SE)$ where SE is the standard error of *b*. In order to check if the value of *b* was significantly different from 3, the Student's t-test was conducted as expressed by the equation according to [16]: $ts=(b-3)/SE$, where *ts* is the t-test value, *b* the slope and SE the standard error of the slope *b*. If $b \neq 3$ so the growth is allometric (negative allometric if $b<3$ and positive allometric if $b>3$) and if $b=3$ so the growth is isometric.

2.3.3 Length at first maturity

The length at first maturity (Lm50) for the assessed species was estimated using the procedure by [17] as Length at first maturity (Lm50) = 2/3 * (L∞). The input parameters for the model included asymptotic length only (L∞).

2.3.4 Growth and mortalities parameters

The Electronic Length Frequency Analysis (ELEFAN) computer program incorporated into FAO-ICLARM Stock Assessment Tool (FiSAT) was used to estimate population parameters (mainly growth parameters, mortality and exploitation rates).The growth of *Polydactylus quadrifilis* was determined using the Von Bertanlanffy growth function (VBGF) given below:

$$L_t = L_\infty \left[1-e^{-K(t-t_0)}\right] \quad [18]$$

Where, Lt = length (cm) at age, t; L∞ = asymptotic length (cm); K = growth constant (yr^{-1}); to= theoretical age at length zero.

The estimates of L∞ and K were obtained using ELEFAN in the FiSAT software [14], while t_0 was estimated using:

$$\text{Log}(-t_0) = -0.392 - 0.275 \text{ Log } L_\infty - 1.038 \text{ Log } K \quad [19]$$

Using FiSAT program, the total mortality coefficient (Z) was estimated by linearized length-converted catch curve analysis [18]. Natural mortality of the fish stock in the lagoon was estimated using:

$$\text{Log } M = -0.0066 - 0.279 \text{ Log } L_\infty + 0.6543 \text{ Log } K + 0.4634 \text{ Log } T \quad [20]$$

Where, M = natural mortality and T (°C) = annual mean water temperature

The fishing mortality (F) describing the rate of mortality due to fishing activities was estimated from the relationship:

$$Z = F + M \ [21]$$

An index of goodness of fit, called Rn, was determined by automatic computer [22].

The overall growth performance index (φ') was quantified using the model of [23]. The performance index is defined as:

$$\varphi' = \text{Log}_{10} K + 2 \text{Log}_{10} L\infty.$$

The potential longevity of *P. quadrifilis* was estimated according to the following equation [24]:

$$T \max = 2.9957/ K.$$

The length-converted catch curve method [25] was used to estimate the instantaneous rate of total mortality (Z) by using the FiSAT program.

The instantaneous rate of natural mortality (M) was obtained by the equations of [19] as:

$$\text{Log } M = [- 0.0066 - 0.279 \text{ Log } L\infty + 0.6543 \text{Log } K + 0.4634 \text{ Log } T]$$

The fishing mortality (F) was estimated by subtracting the value of natural mortality from the total mortality as F = Z –M, while the exploitation rate E = F/Z. The probability of capture was estimated from length-converted catch curve, using the running average technique to determine Lc [26]. Beverton and Holt Y′/R model with selection ogive-opted routine incorporated into FiSAT program was used to analyze the relative yield-per-recruit (Y′/R) and relative biomass-per-recruit (B′/Y) of the fish stock in the lagoon. The relative biomass per recruit (B'/R) was estimated as B'/R = (Y'/R)/F. E max which depicts exploitation rate producing maximum yield, E0.1 highlighting exploitation rate at which the marginal increase of Y'/R is 10% of its virgin population with E0.5 implying exploitation rate under which the population is reduced to half its virgin biomass were computed using the procedure incorporated using the Knife-edge option fitted in the FiSAT II Tool [27].

3. RESULTS

3.1 Size Distribution and Length-Weight Relationship

A total of 741 specimens of *P. quadrifilis* were examined during the study period. The standard length of individuals was ranged from 11 cm to 70 cm. The overall size distribution showed a modal length class of 19-21 cm indicating a unimodal distribution of *P. quadrifilis* exploited in the Ebrié Lagoon (Potou sector). Small sized (11-20 cm) specimens were more numerous and represent 73% of the total population (Fig. 2).

The growth coefficient value b of length-weight relationship of *P. quadrifilis* population was calculated as 3.03 that was not significantly different ($p > 0.05$; ts = 0.9771) from the hypothetical value (3) showing an isometric growth (Table 1). However, the regression coefficient (r^2) of the equation (0.96) indicated that there was a strong positive correlation between weight and length of the *P. quadrifilis* population in the lagoon. The 95% confidence limits for b (CL 95%) were ranged between 2.60 and 3.44.

3.2 Estimation of Growth and Exploitation Parameters

Fig. 3 illustrates the growth curves fitted to the monthly length-frequency distribution of *P. quadrifilis* in Ebrié lagoon (Potou Sector). The growth parameters which are the asymptotic length (L∞ = 60 cm), the growth rate (K= 0.33), the longevity (t max = 9.09 year) the theoretical age at length zero ($t_{0=}$), and the growth performance index (φ'= 3.065) were estimated by FiSAT and presented in Table 2.

The annual total mortality rate (Z) derived from length frequency catch curves was 1.10 year^{-1} (Fig. 4). The natural mortality rate (M) derived from Pauly's equation was estimated at 0.70 year^{-1} and the fishing mortality rate (F) was 0.40 year^{-1}. The exploitation rate (E) was 0.36 (Table 2). This rate is clearly weak at the Allowable limit of exploitation (E max).

3.3 Length at First Capture and Recruitment Patterns

The estimated length at first capture L_{50} or Lc (length at which 50% of the fish entering the gears are retained) was 10.60 cm (Fig. 5). The annual recruitment pattern of *P. quadrifilis* in the Ebrié Lagoon (Potou Sector) indicated that recruitment occurred throughout the year with the highest recruitment in the month of August and lowest in January (Fig. 6).

3.4 Relative Yield and Biomass per Recruit

The plot of relative yield-per-recruit against exploitation rate showed that the current exploitation rate (E current) was less than the maximum exploitation rate (E current < E max) (Fig. 7). However, the present exploitation rate was higher than the rate of exploitation at which 50 % of the biomass-per-recruit was fished ($E_{0.5}$) (E current > E0.5).

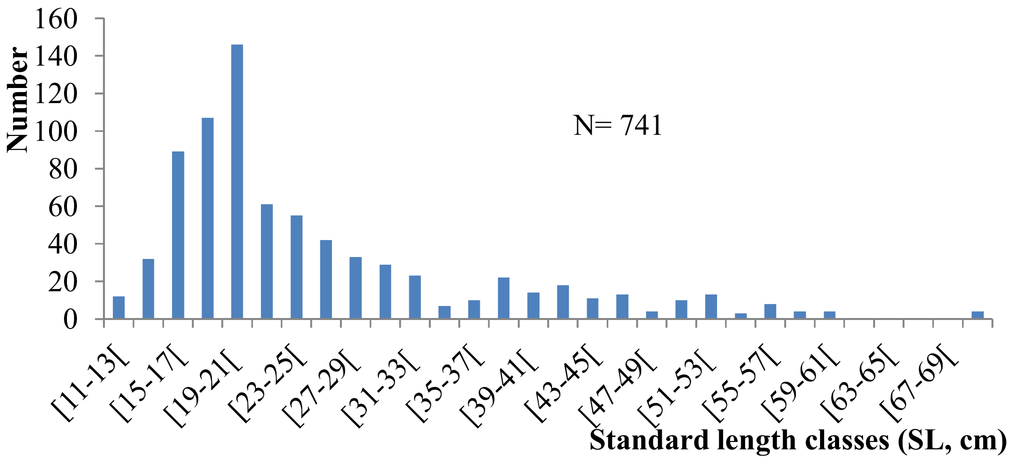

Fig. 2. Size distribution of *P. quadrifilis* in Ebrié lagoon (Potou sector) from April 2004 to March 2006

Table 1. Mean, range and length-weight relationship of *P. quadrifilis* in Ebrié lagoon (Potou sector) from April 2004 to March 2006

Species	Length		Weight		Parameters of LWR			
	Min-Max	Mean±SD	Min-Max	Mean±SD	b	r^2	ts	Gr
P. quadrifilis	11-70	24.71±9.69	13– 3901	269.29±179.8	3.03	0.96	0.971	I

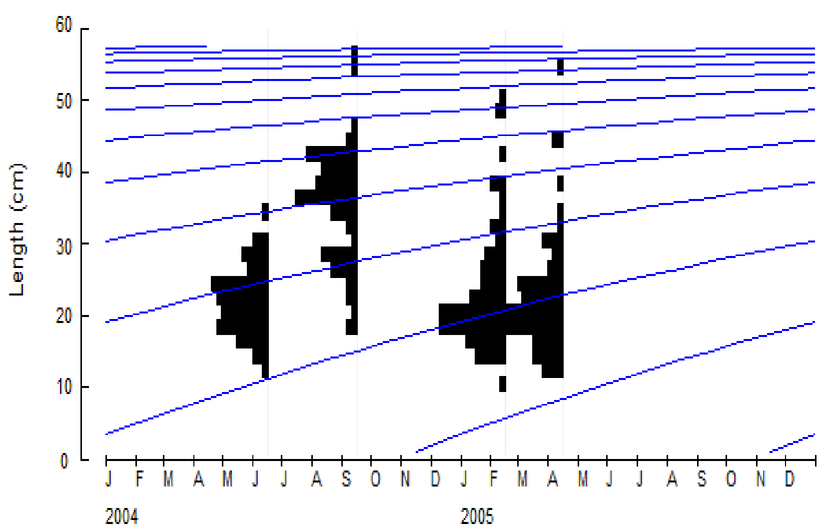

Fig. 3. Von Bertalanffy growth curve of *P. quadrifilis* in Ebrié lagoon (Potou Sector) from April 2004 to March 2006. Lines superimposed on the histograms links successive peaks of growing cohorts as extrapolated by the model

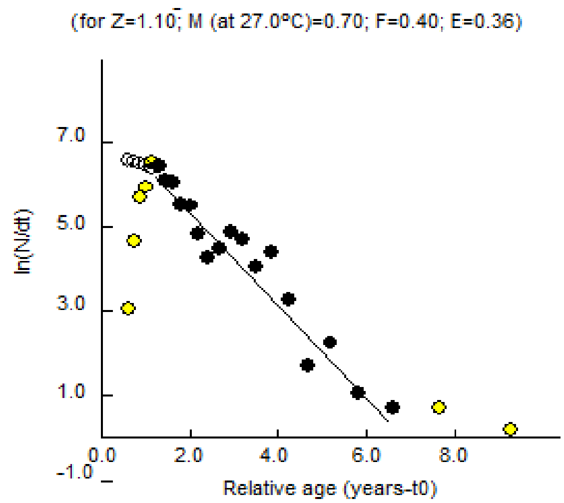

Fig. 4. Length-converted catch curve for *P. quadrifilis* in the Ebrié Lagoon (Potou sector) from April 2004 to March 2006

Table 2. Estimated population parameters of *P. quadrifilis* caught in Ebrié lagoon lagoon (Potou sector) from April 2004 to March 2006

Population parameters	Values
Asymptotic length (L∞, cm)	60
Growth rate (K, year $^{-1}$)	0.33
Longevity (tmax, year)	9.09
Growth performance index (φ')	3.06
Mean length at first sexual maturity [Lm (cm)]	40
Natural mortality (M, year^{-1})	0.70
Fishing mortality (F, year^{-1})	0.40
Total mortality (Z, year^{-1})	1.10
Exploitation rate (E)	0.36
Allowable limit of exploitation (E max)	0.44
Mean length at first capture L_{50} (cm)	10.60

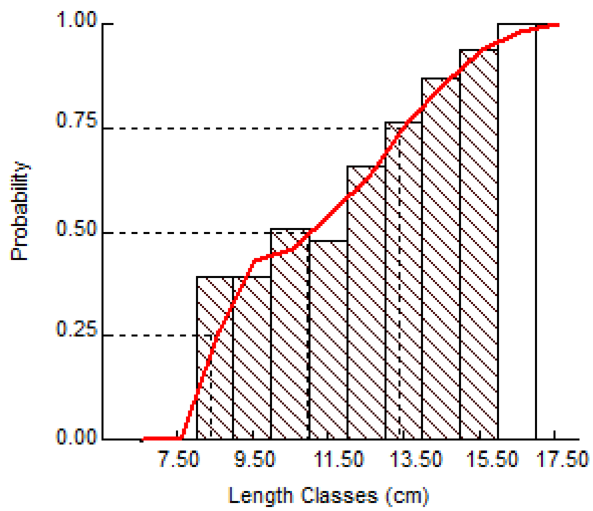

Fig. 5. Probabilities of capture pattern of pooled population of *P. quadrifilis* in Ebrié lagoon (Potou Sector) from April 2004 to March 2006

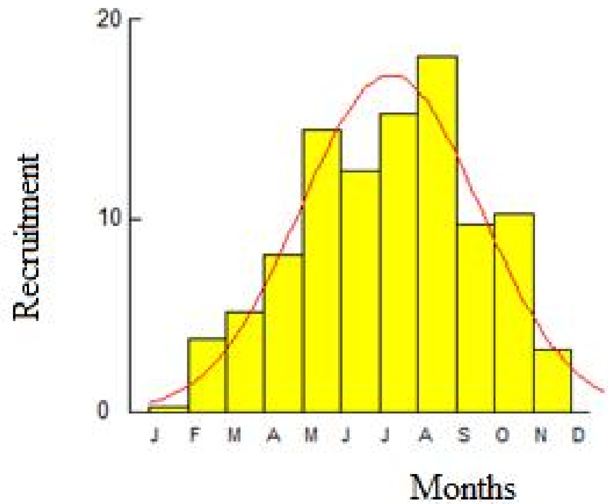

Fig. 6. Recruitment patterns of *P. quadrifilis* in the Ebrié Lagoon (Potou sector) from April 2004 to March 2006

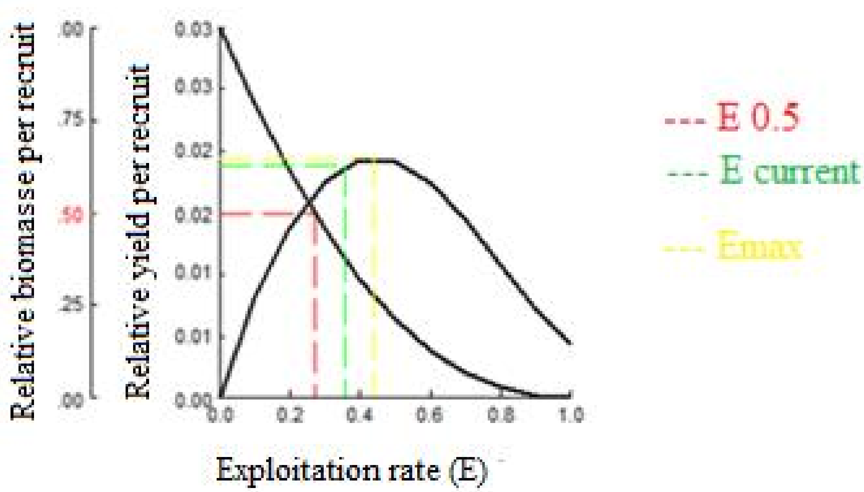

Fig. 7. Relative yield-per-recruit (Y′/R) and biomass-per-recruit (B′/R) plot for *P. quadrifilis* at different rates of exploitation in the Ebrié Lagoon (Potou sector) from from April 2004 to March 2006

Table 3. Comparison of growth parameters estimates from the present study and other studies

Authors	Location	(L∞, cm)	(K, year $^{-1}$)	(φ’)
[31]	Gambia estuary	170	0.22	*
[31]	Nokoué lagoon	22	0.88	*
[32]	Coastal zone Grand-Lahou	102.4	0.40	3.91
Current study	Ebrié lagoon (Potou sector)	60	0.33	3.06

4. DISCUSSION

The length frequency distribution is useful for growth and age determination. The length composition of a fish population often exhibits mode among fishes. Thus our findings were in agreement with the unimodal class distribution reported in Ologe lagoon for *P. quadrifilis* by [28].

However the size range of the current study was higher than the size range (9 cm-32.7cm total length) recorded for *P. quadrifilis* in Ologe lagoon (Nigeria) by [28]. The growth coefficient and regression coefficient indicated isometric growth and strong correlation between length and weight, respectively. The growth coefficient value b from this study was different from the value (2.34) obtained by [28] in Ologe lagoon (Nigeria) where allometric growth was observed for *P. quadrifilis.* The b values of length-weight relationships are known to vary with geographic location, environmental condition, season, stomach fullness, diseases and parasite loads [29].

The observed asymptotic length was lower than estimated for Gambia estuary and Grand-Lahou coastal water by [30] (Table 2). However the observed asymptotic length was greater than the value recorded in Nokoué lagoon (22 cm) by [30]. Further, the growth rate was lower than estimates by [30]. K value of the current study was greater than the value recorded in Nokoué lagoon by [30]. Potential causes for the observed variation in estimates for the asymptotic length (L_∞) and growth rate (K) in comparison with other studies include environmental condition, size classes obtained and the computational procedures [31]. Estimated growth rate (K) was found to be lower than 0.34, demonstrating that *P. quadrifilis* is a slow growing fish species, evinced by the estimated long lifespan [32]. Growth performance index from the study was inside the range (2.65-3.32) designated for fish species with fast growing performance [33] indicating that *P. quadrifilis* has a fast growth performance in Ebrié lagoon (Potou sector).

The estimated length at first capture Lc was lower than the corresponding length at first maturity (40 cm). This could be explained by a presence of high fishing pressure and/or the mesh sizes of fishing gears. Indeed, fishes were caught before reaching their matured stage. From the study, the ratio of $Lc50/L_\infty$ was estimated as 0.17 lower than 0.5, which signifies the presence of small sizes of *P. quadrifilis* within the catches. According to [34], ratio of $Lc50/L_\infty$ lower than 0.5 implied small sizes of individuals within catches. Recruitment has been described as a year-round phenomenon for tropical fish species [35]. The presence of recruitment through the year indicated that recruitment is continuous. Continuous recruitment could contribute to decrease the overfishing of the specie. Our results exhibit one recruitment pulse which was not conform with [36] assertion of a double recruitment pulse per year for most of tropical fish and short lived species.

The calculated total mortality rate from the present study was greater than the estimated (0.84 $year^{-1}$) by [30] in Gambia estuary and greatly lower than the estimated (2 $year^{-1}$) by [30] in Nokoué lagoon. The observed disparity in estimates of total mortality rates (Z) could be due to the high estimates of natural mortality (M) as well as the computation procedure applied in the estimation of other inputs (parameters). The computed fishing mortality rate (F) was lower than the corresponding natural mortality rate (M) from the present study, hence *P. quadrifilis* population is more prone to naturally induced mortality situations than fishing mortality. This could be related to the fact that accessed catch consists of more juvenile fishes than adults in the fishing area. According to [37], all juvenile and other small fish are vulnerable to predation by piscivorous fish. The recruitment pattern shows a continuous recruitment consists of one peak seasonal pulse. It is expected that the major recruitment peak (Jun-July) in this study should correspond to the major spawning season of the species.

From the Y′/R curve, the current exploitation rate (E present) which has not reached the maximum level of exploitation (E max) suggests that the stock was not overexploited and E present could be applied for sustainable exploitation of the *P. quadrifilis* fishery. However, the B′/R curve of *P. quadrifilis* in the lagoon which indicated that E present > E50 (0.28) implies that a considerable increase in the current exploitation rate of the *P. quadrifilis* stock could lead to depletion of the fish stock.

5. CONCLUSION

P. quadrifilis in Ebrié lagoon is currently exhibiting light overfishing signs with implications on food security. Therefore, urgent management interventions are needed to safeguard this commercially important fish species from possible collapse in the future.

ETHICAL APPROVAL

As per international standard written ethical permission has been collected and preserved by the author(s).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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