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Growth assessment of croakers (*Pseudotolithus* species) in West African waters

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Introduction: The genus *Pseudotolithus*, commonly called croaker, is represented by the three main species found in West African waters.

Methods: In total, 934 individuals were sampled in 8 locations in Senegal, Ghana, and Nigeria. Several tests identified using sectioned otolith as the best method for determining the croakers' age. The marginal increment analysis validated the age data.

Results: The relationship between total length and total weight was significant for all species. This relationship is significantly different according to the geographical area. There was significant sexual dimorphism in *P. senegalensis* and *P. typus*, and the reproduction period presented a significant effect on the body length-weight relationship of *P. senegalensis*. The von Bertalanffy growth model constrained by $t_0 = 0$ was the best fit for the observed age data from the three species in the sampled countries. The asymptotic length $TL\infty$ was estimated from 26.6 cm for *P. elongatus* on the Nigerian coast to 42.2 cm for *P. senegalensis* on the Senegalese coast. The growth rate K ranged from 0.58 for *P. senegalensis* to 1.12 for *P. typus*.

Discussion: The growth was significantly different among the three sampled countries for *P. senegalensis*. Conversely, there was no significant difference of growth between specimens of *P. typus* from Nigeria and Ghana. Finally, there was no significant sexual dimorphism in the growth of *P. senegalensis* in Senegalese waters. This new information on the biology of these three croaker species is essential for the future assessment and management of these commercial species in West African waters.

KEYWORDS

Senegal, Ghana, Nigeria, age, otolith, growth model, aging validation study

1 Introduction

The Gulf of Guinea, a West African body of water, is defined as the oceanic waters from Senegal to Angola. Approximately 40% of the West African population lives in the coastal areas, and consequently, the fisheries industry is an important economic sector and plays a role in the food security of Africa (1–3). However, these fisheries are existentially threatened by climate change impacts and anthropic pressures, such as pollution and unsustainable fishing practices (4). Among the commercial species, the first fish family caught by artisanal fisheries is Sciaenidae, which includes croakers, drums, maigres, and weakfishes (5, 6). The genus *Pseudotolithus*, commonly called croakers, is an abundant fish group that includes several very important commercial species, especially in the Gulf of Guinea, where it accounts for ~40% of the value of commercial landings (1, 7–9). *P. senegalensis*, *P. elongates*, and *P. typus* are three species widely distributed along the West African coast from Senegal in the north to Angola in the south (5). Since 1994, the total catches of *Pseudotolithus* have been decreasing, potentially because of overfishing by industrial fishing fleets (1, 3). Growth studies were initially carried out from 1960 to 1971 (7, 10–13), but since then, only two studies have followed the growth of the mainly commercial fish in the Gulf of Guinea (3, 6). Consequently, the objective of this study is to evaluate, with good accuracy, the growth of *Pseudotolithus* species in West African waters according to the physiological and/or geographical factors, especially for *P. senegalensis*, to provide biological data, an essential preliminary step for stock assessment.

2 Materials and methods

2.1 Fish sampling

In total, 934 individuals belonging to the three studied croaker species (*Pseudotolithus elongatus*, *senegalensis*, and *typus*) were sampled in eight different locations in three countries of West Africa. The three croaker species (210 individuals of *P. typus*, 174 individuals of *P. senegalensis*, and 48 individuals of *P. elongatus*) were sampled in January 2022 in Nigeria (three locations: Ibeno Beach, Ibeno, Akwa Ibom State; Ogulagha, Warri, Delta State; and Makoko, Lagos Island, Lagos State) and Ghana [three locations: Apam Beach, Apam, and Elmina Beach Market, Cape Coast (both in the Central Region); and Albert Bosomtwi Sam Fishing Harbor, Sekondi-Takoradi; Figure 1]. Another 502 individuals of *P. senegalensis* were obtained between August 2015 and July 2016 in the fish markets of Joal and Mboro (Senegal).

All individuals were analyzed in the laboratory to measure, with high precision, individual parameters: total length (TL, measured to the nearest millimeter) and total weight (W_T, measured to the nearest gram). The macroscopic observation of the gonads was applied to evaluate the sex and sexual maturity stage. Finally, both sagittal left and right otoliths were extracted from the cranial cavity, cleaned with water, and stored dry before being shipped to Ifremer (Boulogne sur mer, France).

2.2 Total length/total weight relationship

All individual data of biological parameters were graphically observed to identify and delete the potential outliers. For each species, to estimate the allometric relationships between total length/total weight, a base-10 logarithm was fitted to data:

$$W_T = a\,TL^b$$
$$logW_T = log\,a + b\,(log\,TL)$$

where a is the intercept and b is the slope named the growth coefficient (14–16). To test the effect of the explanatory variables {sex [*Se*], sampling country [*Co*], sampling location [*Lo*], and reproduction period [*Re*, defined from November to March; (17)]} on the relationship between total length and total weight, a completed generalized linear model was applied for each species:

$$Log\,W_T \sim Log\,TL + Log\,TL:Co + Log\,TL:Co:Lo + Log\,TL:Se + Log\,TL:Re + Log\,TL:Re:Se + \varepsilon.$$

With the interaction between each factor and the length (sex: *Log TL:S*, geographical area: *Log TL:Co*, and *Log TL:Co:Lo*, reproduction period: *Log TL:Re*, and the physiological state by sex: *Log TL:Re:Se*). When a factor showed a significant effect ($p < 0.05$) on the TL–W_T relationship, the analysis was realized for each factor modality.

To understand the difference in the $TL–W_T$ relationship, the condition factor, Le Cren's (14) index, *Kn* (i.e., fish showing the high value of *Kn* are heavy for their length), has been used:

$$Kn = \frac{100\,W_T}{TL^3}$$

The difference between this observed growth coefficient for each fish species and the theoretical value ($b = 3.0$) was tested with a one-sample t-test.

2.3 Aging method

As there has been no previous direct growth study for these species, calibrating the tests of the aging method was necessary. Whole and sectioned otoliths were tested to analyze the growth ring patterns. The image processing was carried out using the Icy image analysis system (18). Finally, to limit interpretation bias, each image was independently analyzed by two expert readers, and after this step, the images presenting a difference in age were discussed to increase precision, which, for this study, is defined as the reproducibility of repeated measurements on the otoliths or another calcified structure (19). Alternating translucent and opaque bands were visible in whole otoliths. It was assumed that each annual growth ring consisted of one opaque ring and one translucent band. The age was defined by age group; for example, a fish in age group 0 lived between 1 and 364 days (i.e., between hatching and before 1 year), as recommended by international expert groups (19–21).

2.4 Age validation

No growth validation studies (i.e., mark–recapture of wild individuals, captive rearing of either chemically labeled fish of unknown age or known age, etc.) had not been applied to these species, marginal increment analysis (MIA) was used. This technique assesses the periodicity of increments in calcified structures (22). MIA is a quantitative approach that relies on measuring the size of the increment under formation [named the marginal increment (MI)] as the distance between the last growth ring and the edge of the calcified structures. The relative measure of the MI is given by

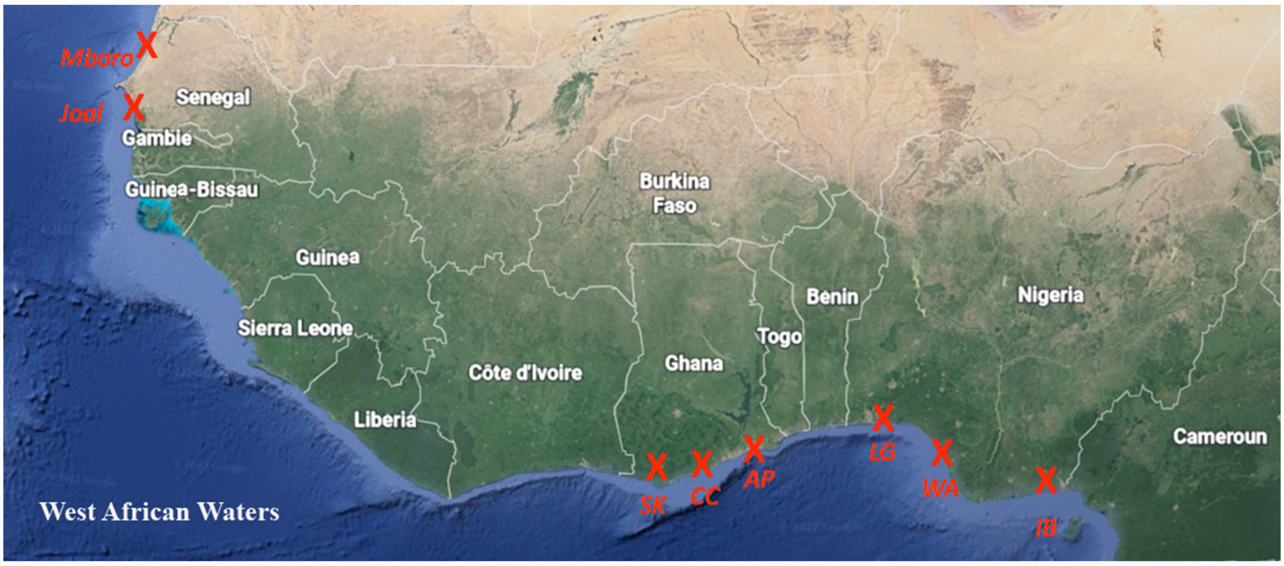

FIGURE 1
Sampling countries and locations of croaker species from Senegal to Nigeria in the Gulf of Guinea (Atlantic Ocean). The three croaker species were sampled in Nigeria (IB, Ibeno Beach; WA, Warri; LG, Lagos Island), in Ghana (AP, Apam Beach; CC, Cape Coast; SK, Sekondi-Takoradi), and in Senegal (Mboro, Joal).

$$MI = \frac{R_O - R_n}{R_n - R_{n-1}}$$

where R_O is the otolith radius measured from its focus to the edge, R_n is the distance between the focus and the last growth ring n, and R_{n-1} is the distance between the focus and the last-but-one growth ring $n-1$. If growth rings are formed annually, the MI will thus exhibit an intra-annual periodic pattern that can be observed by plotting the MI against the date of origin, that is, the month at which the specimen was captured. The *MI* was measured for each specimen using the otolith and plotted against the catch month. A sinusoidal regression of *MI* against the month of capture m with a period of 12 months was used to test for the annual periodicity of growth ring formation after linearization:

$$MI \sim a + b\sin\left(\frac{2\pi}{12}m + c\right) = a + b\sin(c)\cos\left(\frac{2\pi}{12}m\right) + b\cos(c)\sin\left(\frac{2\pi}{12}m\right)$$

so that

$$MI \sim \alpha_0 + \alpha_1\cos\left(\frac{2\pi}{12}m\right) + \alpha_2\sin\left(\frac{2\pi}{12}m\right)$$

with

$$a = \alpha_0,\ b = (\alpha_1^2 + \alpha_2^2)^{1/2},\ \text{and } c = \arctan\left(\frac{\alpha_1}{\alpha_2}\right)$$

Linear regression was used to statistically validate an intra-annual pattern in the growth rings. The classical assumptions of the linear models (normality, homoscedasticity, and absence of trends in the residuals) were verified before to realise the growth models.

2.5 Growth model estimation

To optimize the growth model from the sampled individuals, the length at age (TL_t) was back-calculated from the Fraser–Lee procedure (23) after checking the significant linear relationship between fish and otolith lengths:

$$TL_t = TL_c + (TL_c - TL_{bi})\ x\ \frac{(R_t - R_o)}{(R_o - R_{bi})}$$

where TL_t is the length at age at age t, TL_c is total length at capture, TL_{bi} is length at the biological intercept, R_t is otolith radius at age t, R_o is otolith radius at capture, and R_{bi} is otolith radius at the biological intercept.

The growth patterns were described according to four different growth models:

- the unconstrained von Bertalanffy model (24):

$$TL_t = TL_\infty.(1 - e^{-K.(t-t_0)})$$

- the von Bertalanffy model with forced $t_0 = 0$:

$$TL_t = TL_\infty - (TL_\infty .e^{-K.t})$$

- the Gompertz (25) model:

$$TL_t = TL_\infty . e^{\ln\left(\frac{TL_1}{TL_\infty}\right) . e^{-K.(t-1)}})$$

- the logistic model (26):

$$TL_t = \frac{TL_\infty}{1 + \left(\left(\frac{TL_\infty}{TL_1}\right) - 1\right) * e^{-K.t}}$$

where TL_1, TL_t, *and* TL_∞ are, respectively, the length at age 1, the length at age t, and the asymptotic length and K is the rate at which the asymptote is reached, also called the growth coefficient. The best growth model was the bias-corrected form of the Akaike information criterion [*AICc*; i.e., gave the smallest value of *AICc*; (27, 28)]. The *AICc* balances the trade-off between the fit quality and the number of used parameters (29) while accounting for small-sample bias and is defined as

$$AICc = 2k - 2\ln(TL) + \frac{2k(k+1)}{n-k-1}$$

where n is the sample size, k is the total number of parameters of the model, and TL is its likelihood.

Fish growth was estimated using the growth performance index [ϕ; (30)]:

$$\phi = logK + 2log(TL_\infty)$$

The growth performance index was preferred for growth comparison rather than comparing TL_∞ and K individually. These two parameters of the growth model are correlated (31).

To test the growth variation according to the different effects of the selected species, the sampling country, and sexual dimorphism (difference between the females and males) on the back-calculated length, four mixed-effects models were fitted, with the age and the interaction of age/species, age/country, and age/sex as fixed effects. Random effects were used to account for variability due to each individual, which could present several back-calculated lengths for all ages. Finally, the significance of back-calculated length at 5% was tested by likelihood ratio tests.

Statistical analyses were performed using the following packages in the statistical environment R (40): *ggplot2* (32), and *car* (33).

3 Results

3.1 Morphological parameters

Measured total length and total weight for all species ranged, respectively, from 16.0 to 58.8 cm and from 20.7 to 1,720.3 g (Table 1). Important differences were observed in weight for the same total length among the three croaker species, with *P. senegalensis* having the highest weight and *P. elongatus* having the lowest (Figure 2). Among the three croaker species, all showed a significant correlation ($p < 0.05$) between total length and total weight (Table 1). The body parameters from the length–weight relationships showed that the initial growth coefficient a varied

TABLE 1 Relationships between total length (TL; cm) and total weight (W_T; g; the significance of this relationship, number of individuals, details of each measurement, parameters a and b, and the *p*-value of each potential effect).

Species		*N*	TL (cm)			W_T (g)			W_T/TL relationship					Effects				
			Mean	*SD*	Range	Mean	*SD*	Range	*p*-value	*a*		*b*						
										Value	*SD*	Value	*SD*	Country	Location within the country	Sex	Reproduction period	Reproduction period by sex
Bobo croacker	*Pseudotolithus elongatus*	48	27.7	2.8	22.5–34	201.7	51.4	135.6–329.8	<0.001	0.162	0.115	2.142	0.211	-	0.014	0.835	-	-
Cassava croaker	*Pseudotolithus senegalensis*	676	34.7	6.5	16–58.8	407.8	231.8	20.7–1,720.3	<0.001	0.010	0.001	2.955	0.026	<0.001	<0.001	<0.001	0.03945	<0.001
Longneck croaker	*Pseudotolithus typus*	210	31.4	5.3	22.5–54	244.0	163.0	75.0–1,242.2	<0.001	0.005	0.001	3.132	0.031	<0.001	<0.001	<0.001	-	-

The significant relationships shown in blue cells. "-" indicates that the effect was not tested.

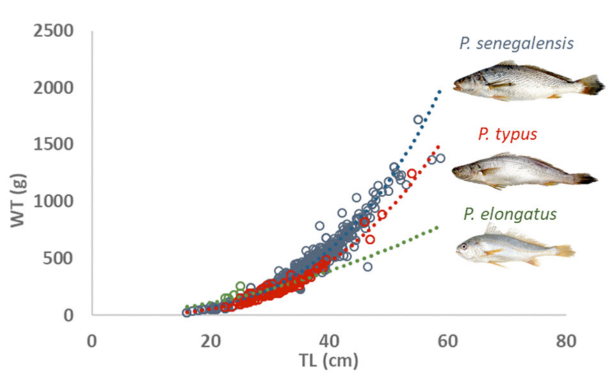

FIGURE 2
Total length/total weight relationship of the croaker species from the western coast of Africa.

from 0.005 to 0.162, and the growth coefficient b ranged from 2.142 ± 0.211 (for *P. elongatus*) to 3.132 ± 0.031 (for *P. typus*). For *P. elongatus* and *P. senegalensis*, the specimens had thin, elongated bodies (i.e., $b < 3.0$), while *P. typus* have thicker bodies (i.e., $b > 3.0$). The geographical and physiological effects on the relationship between total length and weight were also analyzed. For the geographical effect, two geographical scales (i.e., at the country level and, after, the location within the country) were used and for all species, the geographical effect was significant showing the difference among the sampling countries and between the locations within the country too (Table 1). The second effect was the physiological effect with two different levels (i.e., between the males and the females, between the reproduction and the sexual rest period, and, finally, the interaction between these two levels). The TL–W_T relationship showed a significant difference between males and females for *P. senegalensis* and *P. typus* ($p < 0.05$), while for *P. elongatus*, there was no significant difference. The second level of the physiological effect was tested only for *P. senegalensis*, which presented the monthly sampling for 1 year. For this species, the TL–W_T relationship changed significantly between the reproduction period and the sexual rest period. Finally, this modification during the year depends on the sex analyzed (Table 1).

The fitness of each fish species according to sex (females vs. males), geographic factor (Senegal, Ghana, and Nigeria and, for the sampling country, the mean value was estimated for each location), and the reproduction period (active vs. sexual rest) was followed from the condition factor (*K*; Supplementary Table S2). Among the three croaker species, only *P. typus* showed sexual dimorphism, with the mean condition factor of females being smaller than that for males. For the geographical factor, there were some differences for each species between the sampling countries and/or locations. However, no trend was observed for all species from the eastern part to the western part of the Gulf of Guinea.

3.2 Growth parameters

The whole sagittal otolith and the sectioned otoliths of the same individuals were tested and the aging data showed

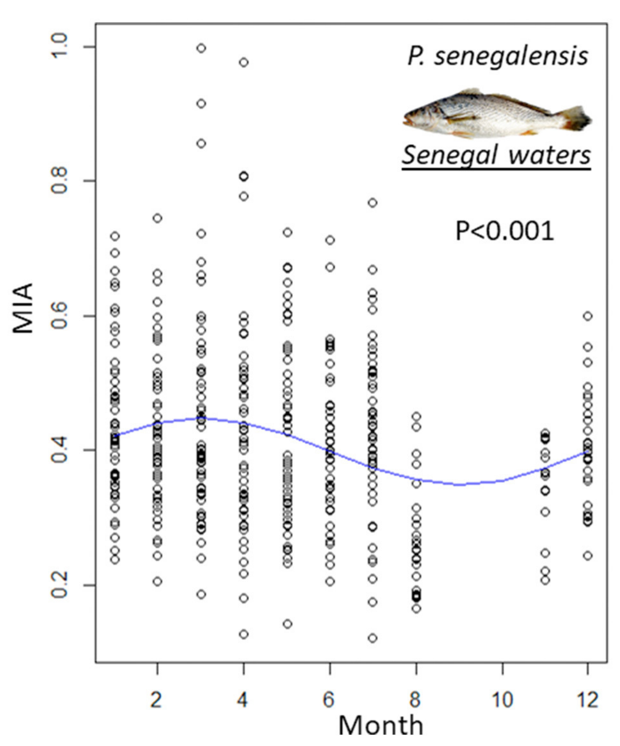

FIGURE 3
Marginal increment analysis (MIA) per sampling month (blue solid line; mean ± standard deviation) of *P. senegalensis* sampled in Senegalese waters. The continuous blue curve represents the fit of a sinusoidal regression of marginal increments per month for 12 months to test for annual periodicity.

that the best otolith preparation method was the sectioned otolith. These preparations were analyzed under transmitted light microscopy to count the growth increments along the longest growth axis. The individuals' ages ranged between 1 and 7 years. Before realizing the first growth analysis, applying the aging validation method is very important. The MI analysis of *P. senegalensis* allowed a significant intra-annual variation in their growth ($p < 0.001$; Figure 2, upper panel) to be detected. From November to March, the growth of marginal increments is maximal, and from April to October, it is reduced, revealing an annual rhythm in growth ring formation (Figure 3). For *P. elongatus* and *P. typus*, the available data were sampled during 2 or 3 months. Consequently, the MIA was applied only to *P. senegalensis*.

For the three croaker species (*P. elongatus*, *P. senegalensis*, and *P. typus*), the age range was 1–7 years, except for *P. typus*, which had only one specimen aged to 4 years (Figure 4). The von Bertalanffy growth model constrained with $t_0 = 0$ was the best fit for the observed age data from the three species in the sampled countries (Senegal, Ghana, and Nigeria; Table 2). The asymptotic length TL∞ varied from 26.6 cm for *P. elongatus* along the Nigeria coast to 42.2 cm for *P. senegalensis* along the Senegal coast (Table 2). The rate at which the asymptotic length was reached, *K*, ranged from 0.58, for *P. senegalensis*, to 1.12, for *P. typus*. Consequently, for these croaker species, the growth performance index (ϕ) varied from 2.73 to 3.24 (Table 2). Comparisons of

TABLE 2 Biogeographic comparison of the biological parameters of croaker species with the details of sampling [number of samples, observed maximum total length (TL), and age] of the growth model (model used with the type of method being length frequency analysis, LFA, for otoliths and its preparation technique).

Species	Geographical area	Sampling period	Sampling			Growth model				ϕ	Sources
			N	TL max	Age max	Method	Growth model	TL_{∞}	*k*		
P. senegalensis	**Senegal**	**2022**	**1,262**	**51**	**7**	**Sectioned otolith**	**VB with $t_0 = 0$**	**42.21**	**0.58**	**3.01**	**This study**
P. senegalensis	Guinea	1985–1992		110		LFA		60.8	0.35	3.11	(6)
P. senegalensis	Liberia					LFA		69.42	0.13	2.80	(38)
P. senegalensis	Ghana	2012–2013		110		LFA		110.3	0.2	3.39	(39)
P. senegalensis	**Ghana**	**2022**	**100**	**51.4**	**4**	**Sectioned otolith**	**VB with $t_0 = 0$**	**34.96**	**0.70**	**2.93**	**This study**
P. senegalensis	Benin (East part, Cotonou)	2008–2009	865	31.6		LFA		51.4	0.24	2.80	(3)
P. senegalensis	Benin (West part, Djegbadji)	2008–2009	865	31.6		LFA		51.4	0.16	2.63	(3)
P. senegalensis	**Nigeria**	**2022**	**82**	**33.4**	**4**	**Sectioned otolith**	**VB with $t_0 = 0$**	**33.60**	**0.63**	**2.85**	**This study**
P. senegalensis	Congo	1964	174	50	9	Burnt and broken otolith	VB without constraint	55.54	0.30	2.97	(13)
P. elongatus	Guinea	1985–1992		42		LFA		53.2	0.4	3.05	(6)
P. elongatus	Sierra Leone	1959				Burnt and broken otolith	VB without constraint	51.76	0.0214	1.76	(35)
P. elongatus	**Nigeria**	**2022**	**100**			**Sectioned otolith**	**VB with $t_0 = 0$**	**26.62**	**0.76**	2.73	**This study**
P. elongatus	Congo	1959				Burnt and broken otolith	VB without constraint	46.74	0.0228	1.70	(35)
P. typus	Guinea	1985–1992		109		LFA		73.8	0.35	3.28	(6)
P. typus	Liberia					LFA		69.42	0.14	2.83	(38)
P. typus	**Ghana**	**2022**	**35**	**51.4**	**3**	**Sectioned otolith**	**VB with $t_0 = 0$**	**39.22**	**1.122**	3.24	**This study**
P. typus	Benin (East part, Cotonou)	2008–2009	511	31.4		LFA		56.2	0.16	2.70	(3)
P. typus	Benin (West part, Djegbadji)	2008–2009	511	31.4		LFA		56.2	0.15	2.68	(3)
P. typus	**Nigeria**	**2022**	**152**	**46**	**4**	**Sectioned otolith**	**VB with $t_0 = 0$**	**41.35**	**0.58**	3.00	**This study**

TL, total length; LFA, length frequency analysis; VB, .
The parameters of growth model and growth performance index (ϕ) are presented.

the growth curves of these three species in West African waters showed that, among these species, growth was very different (Figure 4A). For one species, *P. senegalensis*, the results of mixed-effects models showed that the growth of one species could be significantly different among the samples from the three countries, whereas for the *P. typus* specimens from Nigeria and Ghana, the difference in their growth was not significant (Figure 4). Finally, the growth difference between males and females was tested for *P. senegalensis* from Senegalese waters, and no significant effect of sexual dimorphism on the growth of this species was found (p = 0.251; Figure 4).

4 Discussion

Age and growth data were analyzed for three croakers (*Pseudotolithus*) species in the western part of Africa around the Gulf of Guinea from Senegal to Nigeria. First, the total length and total weight relationship (LWR) were analyzed and showed significant differences among the species and within each species, with geographical and physiological (i.e., males vs. females or sexual rest vs. reproduction period) factors influencing significantly the LWR of the croaker species, a result similar to other species (34). This morphological information on the fish body can be used to

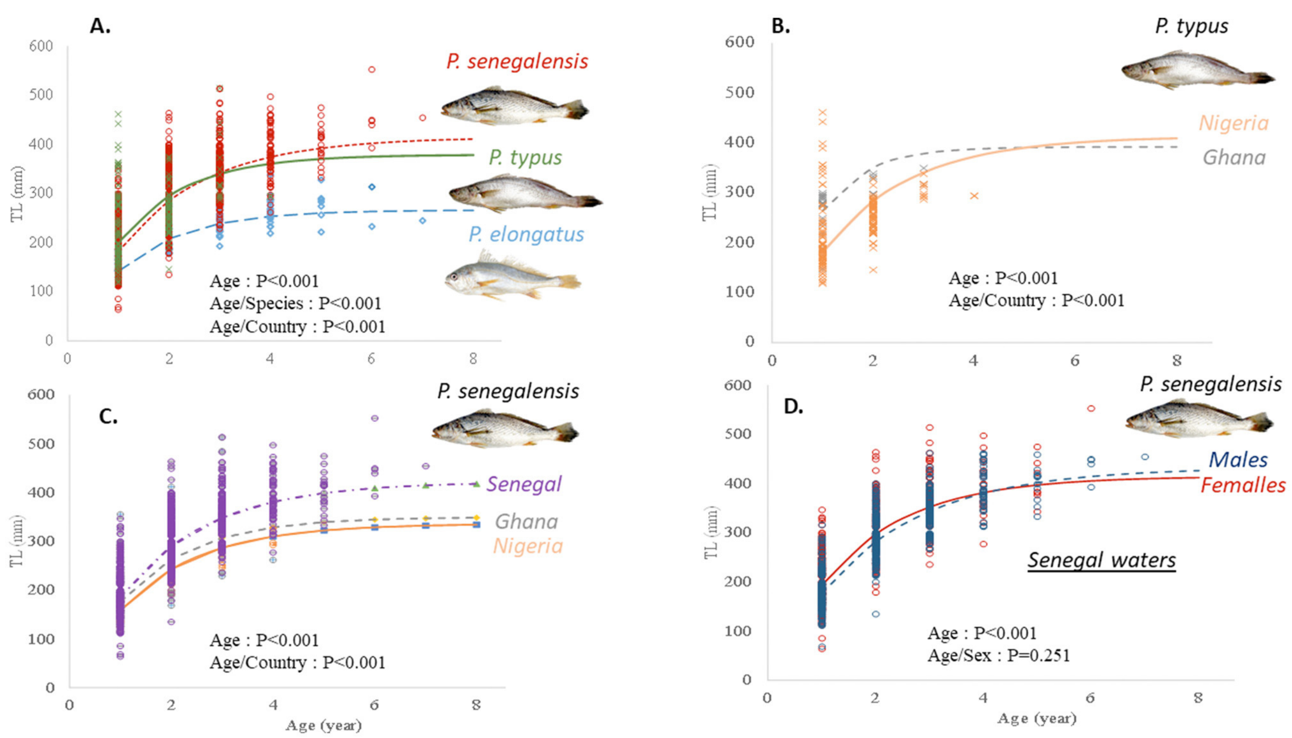

FIGURE 4
Growth curves of the croaker species in the Gulf of Guinea fitted to individual length at age. **(A)** Comparison of growth curves among three croaker species; **(B)** Comparison of the growth curves of *P. typus* between the Nigeria and Ghana samples; **(C)** Comparison of the growth curves of *P. senegalensis* from Senegal to Nigeria; **(D)** Comparison of growth curves of *P. senegalensis* in Senegalese waters between females and males. For each growth data set, the probability of each factor or the interaction between two factors tested according to the mixed-effects model is presented. MIA, marginal increment analysis.

evaluate the parameters, such as growth and mortality, of other fisheries. This knowledge of factors that modify the LWR is essential to precisely determine the individual composition of all catches used in the stock assessment.

Age data were measured from the sagittal otolith; after testing different preparation methods, the highest accuracy of the age data was obtained from the sectioned otoliths. The results from the transversal section of the sagittal otoliths allowed better observation of the growth rings, especially close to the edge, compared to whole otoliths or burnt and broken otoliths as used in previous studies [(13, 35); without preliminary tests to evaluate the bias due to different preparation methods of otoliths for the age data]. Previous growth studies on croaker species were realized from only the proxy of the length frequency analysis (LFA). Using whole or broken otoliths is a preparation method that underestimates the age of the old fish. Similarly, extracting the old-age classes is difficult using the LFA approach (21). Consequently, comparing this new growth study of croakers in the western part of Africa with the previous studies is difficult without introducing the bias due to the method used to calculate the growth parameters. The annual periodicity of our age growth estimation from the sectioned otoliths was validated from the MIA for *P. senegalensis* in the waters of Senegal. For *P. elongatus* and *P. typus*, the data were sampled during 2 or 3 months only. Consequently, these available data are well-distributed throughout the year. They could be enlarged in the future. However, the MIA for *P. senegalensis* validated the annual periodicity of age growth estimation. In the same ecosystem and with species that are very close phylogenetically, the age validation for a species (*P. senegalensis*) should be transferable to those of other species belonging to the same genus *Pseudotolithus*, commonly called croakers. This step is necessary to evaluate the precision of the age data, especially in cases in which prior knowledge of age is lacking. For age, MIA, which assesses the periodicity of increments in calcified structures such as otoliths, is the most widely used indirect validation method (21, 22). This indirect method could be confirmed in the future by direct validation methods such as mark–recapture of wild individuals. The second step for optimize the growth analysis used the back-calculation method of the length at age, especially in the first life stages as juveniles, and tested the statistical precision of the several growth models (36). This was not the case for previous studies (13, 35). It was an important approach for the croaker species, for which obtaining an efficient number of specimens for all length classes in all geographical areas is not easy. Finally, the growth model type used is the last step to optimize the biological analysis within one species or among several species. Among different classical growth models, the von Bertalanffy model, with t_0 equalling 0, was the best growth model that fit the data for all the croakers. In the future, the sampling effort of fish must be carried out to validate the choice of the best model for each species, as these data are important to adjust the different models. The previous studies used another von Bertalanffy model [i.e., without constraint; (13, 35)]. Consequently, the growth difference among species or within species between this study and the previous works could be related to not only environmental differences (e.g., temperature fluctuations, food availability and composition, etc.) but also the difference in age acquisition methods and the statistical approach used (Table 2).

To compare growth, the growth performance index could be a good tool. The growth performance index for *P. senegalensis* showed a longitudinal gradient, with the highest values from the western part (i.e., Senegal) and decreasing toward the eastern part (i.e., Benin and Nigeria; Table 2). This growth pattern indicates that *P. senegalensis* growth rates decrease significantly from the western part to the eastern part of the gulf (Figure 4C). It was possible that environmental conditions (i.e., habitats) and/or high fishing pressures (37) explain this higher growth rate result. The observed longitudinal growth gradient for this species must be confirmed in the future using data available from several years of sampling in all locations/countries to validate this trend. However, this trend was not confirmed for the two other species (*P. elongatus* and *P. typus*). In addition, the geographical gradient of growth depends on the analyzed species. For *P. elongatus*, during 1959, there were few studies, and environmental factors and/or methodology bias could explain the very low values observed in Sierra Leone and Congo (35) compared to other studies. For *P. typus*, there was only one previous study on the Benin coast that used the LFA approach (3), but in our study, there was no clear trend between individuals from Ghana and Nigeria.

5 Conclusion

The growth of three croaker (*Pseudotolithus*) species in the Atlantic waters of Africa, from the Senegalese coast in the north to the Nigerian coast in the south, showed the same growth patterns, in particular, fast growth during the first 4 years, followed by a decrease in the growth rate. Comparing the growth rate among the croaker species, in the same age classes, *P. elongatus* showed the smaller growth rate than the other species. Finally, for *P. senegalensis* in the Senegal waters, no significant effect of the sexual dimorphism on the growth for the same age classes was evidenced. These biological data are essential to provide a stock assessment of these very important commercial species in the western part of Africa.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The study was conducted in accordance with the local legislation and institutional requirements. All specimens were from landings commercial fishing boats with commercial species. Ethical review and approval were waived for this study because the fish were obtained from fisheries and were already dead when the calcified structures were extracted.

Author contributions

KM: Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. AE: Conceptualization, Data curation, Investigation, Writing – original draft. KD: Conceptualization, Data curation, Investigation, Writing – review & editing. CM: Formal analysis, Investigation, Methodology, Writing – review & editing. YA: Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing. NA: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. AD: Writing – review & editing. MD: Formal analysis, Methodology, Software, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frish.2024.1498784/full#supplementary-material

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