ORIGINAL ARTICLE

PRELIMINARY STUDY OF BLUE SHARK *Prionace glauca* GROWTH IN MOROCCAN WATERS

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ABSTRACT

Background: The blue shark *Prionace glauca* is a pelagic shark, from the Carcharhinidae family; it is one of the pelagic predators placed at the top of the food chain. Unfortunately this species is classified as near threatened "NT" in the IUCN red list. In Morocco, pelagic sharks, including P. glauca, are mainly caught by drifting longlines and secondly by gill net "bonitard". This fishery is practiced mainly in the southern Moroccan area. **Objectives**: The growth study of P. glauca is done to know in first, the growth mode of this species and secondly to estimate the growth parameters used in stock assessments. **Methods**: Since February 2015, biological sampling sessions have been conducted at the wholesale fish market of Casablanca where the catches of P. glauca are transited from several Moroccan ports. They include size and weight measurements and sex determination. **Results**: The mean sizes of males and females are respectively 184.37 cm and 164.71 cm (TL) indicated that male sharks are larger than females. The juveniles dominate catches during the months of May, June and December. During these periods, it was noted the presence of gravid females, suggesting that the farrowing can be done twice a year in the Moroccan zone. The first gives birth to pups during the winter, which grow for almost six months and appear in the catches during the months of May-June. The second is around the month of May giving birth to pups that grow and appear in catches in the months of December-January. The growth parameters are estimated at L_{∞} = 392.4 cm (TL), K 0.21 / year and t_0 = -0.402 year. This animal grows in size and weight symmetrically and can reach a maximum weight of more than 200 kg at 20 years of age. **Conclusions:** It was found that the blue shark in Moroccan waters has a wide range of size (50- 340 cm TL).The blue shark has a long life, the reason why this animal must be protected against overfishing.

Keywords: *blue shark, linear growth, weight-length, size distribution*.

1. INTRODUCTION

Growth is a characteristic of living beings, each organism grows and reaches its normal size. It means an increase of all dimensions of the organism in relation to time. Knowledge of fish growth is of interest to ichthyologists, fishers, and management specialists. In ichthyology, the study of the growth contributes to the analysis of the structure and the dynamics of the populations and to the evaluation of the natural mortality. The parameters estimated from the growth study must therefore allow, associated with the classical demographic parameters, the development of exploited stock management models and consequently management of the fisheries [1].

The fish has known since its birth two types of growth; weight (length-weight) and linear (length-age). Linear growth requires knowledge of the age of the fish that can be obtained by directly reading otoliths, scales or other hard parts. In the absence of these data, the modal progression analysis of length classes can be treated as size-age data even though they represent lengths at relative ages [2]. It allows to estimate growth parameters, mortality rates ..., to have an image of exploited populations and can thus give some clues on the state of exploited stocks.

In Morocco, although this is not a fishery targeting sharks, a management plan for this resource is being developed. This plan aims to answer the FAO international plan to conserve and protect the sharks. In this context, scientific monitoring has been initiated with the aim of conducting biological and ecological studies as necessary elements for the management of blue shark stocks. The study growth is one of the management plan objectives, it's performed to know the growth mode of this species and secondly the growth parameters necessary for the evaluation models.
In this work, devoted to blue shark growth, both types of growth were studied, using the size distributions to determine the linear growth of this animal and using weight-length measurement data to determine weight growth.

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2. MATERIALS AND METHODS

Biological sampling sessions were conducted during 2015-2017 once a week at the Casablanca wholesale market, which receives blue shark landings from different ports. The origin of the sample was also noted in order to know the area where the animal was captured. Generally, the wholesale market receive the merchandise at 2:00 am and the sales start at 05:00 am, that is why the biological sampling was done before this time to ensure good conditions of job. The total length (TL) of the blue shark individuals (straight line along the body axis with the caudal fin placed in a natural position) was measured to the nearest centimeter using a tape measure. The nature of sex and weight (if conditions allowed) were also noted.

-On the other hand, and to compare the results of different authors who used fork length (FL) or standard length (LS), the total length (TL) of sampling individuals were converted according to the Eq.(1) given by (Kohler and al. (1996) [3]:

$$FL = a \times TL + b \quad (1)$$

Where: **a**= 0.8313 and **b**= 1.3908

or according to the Eq.(2) of Buencuerpo and al. (1998) [4] :

$$TL = 1.262 \times SL + 5.746 \quad (2)$$

In addition, the data from this sampling were analyzed in order to highlight the variations in size structures over time and according to the sex of the animal and the fishing gear used. Structures in global sizes were also processed to estimate first the parameters L_∞, K, t_0, Z, M required for blue shark stock assessments and secondly to define the linear and weight growths of this animal.

2.1. Estimation of growth parameters:

The size structures were used as inputs to turn the FISAT software which is a tool for evaluating stocks and also used to estimate growth parameters. One of the methods proposed on FISAT to estimate the L_∞, K, t_0 parameters is the ELEFAN method, it is a routine that can be used to identify the growth curve that "best" fits a set of length-frequency data [2].
The growth curve is thus plotted according to the eq.(3) of Von Bertalanffy (1938) [5], a universally used equation in fisheries biology:

$$L_t = L_\infty \times (1 - e^{(-K(t-t0))}) \quad (3)$$

L_t: length of fish at time t.
L_∞: asymptotic length that would be reached by the fish at infinite theoretical age.
K: growth rate with which the species grows towards its asymptotic size.
t_0: theoretical age for which the size is zero.

The value of t_0 is replaced by L_0 because the length of the animal at birth is easily given [6]. The Eq.(4) is then given:

$$L_t = L_\infty - (L_\infty - L_0) \times e^{kt} \quad (4)$$

2.2. Estimation of mortality rates

This software also made to estimate the total mortality rate "Z" and natural "M". The usefulness of these two mortalities lies in the knowledge of the exploitation rate "E" and the fishing mortality "F". Also these parameters are used to evaluate blue shark stock.

The estimate of Z mortality was estimated by the "catch curve" method based on length composition. The x-axis corresponds to log (N / dt) where « N » is the number of fish in the length class i, « dt » is the time required for the fish to grow through the length class i, « t » is the age (or the relative age) corresponding to the mid-length of class i, and where b, with the sign changed, is an estimate of Z. The aim consists in looking for a linear regression between the points excluding the age classes considered partially exploited and the size classes considered very close to L_∞.

On the other hand, natural mortality was estimated by the Eq.(5) of Pauly (1980) [7]:

$$\text{Log } M = -0.0066 - 0.279 \text{ Log } L_\infty + 0.6543 \text{ Log } (K) + 0.4634 \text{ Log } (T) \quad (\mathbf{5})$$

With **T** = 18 ° (mean temperature in Moroccan waters)

The two mortalities used to estimate the exploitation rate "E" Eq.(6), give an idea of the proportion of the stock taken by the fishing and subsequently to know the state of the stock.

$$E = F/Z = F/ (M+F) \quad (6)$$

If **E** <0.5: stock under exploited
E = 0.5 equilibrium stock [8]
E> 0.5: overexploited stock.

2.3. Weight growth

The blue shark grows in both size and weight, the relationship between these two parameters is given in the Eq.(7) of Ricker (1980) [29]:

$$W = a \times L^b \quad (7)$$

W: individual weight of the fish (gram);
L: Length of the individual (centimeter);
a: Condition coefficient;
b: Allometric coefficient.

When "b" is close to 3, the weight increases proportionally with the length. On the other hand, b values clearly different from 3 indicate an allometric or asymmetric growth. If b> 3, the weight grows faster than the length and the allometry is therefore greater; If b <3, the weight grows less quickly than the length and the allometry is therefore minor [24].
By combining the two equations 3 and 7, the weight growth equation becomes Eq.(8):

$$W_t = W_\infty (1- e^{(-k(t-t_0))})^b \quad (8)$$

$\mathbf{W_t}$: Weight at time t;
$\mathbf{W_\infty}$: asymptotic weight corresponding to L_∞ ($W_\infty = a \times L_\infty^b$);
K and $\mathbf{t_0}$: Parameters of the linear growth equation.

3. RESULTS AND DISCUSSION

3.1 Size structures

505 individuals, both sexes, were measured during the three years. The sizes are distributed over a range of classes between 50 cm and 340 cm (TL). The size range that dominates blue shark landings is between 120 to 150 cm with a modal class of 130 cm, an average size of 173.83 cm and a maximum size of 340 cm (Figure 1). The maximum size observed in this study is close to that observed on the east coast of Canada by Mac Nel and Campagna (2002) which is 282 cm FL equivalent to 337 cm TL [9]. Offshore Japan in the Pacific Northwest, the maximum blue shark size is 320 cm FL corresponding to 383 cm TL [10]. There is a clear difference between the results of this study and those from the South Atlantic off Brazil and in Caribbean waters and adjacent waters of the North Atlantic. The maximum size recorded in the first zone is much smaller corresponding to 224 cm FL, equivalent to 268 cm TL [11] and that of the second zone is much larger with a maximum size of 350 cm FL equivalent to 419 cm TL [12].

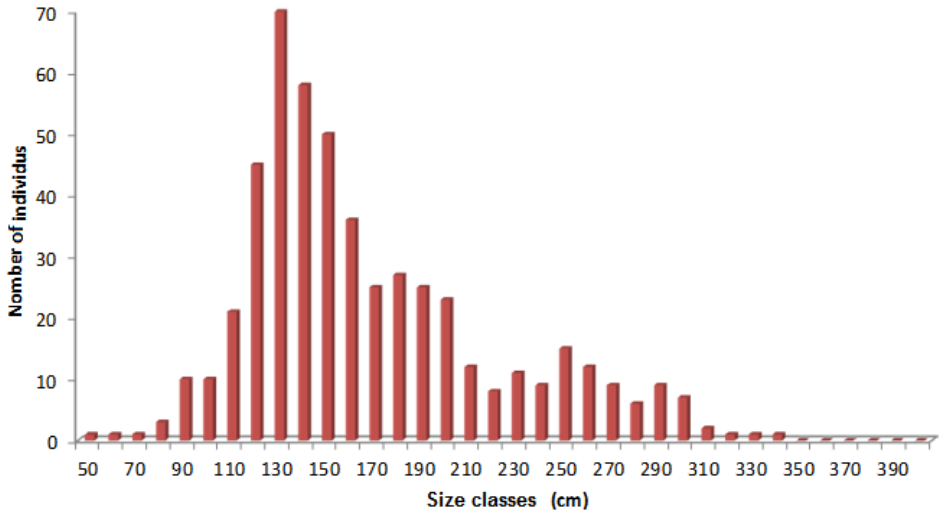

Figure 1: Distribution of blue shark sizes in Moroccan waters (2015-2017).

In addition, by analyzing these data, it has been found that the exploited fraction of the blue shark population in the Moroccan zone includes four cohorts (group of individuals all of the same age and belonging to the same stock). The same finding was noted in a study by Moumni (2005) where the size structure also presented four cohorts (Figure 2)[13].

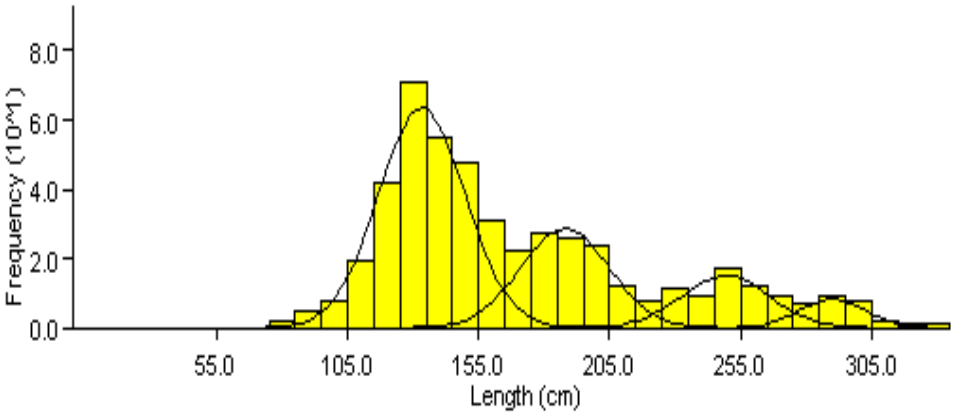

Figure 2: Schematization of the four cohorts representing the exploited fraction of the blue shark stock in Moroccan waters.

The catch curve based on size distributions made it possible to estimate the total mortality rate of the order of 0.74 / year, and the age of first capture estimated at more than two years (Figure 3). The natural mortality rate calculated by Pauly's method is estimated at 0.26 / year. From these two mortalities, it was possible to calculate the exploitation rate which is about 0.65. This value is greater than the exploitation rate in equilibrium.

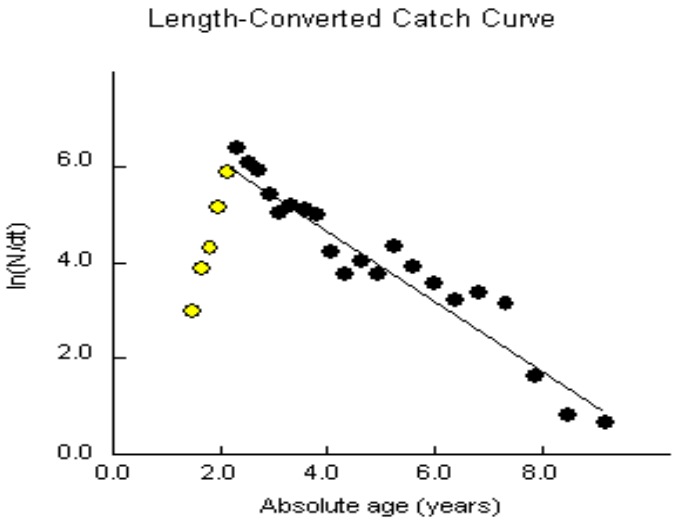

Figure 3: linear regression between the points excluding the age classes considered partially exploited (yellow dots) and the size classes considered very close to L∞.

Comparing these results with those found by Moumni (2005), it was found that the current exploitation rate is lower than that of 2004-2005 [13]. Yet both values remain above the equilibrium exploitation rate, which suggests that the stock may be in a state of overexploitation. Normally, the decision on the state of exploitation of the stock should be pronounced only if the evaluation studies were made at the regional level by grouping all the results of the studies conducted on this species in the North Atlantic area (stock North). Indeed, studies of stock assessments of the North Atlantic have been executed and have indicated that the stock is far from overfished [14].

Interannual size structures

The frequencies in sizes of the two years 2015 and 2016 showed almost the same distribution with a modal class located at 130 cm and mean sizes equivalent respectively to 167.27 and 198.63 cm. It is clear that the individuals in the sample of 2016 are larger than the individuals sampled in 2015. The distribution of the year 2017 showed a

different modal class that is located at 150 cm and the calculated average size is 164 cm, this size is even smaller than the average sizes of the previous two years (Figure 4).

It is interesting to note variations in size distributions in the southwestern Atlantic where Hazin et al., (1994) found that blue shark individuals' sizes in the year 1990 were larger than the current modal classes. This means that shark fishing is important and the stock is likely to be overexploited [15]. Also according to Vögler and al., (2012), the catches were dominated by the matures before the 2000s, above the juveniles dominate the catches [16].

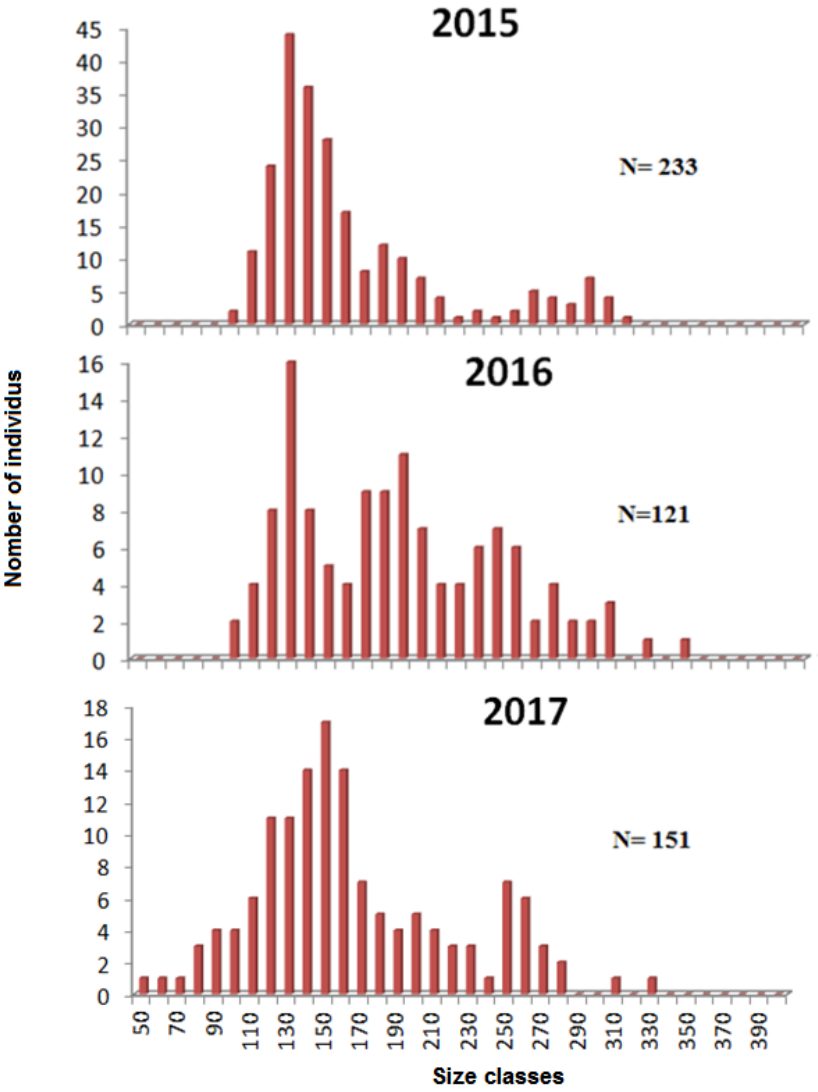

Figure 4: Interannual variations of structures in blue shark sizes

Size structures by sex

The size distribution of females showed a clear dominance of individuals belonging to the size class 130 cm. The males have a main mode grouping together the two classes of size 130 and 140 cm. The largest female size of 300 cm is below the maximum male size of 340 cm (Figure 5)

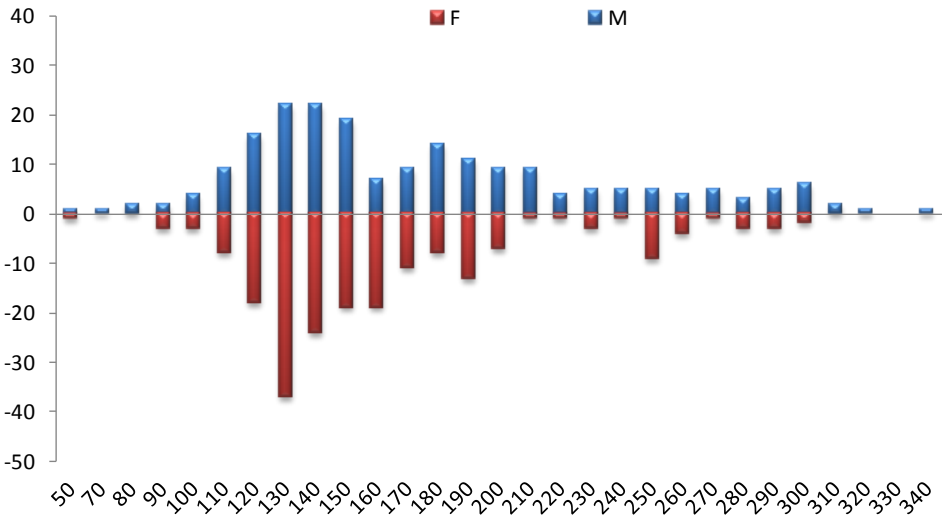

Figure 5: Structures in catch size of both sexes of the blue shark.

From a statistical standpoint, 50% of the female sample comprises individuals of sizes between 50 and 150 cm. The rest of the sample contains individuals larger than 150 cm. For males, 50% of the sample is distributed over a size margin between 50 and 160 cm and the remaining half on a margin between 160 and 340 cm (Figure 6).

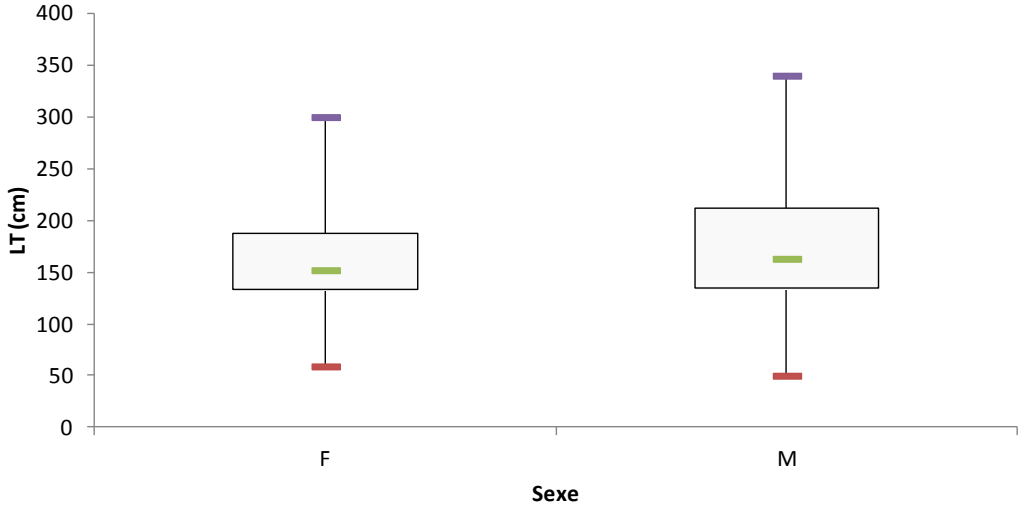

Figure 6: Distribution of the different quartiles.

The average size, estimated at 166.45 cm for females, is less than the average male size of 181.10 cm. The comparison between the two averages was done by statistical tests. The Kolmogorov-Smirnov test [28] showed that the size distribution of the two sexes does not follow the normal distribution, the reason why the Wilcoxon non-parametric test was chosen [28]. The latter confirmed that the sizes of the females are smaller than the sizes of the males (Table 1).

Table 1: Statistical tests used for comparison between mean sizes of males and females;

Test Kolmogorov-Smirnov	H_0: Distribution of sizes of males follows the normal distribution H_1: Distribution of sizes of males doesn't follow the normal distribution	D : 0,14883 p=0.000528 H_0 is rejected
	H_0: Distribution of sizes of females follows the normal distribution H_1: Distribution of sizes of females doesn't follow the normal distribution	D : 0,1519 P = 0.000514 H_0 is rejected
Test Wilcoxon	H_0: the average of the males = the average of the females H_1: The average of the females is lower than the average of the males	W : 14118 p val= 0,006047 H_0 is rejected

The dominance of larger sizes in males was also observed at the eastern Canadian coasts [9] where the modal classes of both sexes are 170 cm (FL) for females and 170 cm and 240 cm (FL) for males. Also in the southwestern part of the equatorial Atlantic blue shark sampled individuals showed larger modal classes in males than in females, respectively 206-215 cm (FL) and 186-195cm (FL) [15]

Monthly size structures

The monthly evolution of blue shark sizes over the three years showed that the structure differs from month to month. Some months have peaks in small and large classes, while others show almost equal percentages of different size classes. The average percentage of individuals in the three years by size class showed that small individuals start to dominate catches mainly during the months of May-June and December, while large individuals show a predominance of catches during the months of March and November (Figure 7).

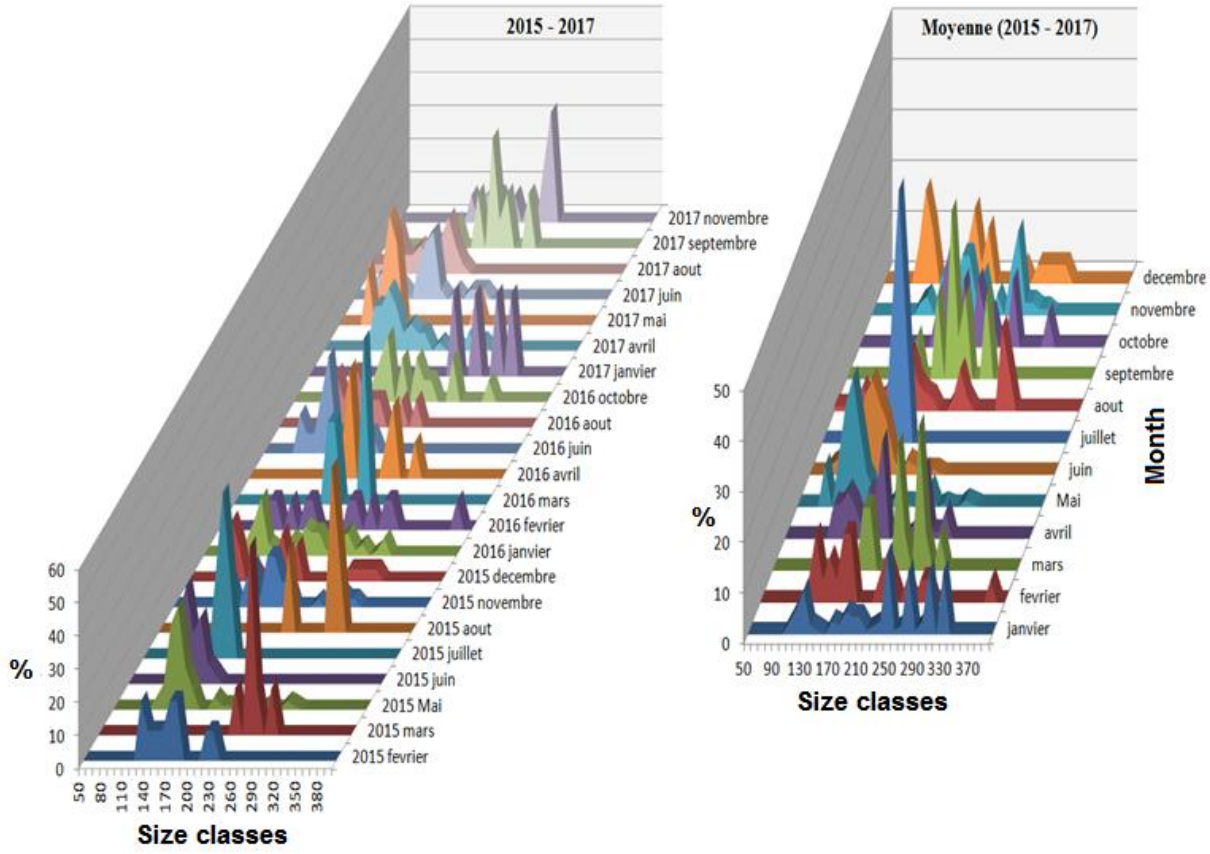

Figure 7: Monthly distribution of size frequencies.

The analysis of this structure by the quartile method showed that indeed the months May, June and December present a maximum of individuals of small sizes. The first quartile representing 25% of the sample corresponds to sizes 130; 129.5 and 122 cm respectively. It appears that the months December, May and June correspond to recruitment of young individuals to the exploitable population (Figure 8). In the region of the Azores Islands, Vandeperre (2014) showed that catches were strongly dominated by juveniles, with higher catch rates during the winter months [17].

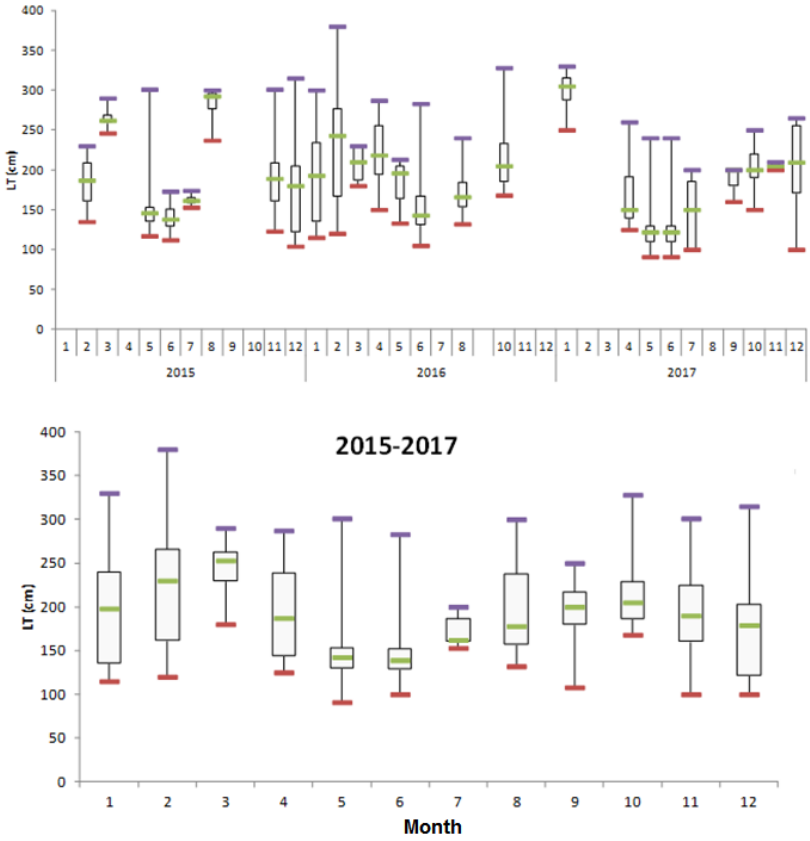

Figure 8: Monthly evolution of the medians of the samples.

Size structure by fishing gear

It was necessary to analyze the size distribution according to the gear used to see if there is a difference in size distribution. In fact, individuals from net catches are generally smaller than those caught by surface longlines (Figure 9). Surveys of fishermen have indicated that the fishing areas exploited by the «bonitard» net are close to the coast, suggesting that blue shark juveniles colonize the shallow waters. It is therefore necessary to take into consideration the two gears used during biological sampling sessions in order to arrive at more correct assessments

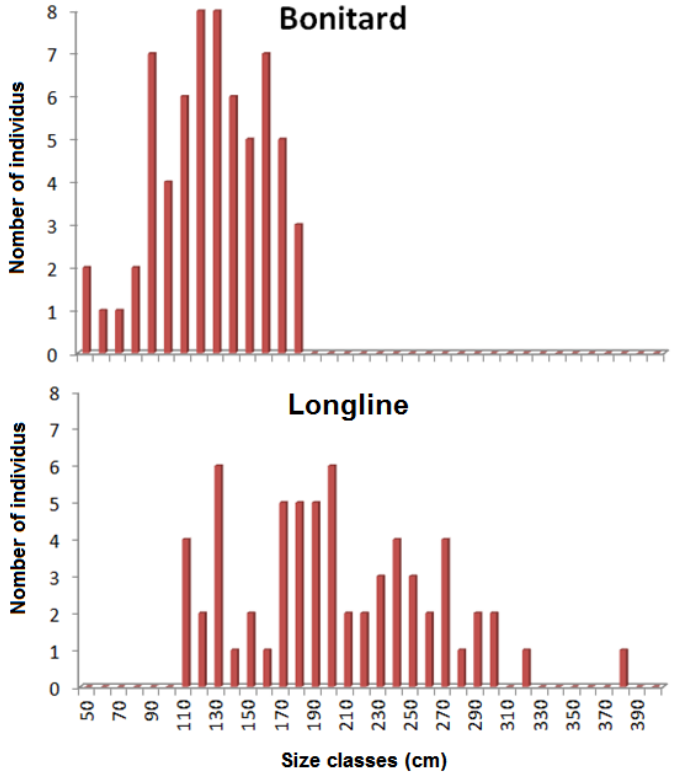

Figure 9: Size distribution of blue shark according to fishing gear.

3.2 Linear growth

Age reading operations were conducted in the INRH Biology Ecology laboratory to directly determine the age of sampled individuals (Figure 67). Unfortunately, the number of vertebrae handled did not lead to convincing results; the information on the date of capture, the size of the individual ... are generally lacking. The estimating age via size structures has been used as an alternative method. The estimated growth parameters for the shark in the Moroccan area are: L_∞ = 392.4 cm (TL), K 0.21 / year and t_0 = -0.402 year.

These parameters made it possible to plot the blue shark growth curve, which clearly shows that the growth rate is very high during the first five years of blue shark age, then decrease between five and ten years and becomes slower at beyond this age (Figure 10).

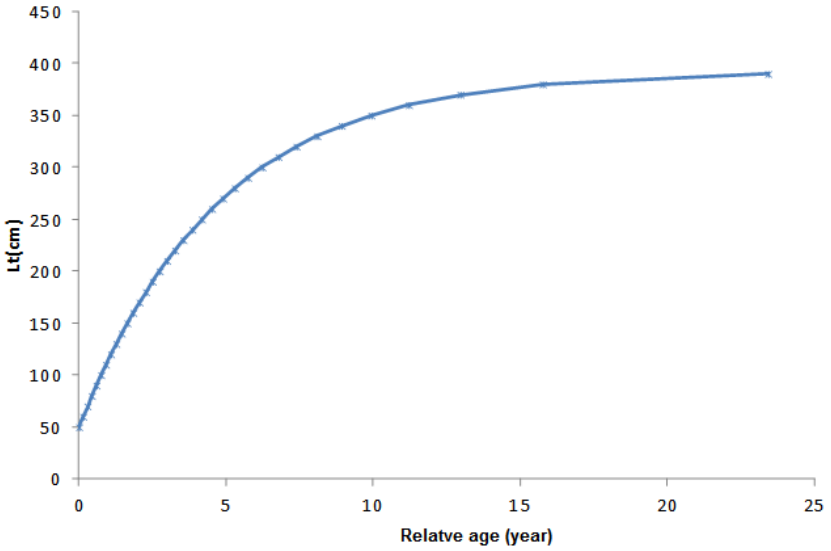

Figure 10: Linear growth curve of blue shark in Moroccan waters.

Growth parameters of this species have been reported in different regions of the world (Table 2). In the North Pacific, Nakano (1994) determined blue shark growth parameters for both sexes from direct vertebral reading. The L_∞ of females is lower than that of males [18].

In California, the asymptotic age in blue sharks is around 20 years with an L_∞ of 265,5 cm (TL), K = 0.223, t_0 = -0.802 [19]. Off the North-East of Brazil the estimated growth parameters are : K = 0.157, L_∞ = 352.1 cm and t_0 = -1.01 years [20]. In the Southwest Atlantic, off Brazil, the parameters were given with an L_∞ equal to 352.1 cm [21].

In the North Atlantic off Cape Hatteras, Skomal (2002) estimated L_∞ at 285.4 FL [22]. The same author mentioned the longevities of males and females who were respectively 16 and 15 years old. Both sexes, according to the same author, had grown similarly up to 7 years, at which time the growth rate had decreased in males while it remained constant in females. Other authors such as Carvalho an al. (2014) and Tanaka and al., (1990) reported values of growth parameters, found since 1966 in five different areas [23, 24].

Tableau 2: Summary of different growth parameters of blue shark

		L_∞ (cm)	K (an-1)	T_o (an)
Maroc		392.5 LT	0.21	-0.402
Pacifique nord (Nakano., 1994)	Femelles	243.3 LS (312.79 LT)	-0.144	-0.849
	mâles	289.7 LS (371.34 LT)	-0.129	-0.759
Californie (Cailliet et al., 1983)		265.5 (LT)	0.223	-0.802
Atlantique Sud-ouest (Lessa et al., 2004)		352.1 LT	0.1571	-1.01
Atlantique nord (Skomal et Natanson, 2002)		285.4 LF (341.64 LT)	0,17	-1.41

3.3 relationship weight-length

Measurements in weight and length of almost 130 individuals of the blue shark, both sexes, could reveal the relationship between weight and length according to the eq.(9):

$$W = 0.000003 \times LT^{3.0389} \quad (9)$$

The coefficient b is almost equal to 3, which indicates that the blue shark has isometric growth and therefore both variables, length and weight, have the same growth rate. Length-weight relationships for the two sexes separately showed results similar to those of the combined sexes (Figure 11).

Studies on the relationship weight-length of this animal worldwide have shown a different finding, it may be related to the conditions of the environment where the blue shark lives (water temperature, salinity, diet ...).

In the northwestern and southwestern Atlantic, the results given showing a slight allometric increase ($W = 0.000003841 \times FL^{3,113}$ [3]) and ($W = 0.00000157 \times FL^{3.104}$ [25]). Other published results have shown that the blue shark's weight-size relationship generally represents a constant b greater than 3 in the Pacific Ocean and sometimes less than 3 in the Atlantic Ocean [26].

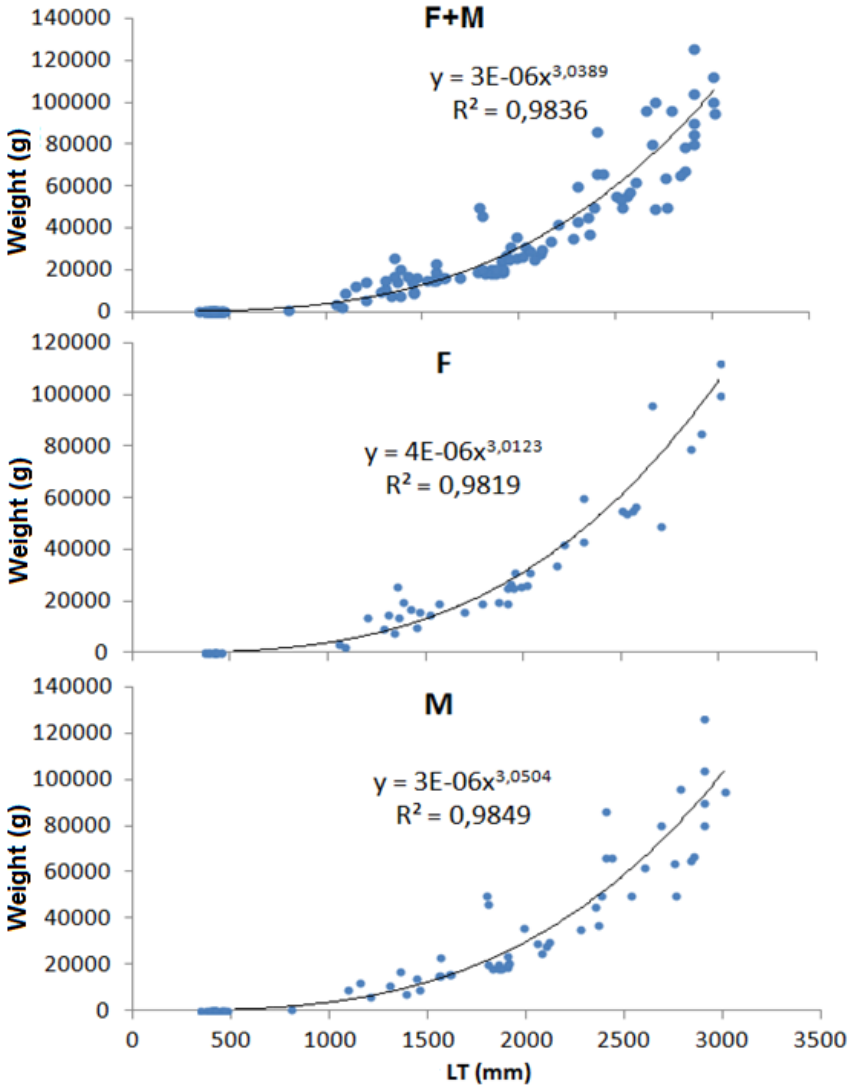

Figure 11: Weight-length relationship of the blue shark.

3.4 Weight growth

The weight-length relationship was used to establish the weight growth curve that shows that the weight growth rate is low during the first age of the animal. An individual who has a length of 47 cm at birth weighs about 300 g. It appears that young individuals grow more in length than in weight during their first age. From the age of 2, the growth rate begins to increase rapidly until the age of 10 years. Beyond this age, growth in weight slowed down and continued with a lower rate until the age of 20 when it began to stabilize (Figure 12).

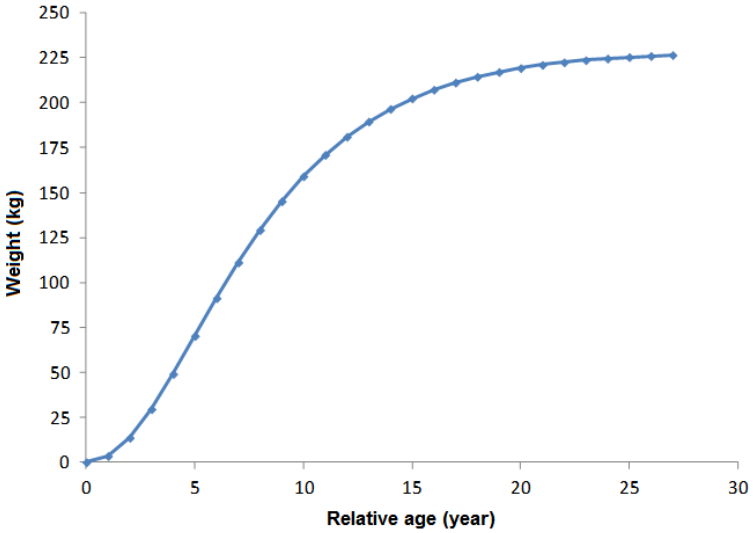

Figure 12: Weight growth curve of blue shark.

4. CONCLUSION

The blue shark in Moroccan waters has a wide margin of size; with the most dominant sizes exist between 120 and 150 cm TL. Mean sizes of males and females of 184.37 cm and 164.71 cm respectively, indicated that male sharks are larger than females.

The size distribution analysis could show a clear difference related to the finshing gear used. In fact, small individuals are caught more by the bonitard net than by the drifting longline. The difference is almost very clear between the seasons; juveniles dominate catches during the months of May, June and December. During these periods, it was noted the appearance of gravid females at term, suggesting that the farrowing can be done twice a year in the Moroccan zone. The first gives birth to pups during the winter, which grow for almost six months and appear in the catches during the months May-June. The second is around the month of May giving birth to pups that grow and appear in catches in the months of December-January.

The growth parameters estimated at L_∞ = 392.4 cm (TL), K 0.21 /year and t_0 = -0.402 year indicate, with reference to other results, that the blue shark has a long life. Maximum age of the shark exceeds 20 years, the reason for which this animal must be protected against overfishing. In terms of weight growth, this animal grows in size and weight symmetrically and can reach a maximum weight of more than 200 kg at 20 years of age.

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