Age and growth of *Mustelus schmitti* (gatuzo), in the coastal region of Buenos Aires and Uruguay

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SUMMARY

The age, growth, and longevity of *Mustelus schmitti* (gatuzo) were estimated from the reading of vertebrae of 193 males (39-90 cm of total length) and 226 females (39-95 cm LT). The curves of growth were adjusted with length data by age using traditional models of three von Bertalanffy and Gompertz parameters and the variants thereof with the length of the fish at birth L_0 fixed. The von Bertalanffy growth function with fixed L_0 (VBGF-2 parameters), although it has not been statistically selected as the model with the best fit, provided the biological parameters with values closer to those observed and / or biologically reasonable. The estimated parameters were $L\infty$ = 96.4 cm LT and k = 0.128 year $^{-1}$ in males and $L\infty$ = 104.1 cm LT and k = 0.109 year $^{-1}$ in females. The longevity was calculated in 20.8 years and 24.7 years in males and females, respectively, while the Age of first maturity was estimated at approximately 4 years for both sexes.

INTRODUCTION

Mustelus schmitti (gatuzo) is the shark most landed by the Argentine commercial fleet (~ 8,000 t per year) (Massa and Hozbor, 2003). It is distributed in South American Atlantic waters between 22º S (Brazil) and 47º 45'S (Argentina), up to 120 m depth (Menni, 1985; Cousseau and Perrotta, 2000; Chiaramonte and Pettovello, 2000). The area of greatest concentration corresponds to the Buenos Aires and Uruguayan coastal area (34º and 41,5º S), at depths less than 50 m. (Figure 1). In this region it is captured throughout the year, mainly as part of a multispecific fishery that operates on the varied coastal (Massa *et al.,* 2004).

Various studies on distribution, abundance, feeding and reproductive aspects have been carried out on this species (among others Menni, 1985, Menni *et al.,* 1986, Cousseau, 1986; Cousseau *et al* ., 1998, Massa 1998; Massa and Lasta, 1999). In age and growth of *M. schmitti* exists in the bibliography a study made from the analysis of modal progression, without discriminate by sex (Massa, 1998). According to Massa (1998), *M. schmitti would* reach sexual maturity approximately at 2.7 years and would grow up to 60% of the maximum length in the first 2 years of life. These values were reported as preliminary, since they should be corroborated by reading growth rings in vertebrae (Massa *et al* ., 2004).

Its biological characteristics (small size, annual reproductive cycle, maturity size) early, among others) and the relatively high biomass values, would allow exploitation sustainable within the group of sharks that are distributed on the Continental Shelf Argentina (Massa *et al.,* 2004). However, the limited information on age validated and growth, makes it impossible to estimate demographic parameters, which are essential for know the productivity of the species subject to exploitation.

The objective of the present study was to estimate the age and growth parameters of gatuzo captured in research campaigns, in the Buenos Aires and Uruguayan coastal area (Figure 1), from the analysis of the vertebrae. We compare 2 growth models and 2 variants of the themselves to determine which of the growth functions provides the best fit to the data.

❖

Figure 1. Study area and fishing hauls where the specimens of gatuzo analyzed.

MATERIALS AND METHODS

The *M. schmitti* specimens were captured during 2 research campaigns carried out by the research vessels of the INIDEP, in the Buenos Aires and Uruguayan coastal area, depths less than 50 (Figure 1) during the years 2003 and 2004. From each individual was recorded the total length (cm), the weight (gr) and the sex. To determine the age, a section of the spine containing 5 to 10 vertebrae, from the region below the first fin dorsal. They were kept frozen until processed in the laboratory.

The vertebrae were cleaned with a 1% solution of endopeptidase serine alkaline (Protex 6L) and then allowed to dry for 24 hrs. The dry vertebrae were mounted on epoxy resin and

then cut sagittally through the focus. The cuts were observed under a microscope stereoscopic with incident light.

The growth patterns of the vertebrae consisted of narrow translucent bands (hyalines) separated by broad bands (opaque). The age of the specimens was estimated from number of hyaline bands minus one, assuming that the first hyaline band corresponded to the birthmark, since it coincided with the change of angle (Figure 2).

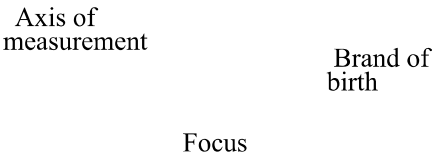

Figure2 Sagittal section of a vertebra of *M. schmitti*

The radius of the vertebra was measured from the focus to the edge, along the axis of the corpus calcarium. The total length (LT) of the specimen was plotted against the radius of the vertebra (RV) to determine if there is a relationship between the growth of the vertebra and somatic growth of the animal The correlation coefficient was calculated and the best regression function between RV and LT. The relationships found in males and females were compared through a Slope and elevation test, using the Student's "t" statistic.

Each vertebra was read independently by 2 readers. To establish the precision in the age estimation the average percentage error (APE) was used (Beamish and Fournier 1981):

for the *jth* individual. In addition, the coefficient of variation (V) was calculated (Campana *et al.* nineteen ninety five).

where *N* is the number of individuals, *R* is the number of times the sample was read, *Tij* is the *i*- th age determination of the *jth* individual, *Tj* is the calculated average age.

Each individual was assigned an average age calculated from the readings performed by the 2 readers. The growth parameters were estimated through the adjustment to the models of Traditional growth (3 parameters) of both von Bertalanffy (MCVB) and Gompertz (MCG). As well as the variant with fixed L_0 of each model was used, incorporating $L_0 = 27$ cm LT (Cortés and Massa, 2006).

MCVB-3 parameters (von Bertalanffy 1938)

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MCVB-2 parameters

MCG-3 parameters (Gompertz 1825),

MCG-2 parameters

where L_∞ , K and L_0 are the parameters of the model, and L_t is the total length at age t , L_∞ is the Asymptotic length, k is the parameter of curvature and determines how quickly an organism reaches L_∞, L_0 is the total length at birth and G is the instantaneous rate of growth at time t.

The estimation of the growth parameters was made using an estimate not linear by the least squares method and with the Marquardt algorithm. As a measure of kindness Adjustment was used:

- the analysis of the mean squared error of the residuals (MSE), given by SCR / glr. where glr are the degrees of freedom of the residuals in the analysis of variance of the non-linear regression and SCR represents the sum of squares of the residuals (or error) and is the part of the variance not explained by the model.

- coefficient of determination (r^2) given by (1- SCR / SCT) where SCR and SCT represent the sum of squares of the residuals and of the corrected total, respectively.

❖ The Akaike information criterion (AIC).

where n is the number of individuals, MSE is the mean square error of the residuals and p is the number of parameters estimated in the growth function (Haddon, 2001).

The three parameters of the von Bertalanffy growth equation obtained for each sex were compared simultaneously using a multivariate Hotelling T_2 test (Bernard, 1981), but with the formulation proposed by Cerrato (1990), according to the following equation:

where N_1 and N_2 represent the amount of sharks in the two groups to be compared and $[P_1 - P_2]$ is the difference vector of the growth parameters, $[P_1 - P_2]'$ is the transposed vector of $[P_1 - P_2]$ Y is the inverse matrix of variance-covariance of the vector difference of the parameters of increase.

Considering "H_o : Equality of vectors of growth parameters between the sexes", the hypothesis H_{or} is accepted if T_2 calculated, is lower than the critical value, obtained by means of the following expression:

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In the equation F corresponds to the percentile of Fisher's distribution with 3 and N1 + N2 - 6 degrees of freedom. The test considers as null hypothesis that the vectors of the parameters of growth are equal and rejects when the calculated is greater than the critical value.

Longevity was estimated as the age at which an individual reaches 95% of L∞ (Taylor 1958). For the MCVB it was obtained by means of the following equation:

$$Longevity = \left(\frac{1}{k}\right) \ln\left[\frac{\left(L_\infty - \left(L_\infty - L_{or}\right)\right)}{L_\infty * 95.01}\right]$$

and for the MCG:

$$Longevity = \left(\frac{1}{k}\right) \ln\left[\frac{\ln\left(\frac{L_0}{L_\infty}\right)}{\left(* 95.0 \ln L_\infty\right)}\right]$$

RESULTS

The vertebrae of 421 *M. schmitti* specimens (196 males and 225 females) were analyzed. captured in the area of highest concentration (Figure 1). The size range was included between 39 and 90 cm TL (average = 65.48 cm and median = 68 cm TL) in males; and in females from 39 to 95 cm TL (average = 69.8 cm and median = 73 cm TL). 50% of the copies analyzed corresponded to individuals between 54 and 76 cm TL (males) and between 60 and 81 cm TL (females) (Figure 3). The specimens between 39 and 53 cm of LT and between 77 and 95 cm of LT they accounted for only 19.5% and 32.3% of the total sample (Figure 3).

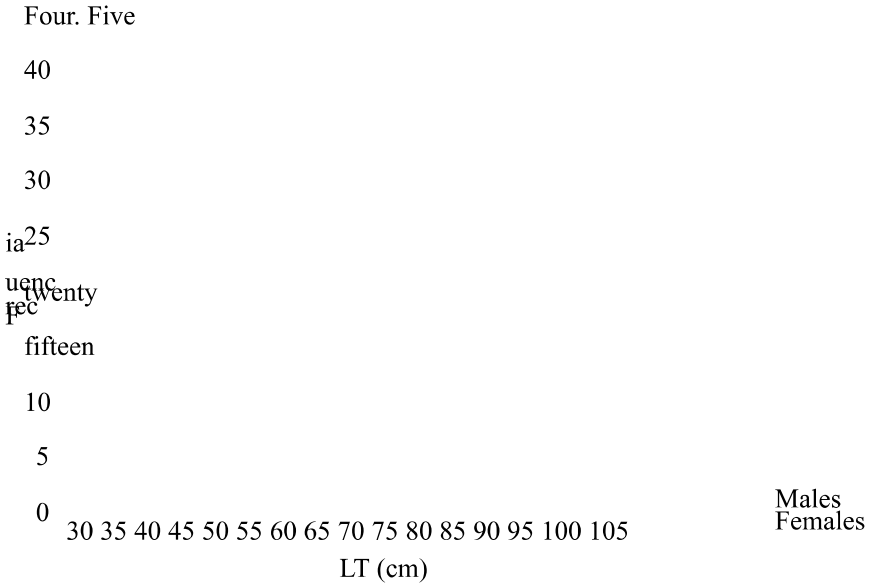

Figure 3: Frequency of sizes by sex of the *M. schmitti* specimens analyzed.

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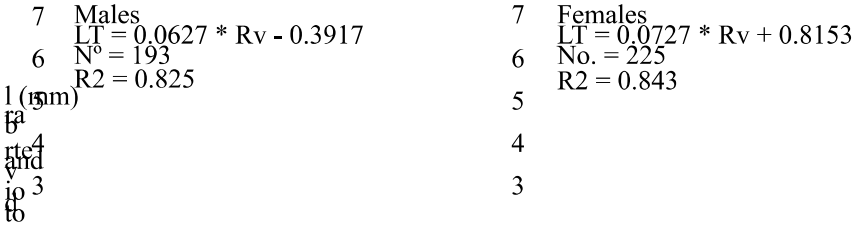
The relationship between the radius of the vertebra (Rv) and the total length (LT) of the specimen, indicated a significant correlation of linear type ($p < 0.05$), both in females and in males (Figure 4). He increase of the vertebra with the total length of the individuals showed that this structure was suitable for determining age (Figure 4). It was determined that there are differences of this relationship between the sexes, both in the slope ($F = 20.86$, $P < 0.001$) and in the intercept ($F = 23.23$, $P < 0.001$). The coefficient of determination was 0.82 and 0.84 in males and females respectively, indicating a directly proportional relationship between the two variables (Figure 4).



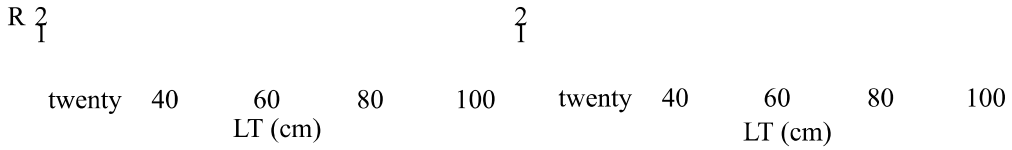


Figure 4. Relationship between the radius of the vertebra (mm) and the total length (cm) in *M. schmitti* .

Only 5 vertebrae of the total analyzed were discarded from the analysis, since they were not enough readable The comparison of the two independent readings indicated that the determination of age it was consistent and with high precision (APE = 6.9%). In addition, the coefficient of variation was calculated (CV), obtaining a value of 9.7%, indicating that the variation between the readings was low according to the values reported by Campana (2001).

The ages estimated in males (n = 193) varied between 1 and 14 years, predominating individuals between 3 and 5 years old with 32% and between 7 and 9 years old with 31.6% of the total number of males analyzed (Table 1). In females (n = 223) the ages varied between 2 and 16 years, being more the specimens of 5 to 6 years old are frequent; and from 8 to 10 years, representing respectively 18.2% and 34.2% of the total number of females analyzed (Table 1). The largest female was 95 cm LT with 13 years and the oldest was 16 years with 92 cm of LT. In males the maximum size registered was 90 cm LT (10 years) and the maximum age determined was 14 years with 83 cm of LT (Table 1). Considering the average sizes by age, it was observed that the growth was similar in both sexes until approximately 75-78 cm of LT, when they reach 10 years. Starting of that age the average sizes of the females were higher than those of the males (Table 1), coinciding with that reported for other shark species Carcharhinformes (Hoening and Gruber 1990).

TABLE 1: Average total lengths (cm) observed, standard deviation (SD), minimum lengths - maximum (Min-Max) and number of individuals (No.) by age by sex.

	MACHOS				FEMALES			
	Average	**Age SD**	**Min-Max**	**Nº**	**Average**	**Min-Max**	**SD**	**Nº**
1	39.0	0.00	39-39	2				
2	42.7	1.74	40-45	eleven	43.8	39-48	2,66	10
3	47.4	3.82	41-54	17	47.7	40-54	4.40	15
4	52.9	3.89	41-60	24	50.3	43-58	4.96	12
5	58.2	4.33	49-66	twenty	59.1	53-66	3,10	21
6	63.0	4.94	52-73	fifteen	62.3	53-69	3.42	20
7	70.8	6.60	58-83	twenty	68.0	59-82	6,13	17

8	75.8	5.54	67-84	16	73.8	64-82	5.62	20
9	76.5	3.18	71-82	25	77.8	65-89	6.38	29
10	77.9	5,19	68-90	fifteen	78.5	66-88	5,01	28
eleven	77.0	2.78	70-82	fifteen	80.4	72-93	5,49	17
12	79.4	4.35	75-85	7	83.0	76-93	6.56	7
13	76.5	0.71	76-77	2	83.3	76-95	5.58	15
14	80.0	4.36	75-83	3	86.0	81-94	3.93	8
fifteen				2	88.7	84-93	4,51	3
16					92,0	92-92		1

Table 2 shows the estimated parameters and the goodness of fit measures of the the growth models of von Bertalanffy (MCVB) and of Gompertz (MCG). The parameters of the von Bertalanffy equation of females and males were significantly different (T_2 = 9.97> = 7.92, p <0.0001). Therefore, all the models were adjusted to size-age data of males (n = 193) and females (n = 223), for each sex separately.

TABLE 2: Estimated parameters and goodness-of-fit measures of the Von growth models Bertalanffy and de Gompertz, adjusted for size-age data of males (n = 193), females (n = 223).

MODEL	L∞	K	The	G	Age maturity	Longevity	R_2	AIC	MSE
Males N = 193									
Von Bertalanffy	90.8	0.163	21.5		4.1	16.7		86.8	612.3 23.1
with L_0 fixed	**96.4**	**0.128**	**27.0 ***		**4.0**	**20.8**		**86.5**	**614.1 23.6**
Gompertz	86.2	0.244	25.4	1.222	1.9	13.0		86.8	602.9 22.0
with L_0	87.3	0.227	27.0 *	1.173	2.2	13.8		86.8	600.9 22.0
Females N = 223									
Von Bertalanffy	100.1	0.125	23.9		4.4	21.8		85.6	740.9 27.0
with L_0 fixed	**104.1**	**0.109**	**27.0 ***		**4.3**	**24,7**		**85.5**	**738.9 27.0**
Gompertz	93.9	0.192	28.0	1.211	2.9	16.5		85.9	736.8 26.5
with L_0	93.0	0.200	27.0 *	1.237	2,6	15.9		86.8	734.0 26.4

* L_0 = 27 cm of LT (Cortés and Massa, 2006)

The adjustments of the growth models were highly significant (P <0.00001) (Table 2, Figure 6). Although the values of r_2, MSE and AIC were very similar between the models analyzed, the MCG presented better fit than the MCVB with high values of r_2 and the lowest values of both MSE and AIC (Table 2).

The asymptotic sizes (L∞) estimated from the traditional MCG (3 parameters) and with L_0 Fixed (2 parameters) were lower than the maximum length observed in both males (90 cm TL) as in females (95 cm TL) (Table 2. Figure 6). In contrast the traditional MCVB (3

parameters) and with fixed L_0 (2 parameters) provided values of L_∞ higher than the sizes maximum observed in both sexes. (Table 2).

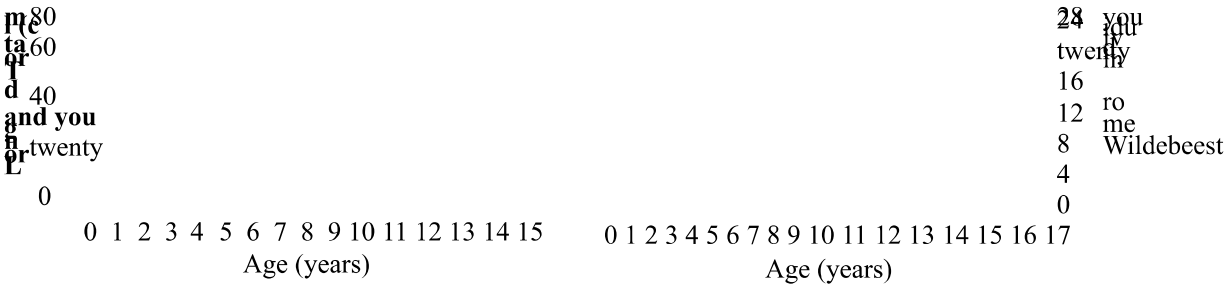


Figure 6. Estimated growth curves from observed height-age data in males and females of *M schmitti* .

The lowest growth coefficient (k) was obtained with the MCVB-2 parameters (k = 0.128 and 0.109 years $^{-1}$) in both males and females, while the highest value was provided by the MCG-2 parameters (Table 2). The size of birth (L_0), in general was underestimated, with values estimates that fluctuated between 21.5 and 25.4 cm of LT (Table 2).

The age of maturity was calculated from the mean maturity size 55 cm of LT for males and 56 cm TL for females estimated by Cortés and Massa, (2006). These sizes corresponded to ages between 1,9- 2,2 years in males and 2,6-2,9 years in females applying the Traditional MCG and with fixed L_0 , respectively (Table 2). With MCVB of 3 parameters and with 2 These parameters were estimated between 4 and 4.4 years (Table 2). The longevity was estimated in 13 and 16.5 years based on traditional MCG and in 13.8 and 15.9 years with MCG with fixed L_0 , for males and females, respectively (Table 2). The traditional MCVB estimated longevity at 16.7 and 21.8 years in males and females, respectively. While the MCVB with fixed L_0 estimated it in 20.8 years in males and 24.7 years in females (Table 2).

DISCUSSION

The present study provides the first detailed estimates of age and growth of *M. schmitti* , from readings of vertebrae. While the age estimates have not been validated, the annual formation of the growth ring was assumed, like other species of the *Mustelus* genus (Goosen and Smale, 1997; Conrath et al., 2002). The accuracy of the counts of the growth bands (APE) was good and the estimated value of APE (6.9%) suggests that the Age determination was reasonable. Studies on the age of other shark species (see Cailliet et al., 1990; Lessa et al., 1999) presented similar PSA values.

There are several models and variations of these for the estimation of parameters of growth in fish, of which von Bertalanffy and Gompertz are the most commonly used (See Ricker 1979, Haddon, 2001). The von Bertalanffy growth model (MCVB) has been applied to describe growth in fish, and the Gompertz model (MCG) has been used in the description of larval and juvenile growth in fish and in many invertebrates (Zweifel and Lasker, 1976; Ricker 1979).

Although in studies of age and growth studies have been centralized in the Adjustment of height-for-age data using the von Bertalanffy growth equation, in

recent studies (Cailliet and Goldman 2004, Carlson and Baremore 2005, Neer and Thompson 2005) has pointed out that the function of Gompertz could better describe the growth of animals, that a Once they have reached a maximum size, they continue to grow in weight and volume, but not in length. The selection of an appropriate growth model is important in estimating the specific parameters determined from age (mortality, growth, etc.), given that they are the basis of population dynamics models used in fisheries analysis.

In the present study, the von Bertalanffy (MCVB) and Gompertz models were applied (MCG) to estimate the growth parameters of *M. schmitti,* both in its traditional form with 3 parameters (L_∞, k and L_0) as well as the 2-parameter variant (L_∞ and k) setting the value of L_0 (27 cm of LT). These models provided highly significant adjustments to the observed data of length by age. The measures of goodness of adjustment considered in this study presented similar values between the curves analyzed.

The Gompertz model (MCG) underestimated the value of asymptotic size (L_∞), providing values less than the maximum observed length (90 cm in males and 95 cm in LT in females), both in its traditional form of 3 parameters and with fixed L_0 (2 parameters). Consequently, the rate at which it approaches the asymptotic length increases and, therefore, these models provided the highest growth coefficients (k).

In the case of the von Bertalanffy (traditional) model, he estimated the asymptotic size (90 cm and 100.1 cm of TL in males and females, respectively) in values close to sizes maximum observed, underestimated the value of the size of birth (L_0) 21,5 cm of LT in males and 23.9 cm of TL in females. Cortés and Massa (2006) have reported that gatuzo hatchlings at birth they present an LT of approximately 27 cm.

Finally, the von Bertalanffy model with fixed L_0 (2 parameters) provided the biological parameters with values closer to those observed and / or biologically reasonable. Estimated asymptotic sizes were 96.4 cm TL in males and 104.1 cm TL in females and the values of the growth coefficient (k) obtained from this model were the most low, 0.128 years^{-1} in males and 0.109 years^{-1} in females.

Among the parameters provided by the models, the growth coefficient (k) has has been very useful for the comparison of growth between species (Musick, 2001). Branstetter (1987) categorized the values of k as 0.05-0.10 years^{-1} for the species of slow growth, 0.10 - 0.20 years^{-1} for species with moderate growth, and 0.20-0.50 years^{-1} for fast-growing species.

The estimated growth coefficients in this study, 0.128-0.244 years^{-1} in males and 0.109-0.2 years^{-1} in females, would allow to conclude that the growth of the gatuzo in coastal waters Buenos Aires and Uruguayans are moderate when compared to other shark species. In others species of the genus *Mustelus* , have been estimated values that varied between 0.1 years^{-1} in males of *M. lenticulatus* at 0.695 years^{-1} in males of *M. manazo* . In females have been determined between 0.06 years^{-1} for *M. antarcticus* to 0.42 years^{-1} for *M. lenticulatus* (Tanaka and Mizue, 1979; Yudin and Cailliet, 1990, Moulton *et al.,* 1992; Francis and Francis, 1992; Yamaguchi *et al.,* 1996; Goosen and Smale, 1997; Conrath et al., 2002; Farrell *et al.,* 2010).

As in other species of the genus *Mustelus* , females and males of *M. schmitti* they grow in a similar way during the first years until approximately 75-78 cm of LT. Then, the average sizes by age in females were greater than in males, reaching maximum sizes greater in agreement with other shark species Carcharhinformes (Hoening and Gruber, 1990). This indicates that there would be a difference in growth between the sexes.

The asymptotic length of *M. schmitti* is in the middle range of the estimated L∞ values for other *Mustelus* species , ranging from L_∞ = 71.4 and 88.6 cm in males and females of *M. manazo* (Tanaka and Mizue, 1979) at L_∞ = 155.9 and 233.6 cm in males and females of *M. antarcticus* (Moulton *et al.,* 1992). Within the species of sharks of the genus *Mustelus* , *M. schmitti* represents a medium-sized species with maximum sizes between 90-95 cm TL, which reaches sexual maturity at average sizes, between 59 and 61% of the maximum length observed in the present study. Rojas (2006) determined that *M. dorsalis* needs to reach between 76 and 90% of the size total to mature while other *Mustelus* species have a proportionality between 49-56 % (*M. californicus)* (Yudin and Cailliet, 1990), between 52-66% *(M. henlei*) (Compagno, 1984), and between 51-58% *M. mento* (Compagno, 1984).

The minimum ages of maturity (1.9-2.9 years) estimated from MCG were similar to those reported by Massa (1998), determined from a study of modal progression of total length, without discrimination by sex. According to these values *M. schmitti would* reach almost 60% of the maximum length observed during the first two years, which does not coincide with the readings made in this study. On the other hand, the MCVB with fixed L_0 provided an age value of maturity closer to those observed, 4.3 years in females and 4 years in males.

The maximum ages observed by reading the vertebrae in the present study (14 years in males and 16 years in females), were higher than those calculated in other species of the genus *Mustelus* . Farrell *et al.,* (2010) estimated the maximum ages in 13 years for *M. asterias* , Conrath *et al.,* (2002) calculated the maximum ages between 10 and 16 years in *M. canis* .

The results of the present study allow us to conclude that *M. schmitti,* in the coastal area from Buenos Aires and Uruguay, has a moderate growth for a shark species and matures to a relatively early age. These characteristics could make *M. schmitti* more productive and possibly have a greater capacity to recover from exploitation fishery than other shark populations.

CONCLUSIONS

- The size range for the gatuzo in the Buenos Aires and Uruguayan coastal area was 39 to 95 cm of LT, with a size domain between 54 and 61 cm of LT.
- The relationship between the radius of the vertebra and the total length of the organisms is linear, indicating that there is a directly proportional growth between the structure and the body length
- The ages determined in the gatuzo specimens were from 1 to 14 years in males and 1 to 16 years in females, the most frequent being individuals between 5 and 10 years old.
- Despite not having been selected statistically as the model with the best fit, the MCVB-2 parameters was the growth function that provided the size values asymptotic (L∞), age of first maturity and longevity, more reasonable according to the observed values.
- The parameters of the von Bertalanffy growth model with fixed L_0 (27 cm LT) for the species were: L_∞ = 96.4 cm LT; k = 0.128 $year^{-1}$ in males and L_∞ = 104.5 cm LT; k = 0.109 $year^{-1}$ in females .
- The results suggest that the gatuzo, *Mustelus schmitti* , presents moderate growth

compared to other shark species.

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