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Swordfish growth pattern in the strait of Gibraltar; implications for Atlantic and Mediterranean stock mixing

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Abstract

A growth study of the swordfish in the Strait of Gibraltar was carried out, based on monthly size frequency data collected from the Moroccan driftnet fishery during the period 2006-2011. The growth parameters were estimated by the modal progression analysis (MPA), using both the Bhattacharya and NORMSEP methods. The standard von Bertalanffy growth function (VBGF) for length was found to be: $L_t = 253.6\ [1 - exp\ (-\ 0.17(t + 1.30))]$. The growth pattern of swordfish in the Strait of Gibraltar was found to be very similar to that obtained from past studies in various Mediterranean areas. Given the existing growth differences among Atlantic and Mediterranean swordfish, this suggests that the majority of fish caught in this area most likely belong to the Mediterranean stock. However, further studies are needed to identify the degree of stock mixing.

Keywords: Swordfish, growth, Strait of Gibraltar, stocks mixing.

Introduction

The swordfish is a cosmopolitan species found in the tropical and temperate waters of all the oceans, between 45°N and 45°S. In the Atlantic, the distribution includes the Mediterranean Sea, the Black Sea and the Marmara Sea (Palko *et al*., 1981).

In the Mediterranean, swordfish spawn mainly around the Balearic Islands, in the centre and south of the Tyrrhenian Sea, in the Ionian Sea, in the Strait of Messina and in the Levant basin (Beardsley, 1978; Rey, 1988; Tserpes *et al*., 2001). In the northwest Atlantic, swordfish spawn all year round, mainly in the Gulf of Mexico, south of the Sargasso Sea, east of the Antilles, in the Strait of Florida and along the southeast coast of the United States (Beardsley, 1978; Rey, 1988; Arocha & Lee, 1996).

Research results based on genetic studies have demonstrated that Mediterranean swordfish constitute a unique stock, separate from the north and south Atlantic stocks. Although there is incomplete information on stock mixing and boundaries, it is generally believed that stock mixing is low and limited to the region around the Straits of Gibraltar (Anonymous, 2012).

The annual catches of Mediterranean swordfish have fluctuated between 12,000-16,000 t over the last 15 years. With regard to the north Atlantic stock, the annual catches averaged about 11,551 t in the last decade. The Mediterranean swordfish is considered overfished (Anonymous, 2011), while the North Atlantic stock has been recently rebuilt to the B_{MSY} target, following a long-term management plan established by ICCAT since 1999 (Anonymous, 2010).

The growth parameters are essential elements in population dynamic models used by the International Commission for the conservation of Atlantic tunas (ICCAT) for swordfish stocks assessment. Detailed information and update of these parameters is necessary to take into account growth variability among areas, as well as changes due to biological and environmental factors.

The age and growth of swordfish have been studied primarily using anal fin spine sections (Berkeley & Houde, 1983; Tsimenides & Tserpes, 1989; Megalofonou *et al*., 1990; Tserpes & Tsimenides, 1995; Ehrhardt, 1996; Aliçli & Oray, 2001). Few authors, however, have determined the age of the species either from otoliths (Radtke & Hurley, 1983; Wilson & Dean, 1983), or using length-frequency data (Ovchinnikov *et al*., 1980; De Metrio & Megalofonou, 1987; El Hananch, 1987). Beckett (1974) studied the growth of the Atlantic swordfish from vertebrae.

As regards the Strait of Gibraltar, a Mediterranean and North Atlantic swordfish stock mixing area, very little information is available on the biology and particularly on the growth of the species. In this work we attempt to estimate the swordfish growth pattern in the area based on length frequency data, given that captured animals are directly exported to the European market, which makes it difficult to obtain hard parts for aging purposes.

Given that the aforementioned past studies have clearly demonstrated the existence of growth differences among Atlantic and Mediterranean stocks, our results would help to determine the stock mixing levels in the Strait of Gibraltar. It should be noted that studies providing information on swordfish stock structure are highly recommended by ICCAT (Anonymous, 2012), which is the responsible body for the management of large pelagic stocks in the Atlantic and the Mediterranean.

Materials and Methods

During the period from 2006 to 2011, size sampling of swordfish was conducted regularly in the Port of Tangier, located in the Strait of Gibraltar. All the sampled fish came from the Strait of Gibraltar and the adjacent Atlantic area, the Mediterranean and the North Atlantic swordfish stock mixing area (Fig. 1).

A total of 23,979 swordfish (both sexes combined) were sampled for size and/or weight from the Moroccan driftnet fishery operating in this area; from which 3,287 paired observations of length and weight were collected for the purpose of estimating the monthly length-weight relationships.

The size of fish was measured to the nearest centimetre from the tip of the lower jaw to the fork of the tail (Lower Jaw Fork Length, LJFL), using a measuring tape. The size data were aggregated by 5cm intervals in order to estimate the monthly size frequencies.

The modal progression analysis (MPA) was applied to the monthly length frequency distributions by year. This analysis involves three stages:

(i) decomposition of composite distributions into their components to identify means representing different age groups, using the Bhattacharya's Method (1967). The estimated mean lengths were then used as initial guesses to predict the mean length of the identified age groups, using the NORMSEP method. This approach utilizes the maximum likelihood concept for the identification of normally distributed components in the size frequency distributions (Hasselblad, 1966; Abrahamson, 1971; Pauly & Caddy, 1985).

(ii) Subjective identification and linking of the means perceived to belong to the same cohorts and

(iii) Using the growth increment data from the linking to estimate growth parameters.

The growth parameters were estimated by fitting the Standard VBGF (1) to the growth increment data using 2 different methods.

$$L_t = L_{00}\,(1-e^{(-k\,(t-t_0)}) \quad (1)$$

Fabens method:

Fabens (1965) suggested a method for estimating L_{00}

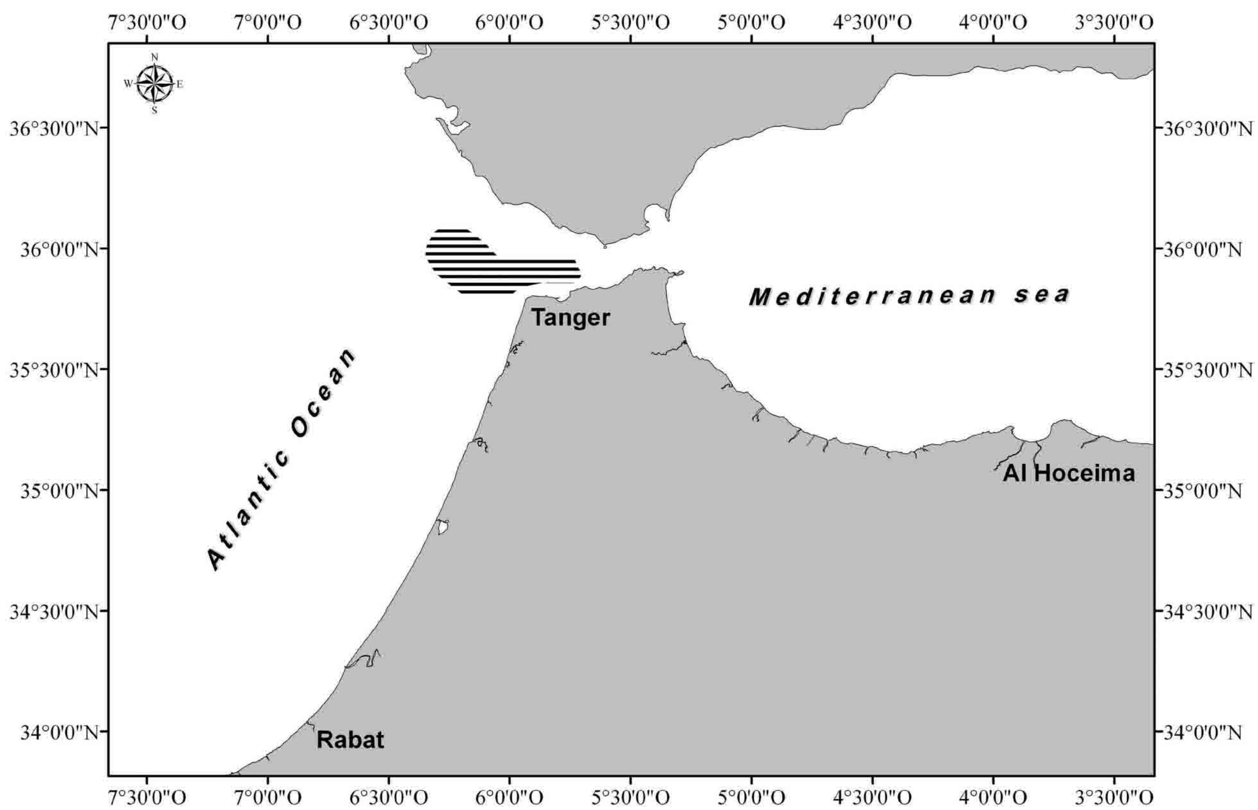

Fig. 1: Fishing grounds (shaded area) of the Moroccan driftnet fleet targeting swordfish in the Strait of Gibraltar.

and K, by predicting length at recapture (Lr') based on the current parameter selection and the length at marking (L_m). The growth parameters are estimated by minimizing the sum of squares of errors (SSE), i.e. The squared differences between the observed length at second reading (L_r) and the predicted length (L_{ri}'):

$$SSE=\sum (L_{ri} - L_{ri}')^2$$

Appeldoorn's method:

Appeldoorn (1987) and Soriano & Pauly (1989) suggested a method allowing the use of growth increment data to estimate the parameters of a seasonally oscillating version of the VBGF. They used Marquardt's algorithm for a nonlinear fit to minimize the following function:

$$SSE=\sum \{L_{i+\Delta t} - (L_{00} - L_i)\, e^{(-(K\Delta t - S_t + S_{t+\Delta t}))}\}^2$$

Where:

$$S_t = (CK/ 2\pi).\ \sin (2\pi\ (t - t_s))$$
$$S_{t+\Delta t} = (CK/2\pi).\ \sin (2\pi\ ((t + \Delta t) - t_s))$$

And

$$t_s = 0.5 + WP$$

C: degree of oscillation

In this analysis, C and WP were set to 0 in order to estimate the parameters of the Standard VBGF that doesn't take into account the seasonal oscillation of growth.

The estimation of t_0 is based on the Von Bertalanffy plot, using linear regression:

$Y = a + bt$
$Y = - \ln(1-(L_t/L_{00}))$
t: arbitrary age of each cohort
L_t: mean length of each cohort at the time t
L_{00}: asymptotic length
$t_0 = - a/b$

The arbitrary age of each cohort was calculated after assigning an age group to the first mean length of each identified cohort, based on the length-age keys available from the literature (Berkely & Houde, 1983; Megalofonou *et al.*, 1990; Tserpes & Tsiminedes, 1995; Aliçli & Oray, 2001; Arocha *et al.*, 2003). It was assumed that the 1st of July was the birth date of different cohorts (Megalofonou *et al.*, 1990; Tsimenides & Tserpes, 1989).

Results

Table 1 summarizes the number of fish sampled by month and year during the study period. Most of the fish (34%) was sampled during the month of May corresponding to the peak of fishing activity of the Moroccan driftnet fleet in the Strait of Gibraltar. The size data are missing for certain months especially from September to December of the period 2006-2008. This could be explained by the fact that there was no size sampling conducted during that period because of the low swordfish landings at the Port of Tangier.

The monthly size distributions of swordfish during the entire period study were polymodal, which means that the catches are composed of several age groups. Fish size ranges from 81 to 251 cm LJFL, but sizes between 110 and 190 cm represent roughly more than 85% of the catches (Fig. 2).

The length-weight relationship for the entire fishing season is illustrated in Figure 3. The estimated length-weight relationship parameters (a, b), the number of fish sampled, the size range, the coefficient of determination (R^2) corresponding to the length-weight relationships, as well as the F test results, for the entire season and by month, are summarized in Table 2. All the F test results are statistically highly significant at 1% level, indicating that the slopes of the relationships are quite different from 0 (b>0)

The Student test results are statistically highly significant at 1% level, which means that parameter b is greater than 3, indicating that swordfish has a positive allometry. This means that the growth rate of swordfish, in terms of weight, is higher than that in terms of length (Table 3).

The analysis of variance test of the applied General Linear Model (GLM) showed that the slopes of the length-weight relationships differ statistically among months ($F = 11.51$, $p < 0.001$)) (Table 4). It is noticeable that for a given size, the fish reached the highest weight in May. This indicates that the fish has a higher condition factor (fat fish) in that month which coincides with intense spawning activities (Fig. 4).

Table 5 shows the mean size of different age groups identified using the Bhattacharya and NORMSEP methods. Up to five (5) age groups were successfully decomposed from the monthly size distributions. Table 6

Table 1. Number of fish sampled for size and/or weight (LJFL) by year and by month during the period 2006-2011.

Year/month	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
2006	406	438	165	283	273					**1565**
2007	92	527			278					**897**
2008	10	535	407		267					**1219**
2009		1442	691	261	259	203	287	760	449	**4352**
2010	190	161	158	307	162	211		905	315	**2409**
2011	2645	5173	1595	893	1955	633	168	69	406	**13537**
Total	**3343**	**8276**	**3016**	**1744**	**3194**	**1047**	**455**	**1734**	**1170**	**23979**

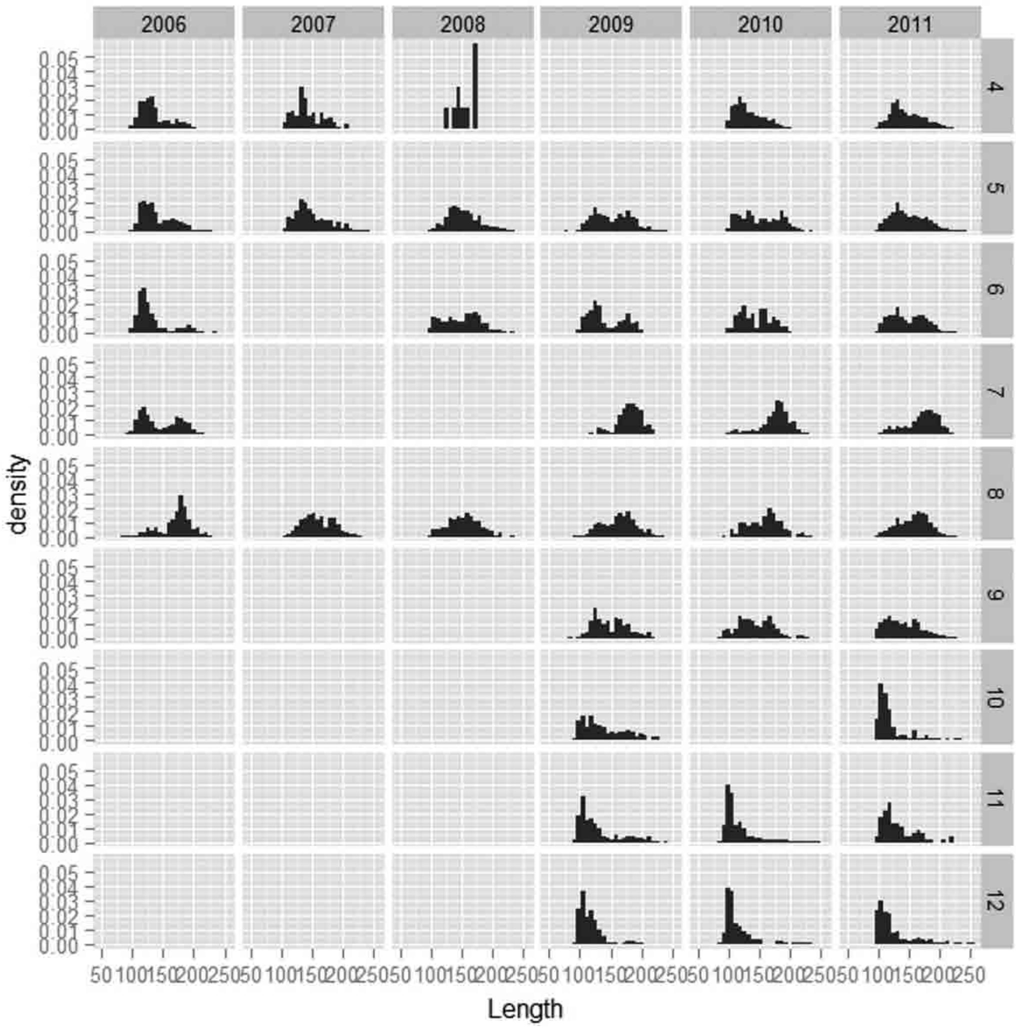

Fig. 2: Monthly size distribution of swordfish landed at the Port of Tangier duringthe period 2006-2011.

Table 2. Length weight relationship parameters (a and b), number, size range, coefficient of determination (R^2) and F test results of AOV, by month and for the entire season for the period 2006-2010.

Temporal strata	a	b	n	LJ-FL (cm)	R2	df	F	Pr (>F)
Apr.	$9x10^{-7}$	3.541	692	90-214	0.95	1, 690	13856	< 2.2e-16
May	$2x10^{-6}$	3.411	1787	89-240	0.94	1,1785	26267	< 2.2e-16
Jun.	$1x10^{-6}$	3.529	320	95-234	0.95	1, 318	6721	< 2.2e-16
Jul.	$2x10^{-6}$	3.412	120	87-194	0.95	1,118	2227	< 2.2e-16
Aug.	$6x10^{-6}$	3.122	323	101-250	0.95	1,321	6343	< 2.2e-16
Oct.	$7x10^{-7}$	3.564	45	107-230	0.91	1,43	416	< 2.2e-16
Entire season	**$2x10^{-6}$**	**3.373**	**3287**	**87-250**	**0.94**	**1,3285**	**52258**	**< 2.2e-16**

displays the progression of the mean size of the cohorts: 2004, 2005, 2006, 2007 and 2008, from July 2006 to August 2011, based on Table 5.

Given the observed growth rate of swordfish, the time interval chosen was large enough to detect the progression of the mean size of the different cohorts easily. The evolution of Cohorts mean size from July 2006 to August 2011 is illustrated in Figure 5.

The current study suggests that swordfish caught in the Strait of Gibraltar grows annually between 34cm for young fish (98 cm) and 9 cm for old fish (195 cm) (Table 7).

Figure 6 displays the mean size of the synthetic cohort aged from 14 to 85 months old (1 to 7 years old). It should be noted that for a given age between 21 and 52 months, the difference in mean sizes between the different cohorts is less than 5%. This suggests that fish of the

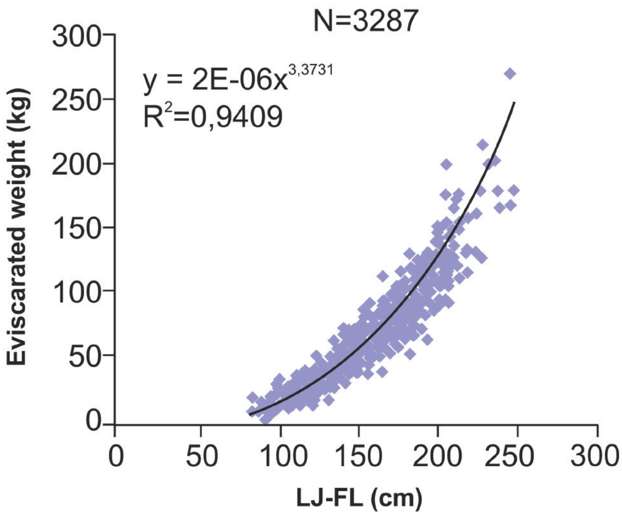

Fig. 3: Length weight relationship of swordfish caught in the Strait of Gibraltar.

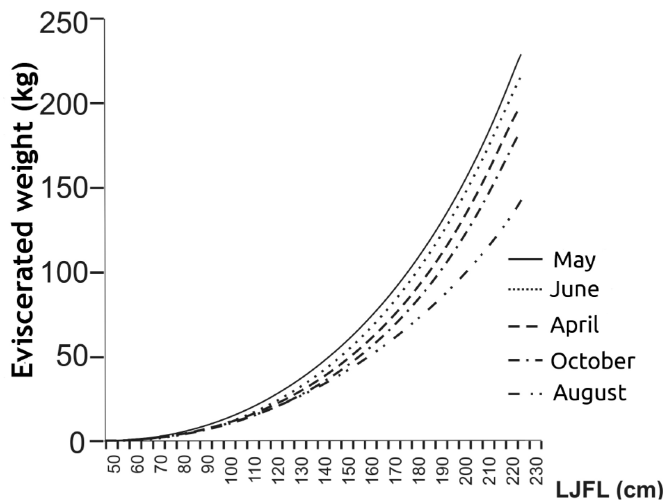

Fig. 4. Comparison of the monthly length weight relationships of swordfish caught in the Strait of Gibraltar.

Table 3. Student test results for the slope of the length-weight relationship (null hypothesis, b=3) of swordfish, by month and for the entire season, period 2006-2010.

Temporal strata	n	Estimate	Standard error	t value	(Pr > t)
Apr.	692	3.541	0.03008	17.985	<0.01
May	1787	3.411	0.02105	19.525	<0.01
Jun.	320	3.529	0.04305	12.288	<0.01
Jul.	120	3.412	0.07231	5.698	<0.01
Aug.	323	3.122	0.03918	3.114	<0.01
Oct.	45	3.564	0.1747	3.228	<0.01
Entire season	3287	3.373	0.01476	25.271	<0.01

Table 4. F test results of anova from GLM modelling.

Factor	df	Deviance	Resid. Df	Resid. Dev	F	Pr(> F)
NULL			3286	1331.14		
Log.LJ.FL	1	1252.41	3285	78.73	57448.529	< 2.2e-16 ***
Month	5	6.08	3280	72.65	55.741	< 2.2e-16 ***
Log.LJ.FL: Month	5	1.25	3275	71.40	11.512	4.856e-11 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 5. Decomposition of monthly size distribution into age groups and their corresponding mean size using the Bhattacharya and Normsep methods.

Date/age group	C1	C2	C3	C4	C5
Jul. 06	110	131	172	208	
Aug. 06	87	125	173	203	
Apr. 07	110	132	162	202	
May. 08	105	131	155	175	192
Jun. 09	111	128	131	178	241
Oct. 09	100	123	155	179	204
May. 10	112	134	155	185	226
Nov. 10	99	118	152	192	222
Aug. 11	108	134	156	171	199

Table 6. Progression of mean size and standard deviation (Sd) for the 2004, 2005, 2006, 2007 and 2008 cohorts.

Date/cohort	*2008*		*2007*		*2006*		*2005*		*2004*	
	Mean size	Sd	Mean size	Sd	Mean size	Sd	Mean size	Sd	Mean size	Sd
Jul. 06									110	9.4
Aug. 06							87	4.6		
Apr. 07							110	6.0	132	11.3
May. 08					105	3.64	131	10.4	155	11.5
Jun. 09			111	7.0	128	2.50			178	13.3
Oct. 09	100	2.8	123	13.8			155	11.76		
May. 10	112	6.4	134	6.2						
Nov. 10					152	21.28			192	3.28
Aug. 11	134	11.65	156	3.36					199	11.0

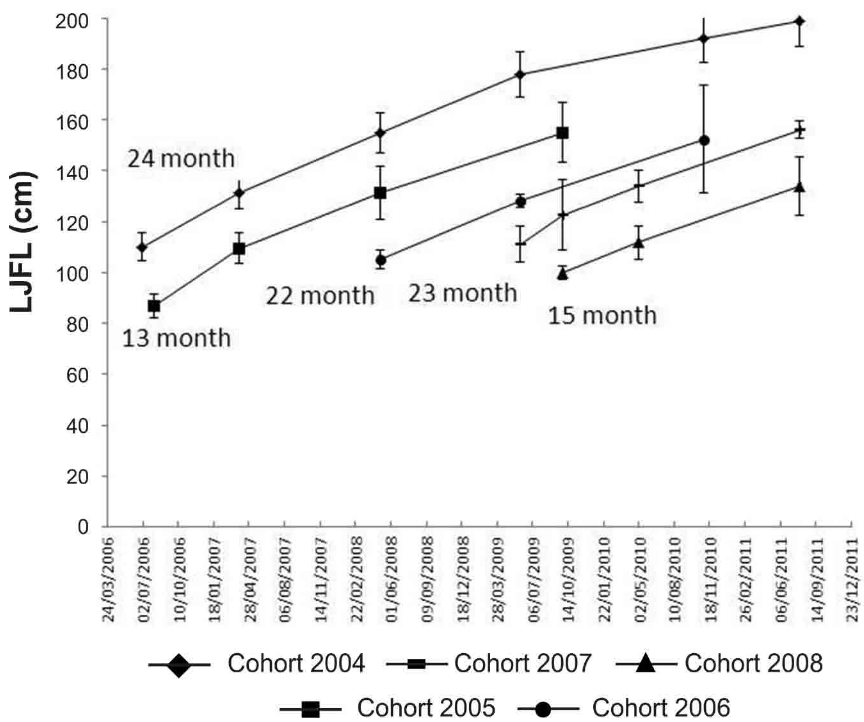

Fig. 5: Evolution of the mean size of 2004, 2005, 2006, 2007 and 2008 cohorts from July 2006 to August 2011(vertical bars represent the standard deviation) LJFL: Lower jaw-Fork length. 24 month, 13 month, 22 month, 23 month and 15 month refer to the first age identified of the cohorts.

Table 7. Growth increment by size estimated for the 2004, 2005, 2006, 2007 and 2008 cohorts.

Date/cohort	*2008*		*2007*		*2006*		*2005*		*2004*	
	ΔL/ΔT	Mean size	ΔL/ΔT	Mean size	ΔL/ΔT	Mean size	ΔL/ΔT	Mean size	ΔL/ΔT	Mean size
Apr. 07							34	98	28	121
May. 08							20	120	21	143
Jun. 09					22	117			21	166
Oct. 09			27	117			17	143		
May. 10	20	106	20	128						
Nov. 10					17	140			10	185
Aug. 11	18	123	18	145					9	195

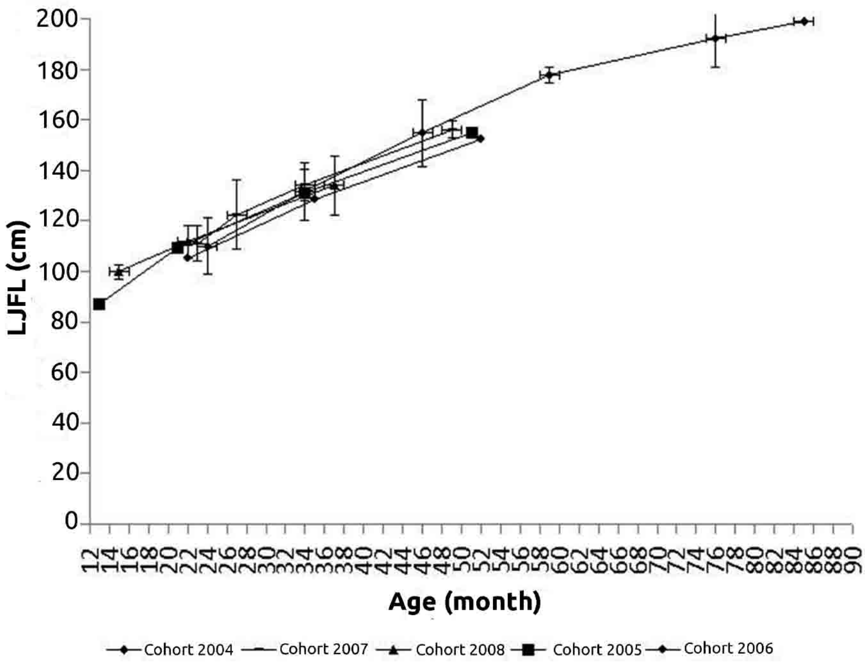

Fig. 6: Evolution of the mean size of the synthetic cohort from 14 to 85 months, obtained from the juxtaposition of the plots of Figure 5. LJ-FL: Lower jaw-Fork length.

same age group have similar growth rates, and that there are negligible cohort effects.

The growth parameters estimated by the current study are summarized in Table 8. Both the Appeldoorn and Fabens models fit well to the data ($R^2 = 0.63$) (Fig. 7) and the estimated growth parameters are quite similar. The Von Bertalanffy plot for estimating the age at zero length (t_0) is displayed in Figure 8.

Discussion

The growth parameters estimated by the current study are similar to those found by other authors for Mediterranean swordfish (Table 9) and consequently, the same is valid for the predicted mean size at age, which is similar to that obtained from previous studies in the Mediterranean (Megalofonou et al., 1990; Tserpes & Tsimenides, 1995;

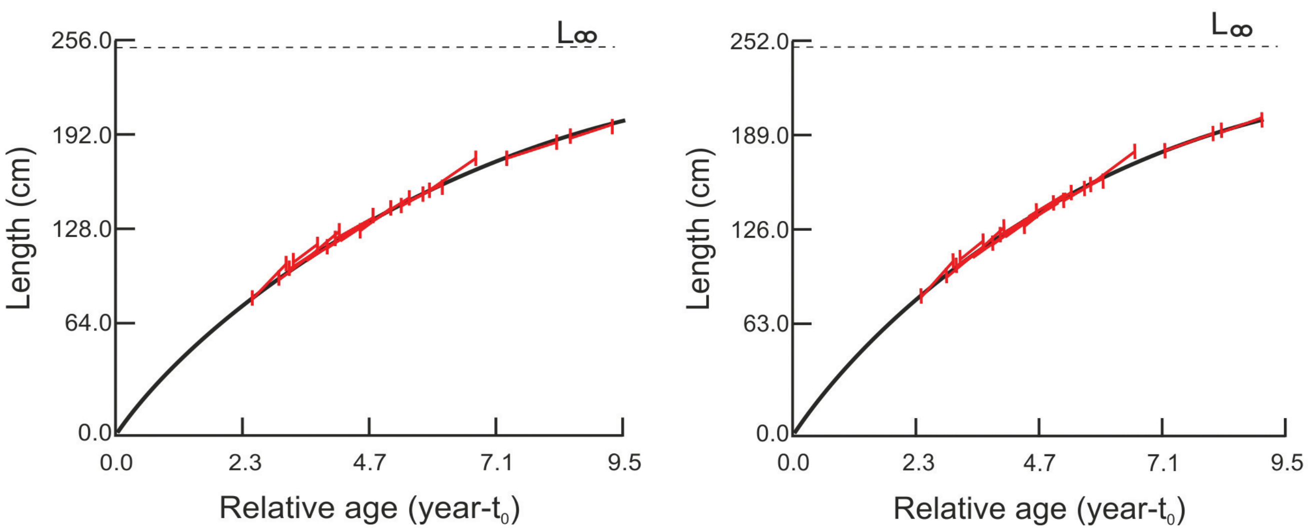

Fig. 7: Growth curves of swordfish using the Appeldoorn (A) and Faben's methods (B). Noise points represent observed data.

Table 8. Growth parameters estimated for swordfish from the Strait of Gibraltar based on growth increment data.

Method	L_{00}	K	t_0	R^2
Appeldoorn(1987)	253.6	0.170	-1.30	0.63
Fabens'(1965)	249.4	0.172	-1.23	0.62

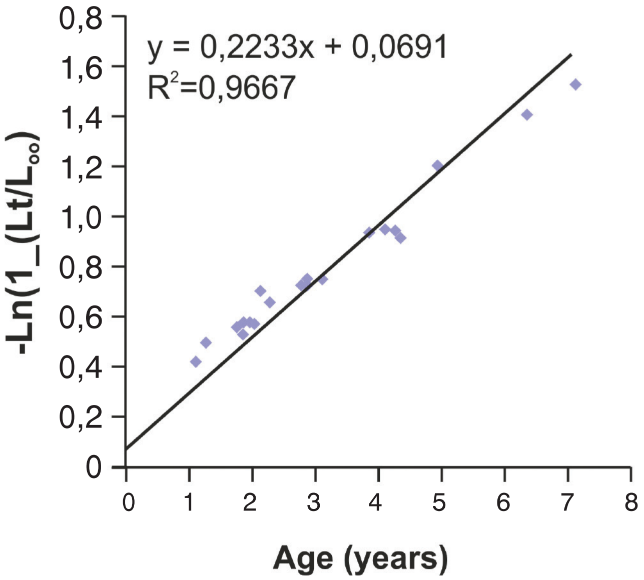

Fig. 8: Von Bertalanffy plot for estimating the theoretical age at 0 length ($t_{0=}$ -a/b).

Aliçli & Oray, 2001). Our size-at-age estimates are particularly close to those reported by Tserpes & Tsimenides (1995), except for the 0-age group (Table 10 and Fig. 9). This difference is probably due to the fact that 0-age fish are not present in our samples. Consequently, the model didn't fit the mean size for this age group well. In general, the size at age differences among the current study and the above-mentioned ones are not greater than 6%.

In contrast, the predicted mean sizes at age from the current study are quite different from those estimated for Atlantic swordfish (Arocha et al., 2003), particularly for ages 1-5. In this case, differences vary from 6 to 22%.

Our results are also in line with previous findings suggesting that the growth of Mediterranean swordfish is rapid during the first 3 years of life, and then slows down rapidly (Tserpes & Tsimenides, 1995; Aliçli & Oray, 2001. The fish grows about 32 cm during its first year of life, and then the annual growth increment decreases progressively to reach around 10 cm at its 7th year of life.

The above findings indicate that swordfish individu-

Table 9. Growth parameters estimated for swordfish by several authors in different areas.

Author	*Method*	*Area*	*FL(cm)*	L_{00}	*K*	T_0
Berkeley & Houde (1983)	Spine	North Atlantic	??????	271cm	0.090	-3.79
Tserpes & Tsimenides (1995)	Spine	Eastern Mediterranean	62-210cm	238.6cm	0.185	-1.40
Aliçli (2000)	Spine	Eastern Mediterranean	52-219cm	252.2cm	0.133	-2.43
Megalofonou *et al*. (1990)	Spine	Eastern Mediterranean	71-207	243.8cm	0.140	-2.6
Arocha *et al.* (2003)	Spine	Northwest Atlantic	63-262cm	464.5 cm	0.002	-

Table 10. Predicted mean length by age of swordfish from different studies in the Atlantic (A), Mediterranean (M) and Strait of Gibraltar (G).

Age	**Berkely & Houde (1982) (A)**	**Arochaetal (2003) (A)**	**Tserpes & Tsemindes (1995) (M)**	**Megalofonou et al. (1990) (M)**	**Alicli (2000) (M)**	**Current study (G)**
0			55	74	70	50
1	99	105	86	97	92	82
2	119	129	111	116	112	109
3	137	146	133	132	130	132
4	153	160	151	147	145	151
5	167	171	166	160	158	167
6	180	180	178	171	170	180
7	192	189	188	180	180	192
8	202	196	197	189	189	201
9		203	204	196	197	210
10		210	210	202	204	216
11		216				
12		221				
13		227				
14		232				
15		236				
16		241				

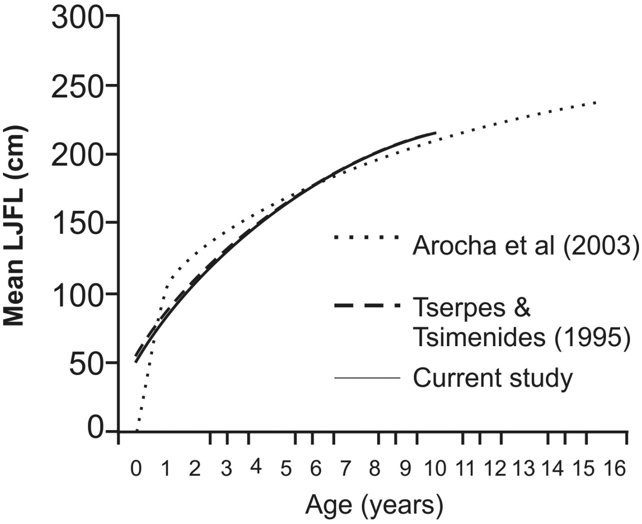

Fig. 9: Comparison of swordfish growth curves between the current study and those used by ICCAT for the assessment of Mediterranean (Tserpes & Tsimenides (1995) and Atlantic (Arocha *et al*., 2003) stocks. LJ-FL: Lower jaw-Fork length.

als caught in the Strait of Gibraltar most likely belong to the Mediterranean stock, as already suggested by past genetic studies (Vinas *et al.,* 2006). The existence of mixing among Atlantic and Mediterranean swordfish in the area is well documented and it is believed that individuals migrate from the Atlantic to the Mediterranean for spawning (El Hannach, 1987; De la Serna & Alot, 1990; Abid, 1998). Although the higher condition factor in our data has been observed in May, which is a month of intense swordfish spawning activity in the Mediterranean, it seems that catches of Atlantic animals are not frequent enough to affect the growth parameter estimates, at least for the young fish caught in this area. Given, however, that growth rate differences among stocks are relatively small at older ages, it is normal to expect that growth studies, such as the current one, will not be able to provide a complete picture of mixing in the Strait of Gibraltar.

As the results obtained from the statistical method are in agreement with those of direct aging of the species using anal fine spine sections, the MPA used in this study can be considered an alternative approach for assessing the growth of swordfish when hard parts are not available. However, this method presents some difficulties especially as regards decomposing size frequency data into age groups for older fish (LJ-FL>200 cm). Further research considering sexually dimorphic growth may help to clarify this question.

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