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Age and Growth of Spiny Dogfish *Squalus acanthias* (Squalidae: Chondrichthyes) in the North Aegean Sea

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Both the authors conceived and designed the study and wrote the article. CCY collected and analyzed the data.

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A B S T R A C T

Male and female spiny dogfish *Squalus acanthias* were collected in the North Aegean Sea from Saros Bay between February 2005 and September 2008. *Squalus acanthias* ranged from 17.1 to 121.6 cm in total length. Age was estimated using the second dorsal spine of 345 spiny dogfish. The coefficent of variation estimated value was 11.1%. Both male and female spiny dogfish readhed 7 years of age. Estimates of the von Bertalanffy growth parameters suggest that females attain a larger asymptotic TL (L_∞=101.21 cm) than males do (L_∞=72.85 cm) and grow more slowly (K=0.15 y^{-1} and 0.27 y^{-1}, respectively). A relationship was determined between the age of spiny dogfish and spine size: their spine length and spine base length (r_s=0.625), and their spine base width (r_s=0.611).

INTRODUCTION

The spiny dogfish (*Squalus acanthias*) is a small demersal shark of temperate continental shelf areas worldwide. The maximum depth recorded for the species is 900 m, although they are most common at depths between 10-200 m (Compagno, 1984). *S. acanthias* has been reported in the North-West Atlantic (Cuba to Greenland), the North-East Atlantic (northern Norway to Morocco, including the Mediterranean and Black Seas), the South-West Atlantic (Uruguay and Argentina) and the South-East Atlantic (South Africa) Oceans. Within the Pacific, it has been reported in Chile, New Zealand and Southern Australia in the south, and from Japan to Mexico (including the Bering Sea) in the north (Compagno, 1984).

Although naturally abundant, this is one of the more vulnerable species of shark to over-exploitation by fisheries because of its late maturity, low reproductive capacity, longevity and long generation spans (25 to 40 years) (Holden, 1973; Stevens *et al*., 2000; Bubley *et al*., 2012). Fishing pressure has in some populations modified the life-history parameters of *S. acanthias* by decreasing the maximum size and size at maturity of females (Bubley *et al*., 2012).

Age data contribute to knowledge of spiny dogfish life-history parameters and reproductive potential (Gallucci *et al*., 2006). Reliable estimates of age are necessary to estimate these parameters accurately and to successfully manage dogfish fisheries (Rice *et al*., 2009). Spiny dogfish belong to the Squalidae family, that are unique among elasmobranchs as they usually have well-calcified dorsal spines that can be used for age estimation (Kaganovskaia, 1933; Templeman, 1944; Probatov, 1957; Holden and Meadows, 1962; Ketchen, 1975; Beamish and McFarlane, 1985; Rice *et al*., 2009). In particular, the second dorsal spine is generally used for age determination, since it tends to be less worn (Campana, 2014). Spiny dogfish was the focus of varied studies concerning age, growth, feeding habits and various traits of reproductive biology for specimens from the southern Black Sea (Avsar, 2001; Demirhan and Seyhan, 2007), and the Mediterranean Sea (Chatzispyrou and Megalofonou, 2005; Capapé and Reynoud, 2011). However, there is no available data pertaining to the age and growth of this species from the Saros Bay, in the North Aegean Sea. The objectives of our study were to determine the age structure of the population by using spine growth bands and to describe the growth of the spiny dogfish sampled from the Saros Bay.

MATERIALS AND METHODS

Spiny dogfish were obtained monthly from commercial bottom trawls, between February 2005 and September 2008. Sampling was carried out in the Saros Bay, in the North Aegean Sea from depths between 5 and 500 m (Fig. 1). Trawl times were approximately 30 minutes in duration with trawl speeds at around 2.5 knots. The total length (TL) of each specimen was measured to the nearest centimetre from the tip of the snout to the tip of the upper lobe of the caudal fin (Orlov *et al*., 2011). The second spine is larger and was less frequently damaged than the first spine, so it was chosen for age estimation (Carlson and Goldman, 2006). Excess muscle and connective tissue were removed using a sharp scalpel

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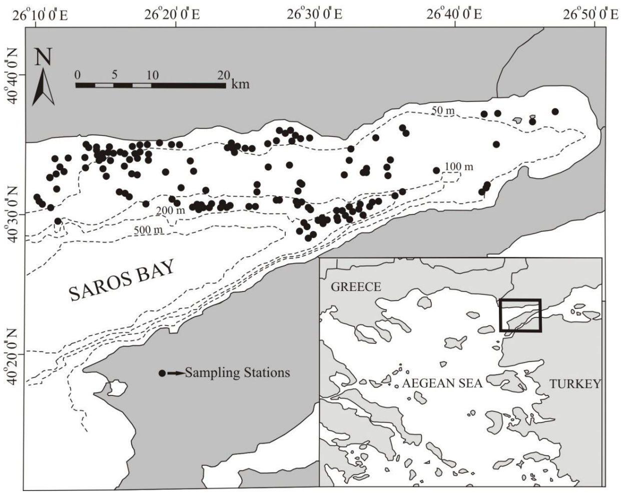

Fig. 1. Map of the study area; Saros Bay, in the North Aegean Sea (Yigin and Ismen, 2010)

and by immersion in hot water for short periods (Irvine *et al*., 2006). Measurements of spine length, as well as of the length and width of the spine's base, were performed with digital callipers with an accuracy of ±0.01 mm (Clarke and Irvine, 2006). Whole spine images were obtained under reflected light using an Olympus SZX16 microscope, a digital camera, and Adobe Photoshop Image Ready CS software. Adobe Photoshop Image Ready CS was used to create digitally enhanced images of the entire spine (Campana, 2014). The images were subsequently digitally enhanced. Growth band readings were more easily examined through whole spine images using this method. Band pairs were counted to assign an age to each specimen by two readers (Skomal and Natanson, 2003). For samples in which readings did not coincide, the procedure was repeated. If no agreement was achieved, the sample was omitted from analysis (Megalofonou *et al*., 2009). An age bias plot systematic differences between the two age readers. A 1:1 line of equivalence was included to indicate where ager x = ager y. The extent of deviation of the 95% confidence interval bars from the 1:1 equivalence line was plotted and indicates the extent of ageing bias (Campana *et al.*, 1995, Mac Neil and Campana, 2002).

Precision estimates for each reader were calculated using the coefficient of variation (CV) as per Chang (1982). The CV was calculated as:

$$CV_j = 100\% \cdot \frac{\sqrt{\sum_{i=1}^{R} \frac{(X_{ij} - X_j)^2}{R-1}}}{X_j}$$

where X_{ij} was the ith age determination of the jth fish, X_j was the mean age of the jth fish and R was the number of times each fish was aged. The von Bertalanffy (1938) growth function was fit to final age estimates and TL data. The von Bertalanffy growth equation:

$L_t = L_\infty (1-e^{-K(t-t_0)})$, where L_t is the length of spiny dogfish (cm) aged t (years), L_∞ is the theoretically maximum length (cm), K is the coefficient of growth and t_0 is the theoretical age at which the length of a spiny dogfish is 0 (Orlov *et al*., 2011).

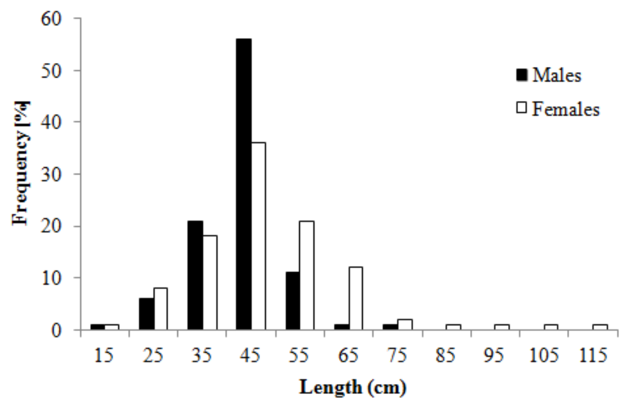

Fig. 2. Length-frequency distribution of female and male *S. acanthias* caught from the Saros Bay, 2005-2008.

RESULTS

A total of 620 spiny dogfish were included in this study, of which 346 were females and 274 were males. Table I shows the number of specimens captured per month and their minimum and maximum sizes. The TL of females ranged from 17.1 to 117.5 cm (mean=52.6±7.9); males were between 20.8 and 121.6 cm (mean=49.1±6.8) (Fig. 2). For age estimates, 345 spine samples (from 203 females and 142 males) were analysed. In most cases, especially among large spiny dogfish, age readings were very difficult to accomplish due to the close location of annual growth bands on spines or they were altogether impossible because of surface damage as a result of which bands were wiped (Fig. 3a). The analysis showed that spine sizes (length, base width and base length) correlated with the age of the spiny dogfish. The highest correlation was found between the age and spine length and spine base length (Spearman rank correlation coefficient r_s=0.625, p<0.05). Between age and spine base width, the correlation was relatively lower but still significant (r_s=0.611, p<0.05).

Fig. 3. Samples of spines of spiny dogfish *Squalus acanthias*: (A) unsuitable for age determination and (B) with visible growth bands that were used for age estimation.

Table I.- Spiny dogfish *Squalus acanthias* recorded and analysed in this study from the Saros Bay in the Mediterranean Sea.

Date	Females N	Min-Max TL (cm)	Males N	Min-Max TL (cm)
March 05	19	27-68.5	10	44-81
April 05	3	57.5-114	2	49.5-56.5
May 05	1	44		
June 05	8	32.6-110	24	21.5-83.6
July 05	10	46-117.5	9	32-121.6
October 05	50	22.5-77	51	24.1-57.8
November 05	20	42-79	7	42-53
December 05	19	45-68.5	15	46.6-87.5
January 06	9	23-51.8	5	40.5-48.5
February 06	36	24.8-72	35	28.5-69.6
March 06	8	45.5-65	19	32-64.2
April 06	1	57.4		
May 06	8	47-74.7	6	35.1-73
July 06	4	29.5-73	2	36.7-52.5
September 06	5	32.5-54.5	5	26.4-52
October 06	6	17.1-69.5	6	23-65.5
November 06	5	47.3-77.1	2	48.4-55
December 06	4	55.6-71	3	46.9-51.8
January 07	2	43.5-63.5	3	51.9-53.2
February 07	2	67.4-101.9	1	58.6
May 07			4	36.1-53
June 07	19	49.9-57.6	5	46.3-54.6
July 07	9	36.1-70.5	7	20.8-54.5
September 07	5	44.8-76.3	3	44.3-52.1
October 07	14	35.4-68.4	8	36.6-55.8
November 07	8	36.3-68.4	3	36.2-43.3
December 07	11	31.3-62.4	7	38-54
January 08	15	31.4-63.3	11	36.8-57.4
February 08	4	30.5-51.5		
March 08	4	51-62.5	5	42-58.7
May 08	15	43-70	4	51-56
June 08	6	47-72	6	44.8-56
July 08	1	60		
September 08	15	42-94.5	6	51-82.3

Table II.- von Bertalanffy growth parameters for *Squalus acanthias* from the Saros Bay in the North Aegean Sea. The results are shown for males and females, as well as for both sexes combined. Numbers in brackets represent the 95% confidence intervals of the estimated parameters.

Sex	L_∞ (cm)	K (year^{-1})	t_0 (year)
Males	72.85	0.27	-0.24
	[50.91-94.79]	[0.04-0.51]	[(-1.50)-1.02]
Females	101.21	0.15	-0.68
	[45.44-156.9]	[(-0.01)-0.31]	[(-1.99)-0.64]
Combined	95.34	0.16	-0.69
	[57.79-132.88]	[0.03-0.29]	[(-1.74)-0.35]

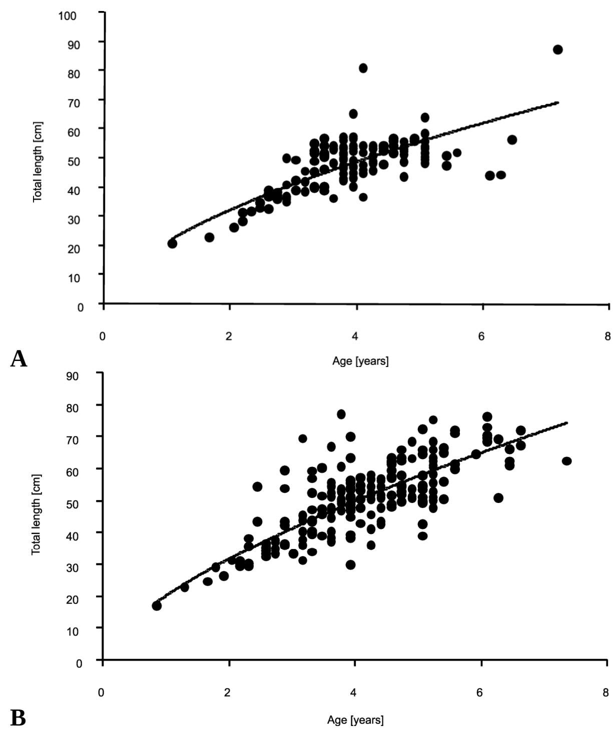

Fig. 4. von Bertalanffy length growth curves for spiny dogfish males (A) and females (B)

The age bias plot revealed minimal variation around the 1:1 plot and no systematic over- or underestimation of age. The precision estimate (CV) for this aging method was 11.1%. The growth in length by age for males and females is shown in Figure 4 and the von Bertalanffy growth parameters are presented in Table II. Calculation of coefficients of the von Bertalanffy growth equation supports sex differences in growth parameters and indicates longer lifetimes in females. The coefficient K characterizing the rate at which individuals attain

Table III.- Parameters of von Bertalanffy growth equation of spiny dogfish *Squalus acanthias* in different regions. L_∞ : theoretical maximum length (cm), *K*: coefficient of growth, t_0: theoretical age (years) at which the length of spiny dogfish is 0.

Regions	Females			Males			Authors
	L_∞	K	t_0	L_∞	K	t_0	
Northwest Atlantic, Washington coast	152.9	0.04	-6.7	101.8	0.71	-5.2	Bonham *et al*., 1949
North Sea	101.4	0.11	-3.6	79.7	0.21	-2.0	Holden and Meadows, 1962
Pacific waters of Canada, Georgia Strait	129.1	0.03	-7.3	96.1	0.07	-5.0	Ketchen, 1975
Pacific waters of Canada, Hekaty Strait	125.1	0.03	-10.6	84.7	0.09	-3.7	Ketchen, 1975
Pacific waters of Canada, Georgia Strait	128.5	0.04	-6.9	97.3	0.07	-4.5	Jones and Geen, 1977
North Sea	137.1	0.05	-4.7	81.7	0.19	-1.5	Sosinski, 1978
Northwestern Atlantic	120.9	0.07	-2.8	85.4	0.14	-1.9	Slauson *et al*., 1983
Northwestern Atlantic	105.0	0.11	-2.6	81.3	0.16	-2.5	Nammack *et al*., 1985
New Zealand	120.1	0.07	-3.5	89.5	0.12	-2.9	Hanchet, 1986
Southwestern Ireland	98.8	0.09	-1.6	79.9	0.21	-1.7	Fahy, 1989
Northwestern part of the Black Sea	258.5	0.03	-2.7	234.2	0.04	-2.9	Kirnosova, 1990
Southern part of the Black Sea	145.0	0.17	-0.7	128.0	0.20	-0.3	Avsar, 2001
Waters of Ireland	112.0	0.07	-3.4	79.5	0.15	-2.5	Henderson *et al*., 2002
Northwestern Atlantic	104.5	0.09	-3.4	91.8	0.11	-3.7	Soldat, 2002
Southern part of the Black Sea	137.7	0.13	-1.7	123.8	0.17	-2.6	Demirhan and Seyhan, 2007
Atlantic coast of Canada	119.5	0.04	-	78.0	0.10	-	Campana *et al*., 2009
Pacific waters off the Kuril Islands	147.2	0.05	-1.3	116.3	0.10	-1.1	Orlov *et al*., 2011
Northwestern Atlantic	100.76	0.12	-	94.23	0.11	-	Bubley *et al*., 2012
North Aegean Sea, Saros Bay	101.21	0.15	-0.68	72.85	0.27	-0.24	Our study

maximum length by individuals was 0.27 and 0.15 in males and females, respectively, which indicates a more rapid linear rate of growth in males as compared to females.

DISCUSSION

Spines of the spiny dogfish (*Squalus acanthias*) have been used to estimate age since the early 1900s (Kaganovskaia, 1933), and the spines of other chondrichthyes are receiving increasing attention as suitable structures for estimating age and growth (Francis and ÓMaolagáin, 2000; Irvine *et al*., 2006; Clarke and Irvine, 2006). Fin spines are generally too large to image under a dissecting microscope, but the growth bands can sometimes be counted visually under a microscope. The high resolution digital images produced in combination with the image analysis system provided excellent detail and clarity for ageing purposes (Cailliet *et al*., 1983). We used a method that captured a digital image of the spine using a digital camera and then enhanced the image prior to age determination (Campana, 2014).

The management decisions of spiny dogfish fisheries are generally based on age-length relationships. Statistical differences in age-length relationships and estimates of growth parameters could be the result of environmental and genetic factors. However, such differences could also be attributed to aging errors resulting from differences in methodology. This bias affected parameter estimates for the von Bertalanffy growth equation (Rice *et al*., 2009). Precision is highly influenced by the species and the nature of the structure being aged, as well as by the reader (Campana, 2001). According to Campana (2001), age and growth studies of elasmobranchs indicated a mean coefficient of variation (CV) of 10% for vertebral centra and 11% for spines. In this study the aging procedure involved use of the second dorsal spine; the CV value of spiny dogfish was estimated as 11.1%.

Previous researchers have reported the greater age range demonstrated by females of the species than males (Holden and Meadows, 1962; Ketchen, 1972; Nammack *et al*., 1985; Henderson *et al*., 2002). Values of asymptotic length (L_∞) for males and females were 72.85 and 101.21 cm, respectively. Males reach their theoretical average maximum length more quickly than females do due to the "*K*" growth rates. This is also the likely explanation for the significant differences found between the age composition of the male and female components of the study sample. Table III shows a comparison of the von Bertalanffy growth parameters for *S. acanthias* estimated in different regions. The differences in growth parameters between those reported in the present study and the results presented by other investigators in Table III may be due to differences in geographical and environmental factors; additionally variability due to specific methods, interpretation and statistical fit may play a very large role (Tanaka *et al*., 1990; Henderson *et al*., 2002).

Valid age and growth information is fundamental to stock assessment and management. Cailliet (1990) lists only 39 species of elasmobranchs for which there are published or ongoing age verification studies (McFarlane *et al.*, 2002). Researchers need to investigate alternative methods for aging elasmobranchs, and we suggest in this regard that the second dorsal spines of *S. acanthias* will be very useful for age determination using digitally enhanced images. However, this study is only the first in a series aimed at providing age and growth parameters for the management of the spiny dogfish in the North Aegean Sea.

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