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*Full Length Research Paper*

# Age, sex ratio, length-weight relationships and reproductive biology of Mediterranean swordfish, *Xiphias gladius* L., 1758, in the eastern Mediterranean

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**In this study, a total of 87 swordfish were collected from the Aegean Sea and northern Levantine Sea. The range of the lower jaw fork length was 99.0 to 161.0 cm (mean 15.45 cm) for males and 87.0 to 188.5 cm (mean 26.02 cm) for females. Females were slightly more numerous than males (39 males and 48 females). The estimated sex ratio was calculated as 1.23. The maximum value of gonadsomatic index (GSI) for the males (2.16) and females (10.09) were observed in June and May respectively. High GSI value which were observed in May (10.09) indicated that the female reproductive cycle started depends on the size of the individuals. In the present study, the length-weight relationship was calculated as $W = 1x10^{-6} L^{3, 4627}$, $R^2 = (0.95)$. The coefficient "*b*" was close to positive allometric values (*b* = 3.46). Total of 48 anal spines (25 males and 23 females) were examined. The ages varied from 1 to 7 and the maximum age was determined as 7. Two-year-old fish were dominant (35.4%).**

**Key words:** Swordfish, *Xiphias gladius*, reproduction biology, sex ratio, length-weight relationship, Eastern Mediterranean.

## INTRODUCTION

The swordfish, (*Xiphias gladius* Linnaeus, 1758) is a pelagic and oceanic species which is distributed in tropical, temperate and sometimes cold waters (Nakamura, 1985). Mediterranean stock has different growth and maturity characteristics from Atlantic (Ehrhardt, 1992; Kotoulas et al., 1995; Tserpes and Tsimenides, 1995) and genetic studies suggest that all the Mediterranean swordfish form a unique stock (Macias et al., 2005a).

Minimum landing size (MLS) is the smallest length at which it is legal to sell a fish. National and/or international regulation affects MLS. Therefore, the value should be determined especially for highly migratory species such as swordfish and tunas. The accuracy of the size-weight relationships is important for the creation of data bases used to in stock evaluation (Tserpes et al., 2003).

To establish the relationships between length-weight of swordfish various landing size data have been collected (Hattor, 1996; Tsimenides and Tserpes, 1989; De la Serna et al., 1995; Alicli and Oray, 2001; Tserpes et al., 2003; Alicli, 2008). However, Mediterranean swordfish has been landed in different weight forms such as round weight (Mejuto and De la Serna, 1993; Alicli and Oray, 2001; Alıçlı, 2008), eviscerated weight (De Metrio et al., 1989; Megalofonou et al., 1991a, 1995; Hattour, 1996), gilled and gutted weight (Orsi Relini et al., 1999; Tserpes et al., 2001, 2003), dressed weight (De la Serna et al., 1995) different length-weight relationships were obtained.

The size-age-at sexual maturity and the sex ratios are fundamental biological parameters used in stock assessments. To control and regulate swordfish fishery,

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**Abbreviations: (L), LJFL**, Fork length; **(W) RW**, round weight; **GSI**, gonadsomatic index; $L_{50}$ , length of the first maturation at which 50% of the individuals are adult; **GW**, gonad weight; **MLS**, minimum landing size.

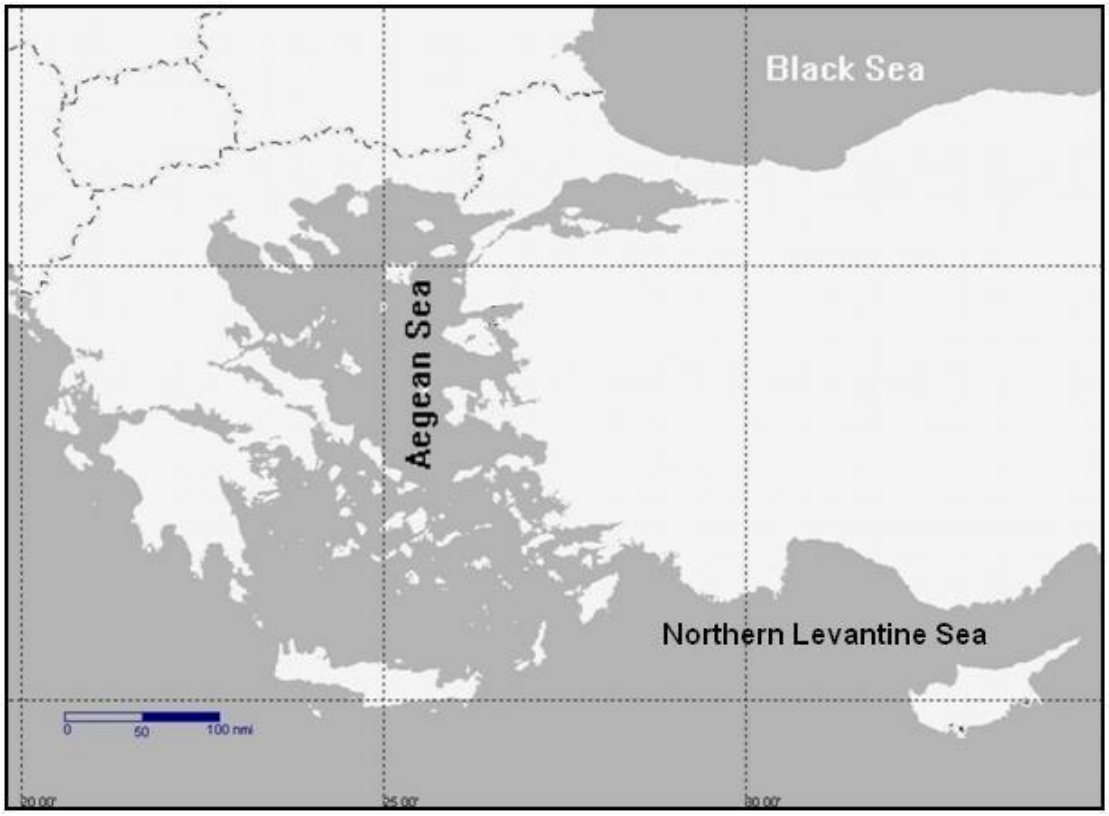


**Figure 1.** Map of the eastern Mediterranean indicating operational seas of Turkish swordfish fleet (scale 100 nmi).

determination of sex, gonad maturity and quantifying the reproductive potential of the fish at capture are important in population dynamics and management models (Macias et al., 2005a). However, information on the reproductive activity of the species is rather limited (Tserpes et al., 2008). However, most of the scientists agree that its spawning occurs in the summer months, begins in June and continues until September (De Metrio and Megalofonou, 1987; Tserpes and Tsimenides, 1995; Orsi Relini et al., 1999; Tserpes et al., 2008) and during this period Mediterranean swordfish migrates in the eastern Mediterranean toward the eastern Levantine Sea for spawning, concentrating in specific areas during the peak of spawning season (Tserpes et al., 2008).

Gonad development is an important issue to establish the spawning season, the size and age maturity, spawning pattern and fecundity (Macias et al., 2005 b). The histological analysis of gonads has proved to be the most adequate technique to establish the status of reproductive maturation for tuna and tuna like species (Schaefer, 1996). At this time, there are no studies regarding reproduction biology of swordfish around Turkish coastal waters. Therefore, the aim of the study was to present information about reproductive activity gonadsomatic index (GSI) values and histological and development of gonads of the species by means of analysis and update information in size and sex composition in the area.

## MATERIALS AND METHODS

A total of 87 swordfish were sampled from the Turkish commercial swordfish fleet operating in the Aegean and northern Levantine Seas (Figure 1).

LJFL (Lower jaw fork length, nearest cm) which is described as projected straight distance between tip of the lower jaw to the fork of the tail (Miyake, 1990) and RW (Round weight, nearest kg) were considered.

The length-weight relationship was determined using the equation $W = a L^b$ (Le Cren, 1951). Where, W is RW in kg and L is LJFL in cm. “a” is exponent and “*b*” is the slope of regression. Values of *b* provide information on fish growth such as $b = 3$ isometry, $b >$ positive allometry, $b <$ negative allometry).

Gonad development was determined based on histological analysis and GSI index. Gonads were removed from the gut cavity and cleaned from external tissue and weighed with an electronic balance (Precisa 3100 C, ± 0.01 g) to calculate the GSI indicating the levels of maturity. GSI was calculated according to Kume and Joseph (1969): $GSI = (GW / LJFL^3)*10^4$ Where, GW (Gonad weight) is in g and LJFL is in cm. To determine the maturity stage of gonads, the sections (1 to 1.5 cm width) were cut from the central part of the single gonad and preserved in 10% buffered formalin solution. Then, the sections were stained with hematoxline-eosin.

**Table 1.** Summarized sample size and length range of swordfish from the eastern Mediterranean.

| Sex | N | LJFL (cm) | Mean LJFL (cm) | S.D. (cm) |
|---|---|---|---|---|
| Male | 39 | 99.0-161.0 | 123.06 | 15.45 |
| Female | 48 | 87.0-188.5 | 143.37 | 26.02 |
| All samples | 87 | 87.0-188.5 | 134.27 | 24.05 |

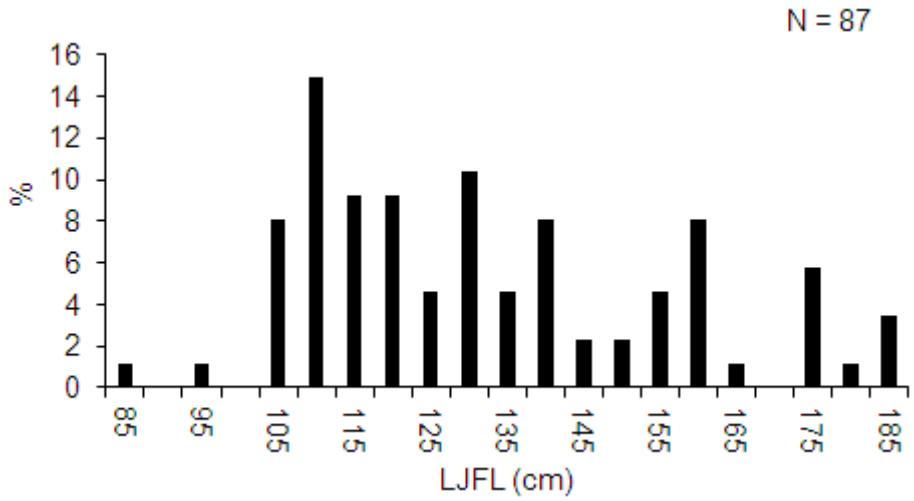


**Figure 2.** Length frequency distribution of swordfish sampled from the eastern Mediterranean.

Gonad development stages were estimated observing sections under the microscope according to Arocha (2002) and Wang et al. (2003). To identify the sex ratio by month expressed as the proportion of females to males: Sex ratio = Female / Male.

To determine the age, anal fin method was used (Berkeley and Houde, 1983). Total of 48 anal fins were collected. Sections were cut from the nearest part of the condoyle towards the tip of the spine using a low-speed saw (IsoMet). Total of four sections (about 0.5 mm thickness) were taken from each individuals. Then sections were read using binocular microscope.

## RESULTS

The LJFL of 87 individuals were examined. The round values varied from 6.5 to 107.0 kg. LJFL varied from 87.0 to 187.5 cm (Table 1).

Analyses of the all samples (N = 87) showed that considerable number of fish consisted of 14.9% up to 110 cm (Figure 2).

The relationship between lower jaw fork length and round weight found to be $RW = 1x10^{-6}\ LJFL^{3,4627}$, ($R^2$ = 0.95). The “a” and ”*b*” values (intercept and slope) was found as $1x10^{-6}$ and 3.46 respectively (Figure 3). As a result, value of *b* showed positive allometric growth (*b* > 3).

In the present study, females were slightly more numerous than males. The sex ratio (F / M) was calculated as 1.23. The ratio between females and males fluctuated from 0.5 to 3.5 by month. The ratio is in favor of females greater than 160 cm and all sample was female greater than 165 cm LJFL.

Total of 48 anal spines were analyzed. The ages varied from 1 to 7. Two-year-old fish were dominant (35.4%) and 25% of the individuals were in one-year-old. 60.4% of the individuals were up to the age of 3 (Table 2).

GSI were calculated for each specimen and on a monthly basis. Monthly GSI for both sexes fluctuated. The values of GSI in males were lower than females. GSI in males reached maximum (2.16) in June. But, for the year round it was below 1. On the contrary, GSI in females increased from May to July and decreased in August and maximum GSI (10.09) was observed in May.

It was determined that the ovaries presented five different development stages of oocytes. These stages were identified as follows; undeveloped stage, developing stage, maturing stage, ripening stage, hydrated stage and post-ovulatory follicle (Figure 4).

## DISCUSSION

Swordfish, *Xiphias gladius*, is commercially important species due to its high marketing demand and consumption in most of the Mediterranean countries such

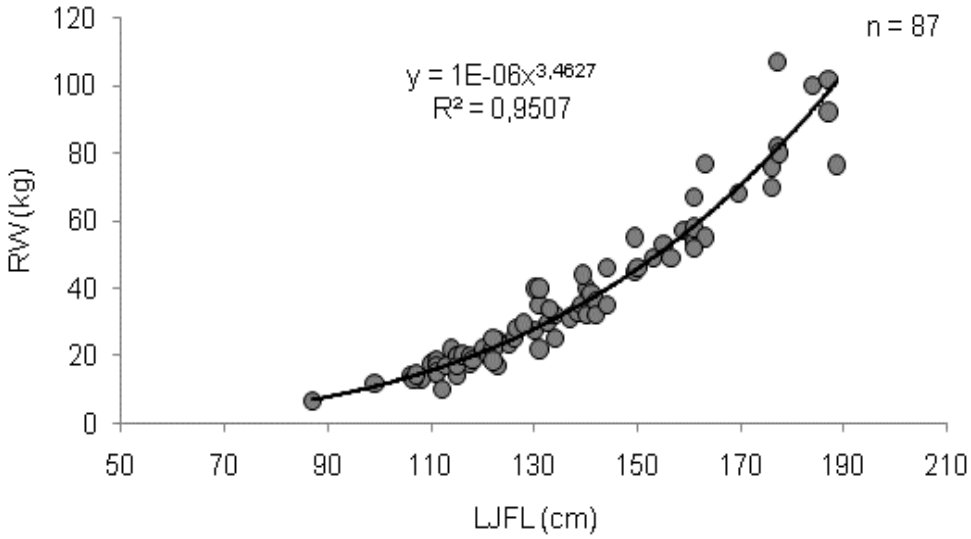


**Figure 3.** Length and weight relationship of swordfish from the Aegean Sea and northern Levantine Sea.

**Table 2.** Summary at statistics on sizes of aged swordfish from the eastern Mediterranean.

| Age group | Male | Female | All sample | LJFL (cm) | Mean LJFL (cm) |
|---|---|---|---|---|---|
| I | 8 | 4 | 12 | 87.0-114.0 | 107.04 |
| II | 12 | 5 | 17 | 103.0-126.5 | 118.12 |
| III | 2 | 7 | 9 | 130.0-144.0 | 138.67 |
| IV | 2 | 2 | 4 | 131.0-156.5 | 146.12 |
| V | 1 | 2 | 3 | 149.0–161.0 | 157.17 |
| VI | - | 2 | 2 | 177.0-177.5 | 177.25 |
| VII | - | 1 | 1 | 188.5 | - |
| All samples | 25 | 23 | 48 | 87.0-188.5 | 127.90 |

as Italy and Greece. Turkish swordfish fleet is composed of multipurpose vessels. Fishing has been carried out intensively in northern Levantine Sea and the Aegean Sea using longlines and traditional harpoons.

In the present study,on gonad maturity, and length at age, and sex were investigated in order to give information of the eastern Mediterranean swordfish population. All samples were obtained from the Turkish swordfish fleet operating in the eastern Mediterranean.

Female swordfish grow more quickly than males during their second year and reach larger size than males (Tserpes and Tsimenides, 1995; Ehrhardt et al., 1996; Sun et al., 2002, De Martini et al., 2007). In the Mediterranean Sea, MLS has been restricted at 90 cm in Spain and 120 cm in Morocco (ICCAT, 2011a). However, minimum catch-at-size data have been reported as 51 cm for the Aegean Sea (De Metrio, 1995); 53 cm for the northern Ionian Sea (De Metrio, 1995); 52.5 cm for the eastern Mediterranean Sea (Alicli and Oray, 2001); 95 cm for the Sicilian fishery (Tserpes et al., 2001) and 87 cm for the Moroccan fishery (Abid and Idrissi, 2010). In the present study, 87 cm was observed as minimum catch-at-size. Differences in size-related catches have been attributed to gear types, limits, selectivity of each gear and the biological status of the animals (Di Natale et al., 2006). Many studies have emphasized that new born individuals (LJFL = 60 to 70 cm) has under fishing pressure in the Mediterranean (Tserpes et al., 2001). Therefore, vulnerable recruitment changes are inventible.

The length-weight relationship is important biological parameters for the creation of data bases used in stock evaluation (Mejuto and De la Serna, 1993). The relationships for the Mediterranean swordfish have been developed based on data collected from the landings of various fisheries (Tsimenides and Tserpes, 1989; De la Serna et al., 1995; Hattour, 1996; Tserpes et al., 2003; Alıçlı, 2008). "*b"* is an indicator factor of growth and it changes depending on species. Avşar (1998) reported that in bony fishes, it is probably equal out between 2.5 and 3.5. Studies emphasized that "*b*" varied from 3.06 to

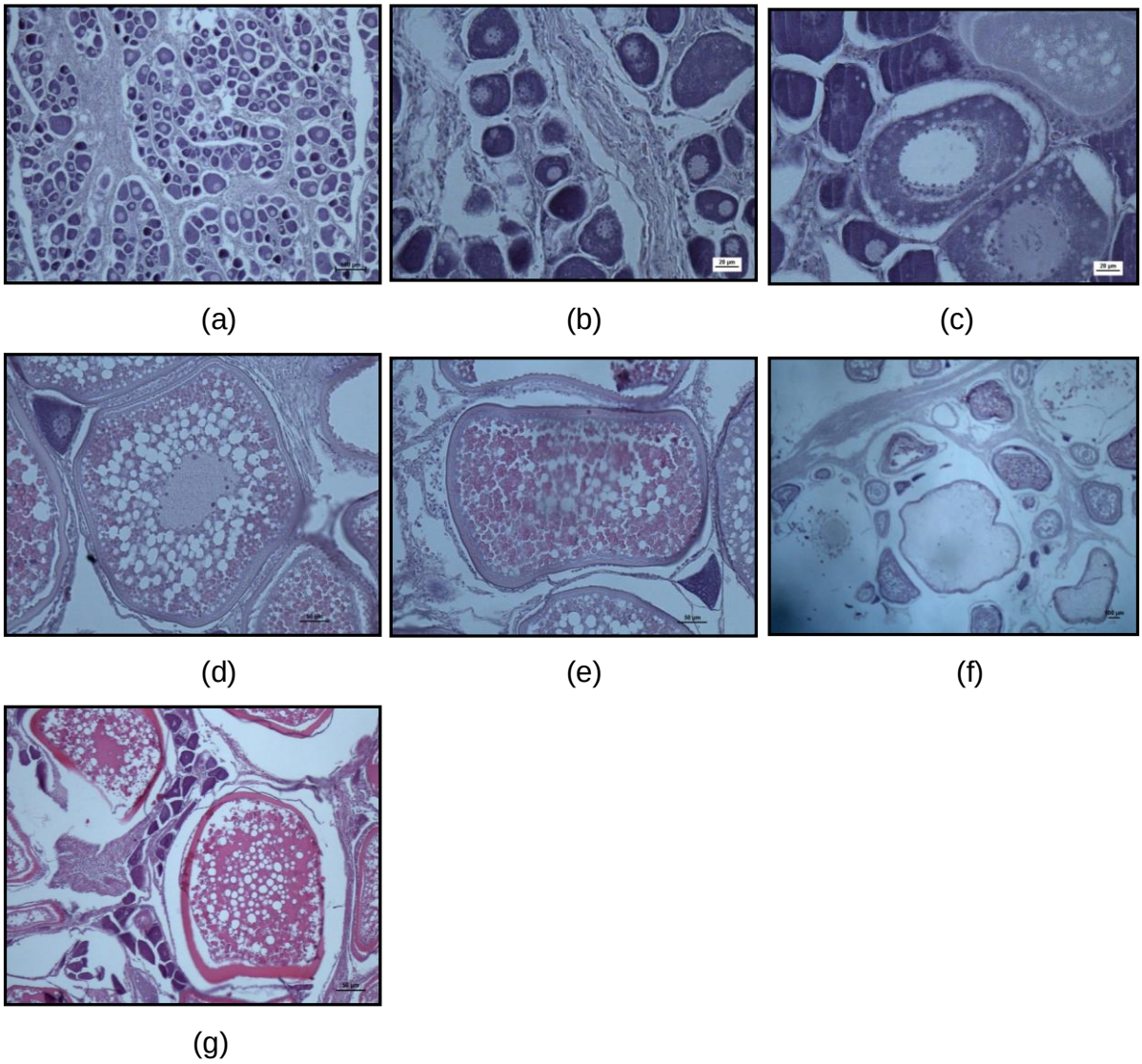


**Figure 4.** Oocyte development stage: (a) General review of ovary (scale bar 100 µm); (b) Undeveloped stage (Perinucleolar oocyte) (scale bar 20 µm); (c) Developing stage (Previtellogenic oocyte) (scale bar 20 µm); (d) Maturing stage (Early vitellogenic oocyte) (scale bar 50 µm); (e) Ripening stage (Vitellogenic oocyte) (scale bar 50 µm); (f) Hydrated oocyte (scale bar 100 µm); (g) Post-ovulatory follicle next to vitellogenic oocyte (scale bar 50 µm).

4.37 for the Mediterranean swordfish (De Metrio et al., 1989; Tsimenides and Tserpes, 1989; Cavallaro et al., 1991; Mejuto and De la Serna, 1993; Hattour, 1996; Alicli and Oray, 2001; Alıçlı, 2008). Our study has revealed that the relationship was a positive allometry (b=3.46). Differences in "*b*" have been attributed to season, habitat, daily basis (Begenal and Tesch, 1978; Dulćić and Glamuzina, 2006) and reproductive activity of the species in the region (Palco et al., 1981; Tserpes et al., 2001; Tserpes et al., 2003).

The measurement of age provides information on the life history and biological factors such as mortality and growth (Sun et al., 2002). Dominance of relatively young swordfish (1-3 years) in the catch has been reported by several authors in the Mediterranean (Di Natale, 1990, 1991; Orsi Relini et al., 1993; Tserpes et al., 1993; De Metrio et al., 1999a; Tserpes et al., 2001; Aliçli, 2008). The studies carried out in Mediterranean show that 50 to 70% of the yearly catch is composed of young individuals (ICCAT, 2011b) and these individuals represent of 87% of Aegean and 25.1% of the western Mediterranean Sea. The age of the species have been reported up to 10 years for the eastern and western populations (Alicli and Oray, 2001; Valerias et al., 2008). The age was determined as 7 years for the Aegean Sea in females (Tserpes and Tsimenides, 1995). In the present study, age of 1 and 2 composed of 60.4% of individuals and the maximum age was 7 in females.

**Table 3.** The sex ratio of swordfish, from the Eastern Mediterranean (Sex ratio = F / M).

| Reference | Area | < 105 | 105-135 | > 135 | Total |
|---|---|---|---|---|---|
| De Metrio et al. (1999b)* | Ionian Sea | 0.92 | 1.22 | 2.5 | 1.09 |
| De Metrio et al. (1999b)* | Western Mediterranen | 0.84 | 0.99 | 2.96 | 1.08 |
| De Metrio et al. (1999b)* | Ligurian Sea | 1.4 | 0.94 | 3.47 | 1.34 |
| Present study | Aegean/N. Levantine Seas | 1.0 | 0.5 | 4.14 | 1.23 |

* Calculated from De Metrio et al. 1999b data.

The fishery based on young individuals as in the Mediterranean leads to an increase in total catch. On the other hand, the fishery composed of young individuals (ages of 1, 2 and 3) leads to change in recruitment negatively (Ward and Elscot, 2000) and causes over-fishing (Konstantinos et al., 2003).

The distribution of swordfish depends on size and sex and varies with seasonal fluctuations in water temperature and prey abundance (Ward and Elscot, 2000). The relationship between sex ratio and body size can provide effective information to reconstruct sex composition from catch data (Sun et al., 2002). Based on the studies carried out in the Mediterranean swordfish, males are more numerous than females especially less than 105 cm. On the contrary, the ratio is in favor of females for bigger than 135 cm (Table 3). The differences in sex ratio have been attributed to size and possible growth and natural differential age - related mortality and possibly from seasonal distribution of the fish (Taylor and Murphy, 1992).

In the present study, the sex ratio was in favor of females for the year round (1, 2 and 3) and for size bigger than 130 cm (~ 3 year of age). Nevertheless, sex ratio changed especially during reproduction period. In this period, average body length for both sexes increased, and the sex ratio reached around 1. Poisson and Fauvel (2009) has reported similar results for the southwestern Indian Ocean. The sex ratio reaches completely in favor of females due to differences in growth rate between sexes. Mejuto et al. (1998) reported that females have reached 100% in the range of 200 to 215 cm in Ligurian Sea. In the present study, this ratio was around 165 cm LJFL.

$L_{50}$ is an essential factor for sustainable fishery. The estimate of length or age at $L_{50}$ is an important parameter for fish stock assessment (Wang et al., 2003). The first maturity size of Mediterranean swordfish has been reported as 82 to 105 cm for male and 106 to 135 cm for female (De Metrio et al., 1989). Di Natale et al. (2002) reported the maturation of females begins as small as 110 cm, and 20 and 50% of the population is matured at 125 cm and 142 cm respectively. De la Serna et al. (1996) estimated an $L_{50}$ of 142 cm for the female swordfish. In south - western Mediterranean, it has been reported that female lower than 125 cm is sexually immature and more than 160 cm is sexually mature (Macias et al., 2005b). It has been reported that mature females as young as the age of 2 (with most mature by age 3), and most males reach maturity by the age of 2 in eastern Mediterranean (De Metrio et al., 1989). The first maturity of females is around 140 cm in the Mediterranean (Abid and Idrissi, 2009). Similarly, in this study, minimum sexual maturity females was found in the age of 3 and 139.5 cm. (Abid and Idrissi, 2009).

Histological analysis of the developmental stages of oocytes is the most accurate method of determining sexual maturity (West, 1990), but the preparation of histological section is expensive and time-consuming (Wang et al., 2003). The histological analysis of gonads has proved to be the most adequate technique to establish the status of production maturation for tuna and tuna like species (Schaefer, 1996). In the present study, histological analysis of gonads showed that the ovaries have five different development stages of oocytes. The stages were interpreted as: The ovaries were inactive from January to April; the maturation began in May; the spawning started in June. In contrast to Wang et al. (2003), hydrated oocytes were observed among our samples sported hypothesis of existence of a major spawning ground in the Levantine basin (Tserpes et al., 2008).

GSI is an alternative method to determine sexual maturity or reproductive activity (Wang et al., 2003). GS ≥ 3 shows reproductively active female in the area (Kume and Joseph, 1969). The study carried out in Spain, the GSI presented for females increase from June to July, and the highest mean value has been observed in July according to the time of the reproduction (Macias et al., 2005b). In the present study, three individuals (139, 177.5 and 188.5 cm in length) exceeding the value of 3 in May indicated the females reproductive cycle could start earlier. In fact, our results supported the findings for the North Ionian and Southern Adriatic Seas (De Metrio et al., 1999b). The differences between maturity time and regions are probably explained by variability in environmental and oceanographic conditions in the Mediterranean Sea (Di Natale et al., 2002).

As a result, the present study supports the previous studies about age, landing size, sex ratio, and reproduction activity of swordfish. Briefly, Mediterranean

swordfish, shows positive allometric growth (*b*=3.46), composed of young individuals, majority of the catch is still younger than three-year-old and < 120 cm LJFL individuals. The juveniles dominate in the catch indicated that the fishing pressure is still on the first and second age classes. These results reveal that the fishing size and age of the Mediterranean swordfish progress to first maturity size. The sex ratio was in favor of females especially greater than > 135 cm and females reach 100% in the range of 165 and 190 cm LJFL. Contrary to previous studies, histological examination of gonads and GSI showed that the maturation start in May depending on fish size and environmental and oceanographic conditions in the region.

Eventually, the fishing activities and the MLS of this species should also be re-regulated taking in to account ICCAT regulations, the value of L50, and actual swordfish stock in the Mediterranean Sea. Mediterranean swordfish fishery should be kept under control via sharing the information between Mediterranean countries. Furthermore, all the arrangements made by international organizations are vital importance for the sustainable swordfish swordfish fishery in the Mediterranean.

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