Biol. Mar. Medit. (2003), 10 (2): 210-222

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REPRODUCTIVE PARAMETERS OF THE MEDITERRANEAN SWORDFISH

PARAMETRI RIPRODUTTIVI DELLO STOCK MEDITERRANEO DI PESCE SPADA

Abstract

Reproductive parameters of the Mediterranean swordfish were derived from measures and gonadal samples of 3358 sexed individuals from the Ligurian Sea (1990–2001).

The overall sex ratio was in favour of females (55%). The length ranges were 55–184 cm LJFJ for males and 55–223 cm LJFL for females. The bulk of the fished stock was formed by fish aged 1 to 3+. Reproduction was clearly seasonal, with a peak in July–August and a tail in September.

Ovarian weight per female length was used to describe the reproductive season and the gonad weight – fish length relationship in the resting season. The latter was used as a tool to separate active and quiescent adult females during the reproductive season. The limit between the two was very close to Kume and Joseph GI = 1. On this basis, a maturation ogive was derived. The female L_{50} was 149 cm LJFL, which corresponds to age 4.

Key-words: Xiphias gladius*, sex ratio, sexual maturity, gonadosomatic indexes, Mediterranean.*

Introduction

Some aspects of swordfish reproduction in the Mediterranean have been known since ancient times. Harpoon fishing has been going on for more than 2000 years in the Straits of Messina (eastern coast of Sicily), giving fishermen the opportunity to observe pairs of fish, generally made up of one large individual, the female, and a smaller one, the male. As found in the same Sicilian waters, swordfish eggs, larvae and juveniles – locally known as "spadelli" – have been described (Sanzo, 1910, 1922, 1930; Sella, 1911; Cavaliere, 1962; Cavallaro *et al.*, 1990). These studies pointed out that reproduction occurs strictly during the summer months, while each year the young are recruited to longline fishery during the autumn: these seasonal characteristics, as will be shown later, become very important in the calculation of biological parameters. When similar studies were extended to other areas, the same seasonality proved to be a common feature in the Mediterranean (Rey, 1987; De Metrio & Megalofonou, 1987; Megalofonou & De Metrio, 1989, Orsi Relini *et al.*, 1996, 1999; De Metrio *et al.*, 1995), but the precise timing of reproduction has yet to be defined.

Knowledge of the reproductive characteristics of the swordfish can help in distinguishing stock units. Moreover, estimates of size and age at sexual maturity are of fundamental importance for analytical stock assessments: mathematical models presently being developed by ICCAT use the reproductive parameters summed up in the maturation ogive to calculate the spawning stock biomass (SSB) and the spawning potential ratio (SPR); different possible steps in the recovery of an over-fished stock are then modelized on the basis of such criteria.

The aim of the present paper is to describe reproductive parameters in a population approach and in particular:

1) to study ovarian maturation per month and possibly to indicate simple criteria to distinguish spawning readiness. 2) to calculate a maturation ogive for the Mediterranean swordfish, taking into account similar studies performed on oceanic populations, mainly in the North Atlantic (Taylor & Murphy, 1992; Arocha & Lee, 1993; 1996; Arocha *et al*., 1994; Hinton *et al*., 1997; Arocha, 2002).

In the Mediterranean, as far as we know, the only study of this kind (De La Serna *et al.*, 1996) shows a maturation ogive calculated using as a reference point a gonadosomatic index (GI) of Kume and Joseph (1969) ≥ 3 to establish female maturity, that is a limit previously applied to oceanic swordfish.

Materials and methods

During the period 1990-2001, the biological parameters of swordfish in the Ligurian Sea were studied as part of a project funded by the Italian Ministero delle Politiche Agricole e Forestali (MiPAF) ("Triennial plans for fishery resources evaluation" 1990-1992; 1994-1995; 1997-2000) and by the E.U. (project XIV-1MED/91/012 "Characterization of large pelagic stocks (*Thunnus thynnus* L., *Thunnus alalunga* Bonn., *Sarda sarda* Bloch, *Xiphias gladius* L.) in the Mediterranean Sea").

Following the fishing activity of the professional fleets based in the harbours of Imperia and San Remo, which produce about 90% of the landings of the Ligurian coast, swordfish catches were monitored during the local fishing season, from June to December. At the beginning, the gears used were both longlines and driftnets, but the latter were limited in number and range of activity by the institution of a protected area for cetaceans (1990-1992) and eventually ceased in 1996 in line with E.U. regulations.

Data collected at landings regarded the fishing grounds and effort, numbers caught, measures (lower jaw/fork length, LJFL) and weight (gutted weight, GW) both of target and by-catch fish. On board, where the fish is eviscerated prior to landing, samples were collected for studies on feeding habits, reproduction and growth.

About 11,600 individuals were measured (LJFL), 3558 of which were sexed by inspection of gonads and 3300 pairs of gonads were sampled and frozen. After being defrosted in the laboratory, gonads were weighted, cut along the longitudinal axis and inspected under the stereomicroscope in order to observe the general characteristics of the parenchyma. In the maturing ovaries, the most advanced oocites were looked for and measured. Sub-samples of gonads were fixed and preserved in formol solutions. In a selected sample, fragments of ovarian laminae with eggs larger than 150 μm were dissociated under the stereomicroscope, and about 2 or 3 hundred eggs measured to derive length/frequency distributions. The presence of materials relating to previous ovulations, such as large abortive eggs or clumps of non-extruded eggs in the lumen, were also taken into account in order to separate virgin and spent individuals.

The indexes which establish correlations between gonad weight and fish length used in the present material are:

KJGI: (gonad weight (g) / $LJFL^3$ (cm)) × 10^4 (Kume and Joseph, 1969)

HGI: ln gonad weight/ln eye-fork length (EFL) (Hinton *et al*., 1997); the latter was also transformed in ln gonad weight/ln LJFL on the basis of the regression EFL/LJFL indicated by the same authors.

To derive a maturation ogive from the present series of data the following points were taken into account:

a) Spawning area. The Ligurian Sea is included in the Mediterranean reproductive areas (cf. Rey, 1987; Orsi Relini *et al*., 1999; Garibaldi *et al.,* in preparation).

b) Spawning season. As will be shown later, the seasonal aspects of reproduction are observed in a temporal sequence of seven months.

c) Adult females in active or quiescent phases of reproduction. In the available literature the reproductive phase in female swordfish is identified on the basis of a KJGI ≥ 3 (De La Serna *et al*., 1996; Mejuto and Garcia, 1997). However, Hinton *et al*. (1997) noted that this criterion underestimates reproduction and, following the indications of Taylor and Murphy (1992), established that a female can be considered in active reproduction if the HGI is ≥ 1.375.

To establish if the two limits were suitable for the Mediterranean fish, we compared the above mentioned indexes with the presence of advanced oocytes in the ovarian laminae following the criteria used by Hinton *et al*. (1997), i.e. taking into account especially the sizes reached by maturing ova (see also Arocha, 2002). We also established the correlation between ovarian weight and fish length during the season of reproductive rest, to indicate the active spawners on the basis of a single gonadal weight.

Results

a) Size and age composition of sampled fish.

Size/frequency distributions of sexed fish are shown in Fig. 1. Lengths range from a minimum of 55 cm LJFL to a maximum of 184 cm in males and 223 cm in females. For both sexes fish of 90–130 cm LJFL form the bulk of the catches.

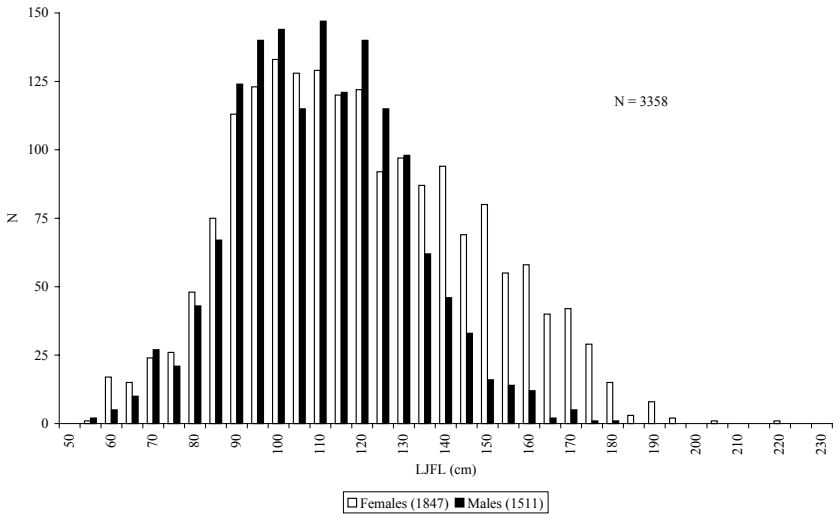

Fig. 1 - Overall length/frequency distributions of sexed swordfish (fishing seasons 1990-2001).
Distribuzioni lunghezza/frequenza dei pesci sessati (stagioni di pesca 1990–2001).

Von Bertalanffy growth functions available for Mediterranean swordfish assign a length of about 85 cm, 110 cm and 135 cm to the fish completing the first, the second and the third year of life, respectively (Tserpes and Tsimenides, 1995; Orsi Relini *et*

al., 1996). The main part of Ligurian catches is therefore made up of ages between 1 and 3 years.

b) Sex ratio and maximum sizes

The sex ratio (Fig. 2) changes with size: up to 130 cm LJFL is close to parity. In sizes larger than 130 cm LJFL, the percentage of females gradually increases; females make up the total at 190 cm LJFL. Large-sized fish are a small fraction of the fished stock (Fig. 1), so the overall sex ratio is 55.0% of females. In particular the last 3 size classes shown in the sex ratio graph (Fig. 2), i.e. females > 180 cm LJFL, are 1.6% of the total fished females.

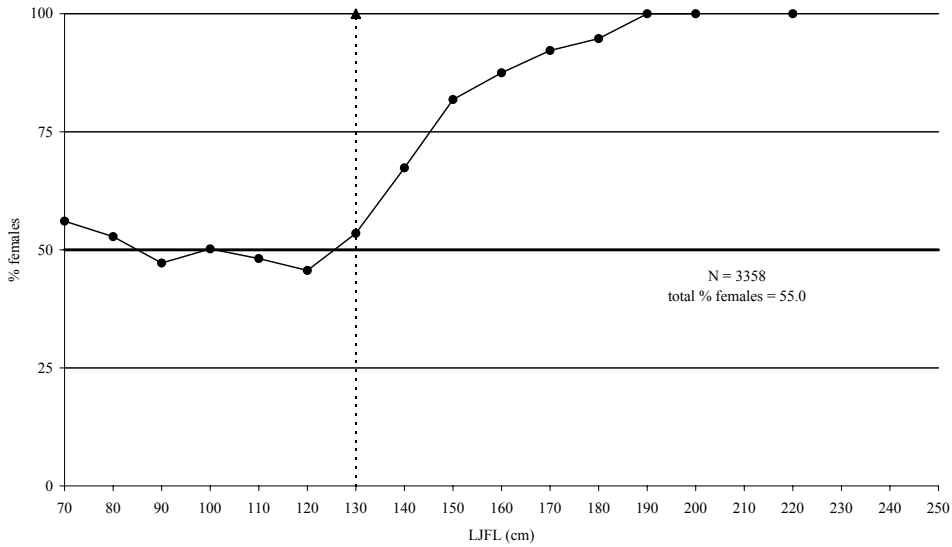

Fig. 2 - Swordfish sex ratio per length (LJFL).
Rapporto sessi in relazione alla lunghezza (LJFL).

c) Reproductive season

The KJGI, calculated as an average value of the fished stock (i.e. with all available sizes), gives a general picture of the timing of the reproductive season of males and females (Fig. 3).

It is worthwhile verifying the limits of this index for the Mediterranean swordfish, in particular the female. By considering ovarian weights in relation to female size (Fig. 4) in temporal sequence (from June to December), the active and resting phases can be separated. In the present sample the resting season is represented by the period October - December and the weight of the resting ovary as a function of the fish size is given by the following equation:

Ovarian weight (g) = 7.9734×LJFL (cm) – 959.84 (n = 120; R^2 = 0.7076)

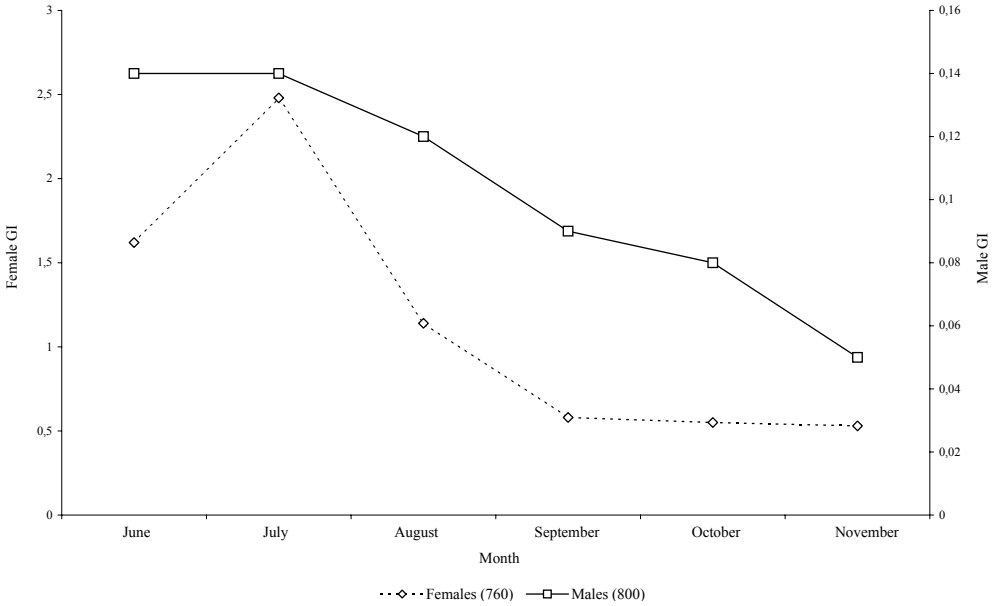

Fig. 3 - Trend of mean KJGI during the fishing season.
Andamento dell'indice gonadosomatico medio (di Kume e Joseph) durante la stagione di pesca.

(dotted line in Fig. 4e, also shown in each monthly graph of the same figure).

This regression line is very close to a Kume and Joseph GI = 1 (Fig. 5); also the latter can be considered a reference point to identify the spawners.

From June to September the ovarian weights located above the resting line indicate the reproducing individuals. In July (Fig. 4b) a reproductive peak can be observed, while June data show the start of reproduction and September data a tail.

It is interesting to note that in June the most advanced gonads (in terms of weight) belong to large fish, while in September few ovaries in activity belong to females of smaller size (about 150 cm LJFL).

d) Female minimum reproductive size

The July and August graphs for ovarian weight in relation to female size (Fig. 4) show the minimum reproductive size found in the present material: two individuals measuring 133 and 131 cm LJFL respectively. In the following calculation of the maturity at length ogive, based on size groups of 10 cm intervals, the first size class will therefore contain the range 130 – 139 cm LJFL.

e) Correlation between ovarian weight and the histological patterns of the ovary

The study of the correspondence between the microscopical anatomy of the ovary and the weight reached by this organ in respect of the body weight (or length) of the female has been done on samples collected from June to December and can be summed up in a selection of size/frequency distributions of oocytes diameters recorded in the ovary (Fig. 6).

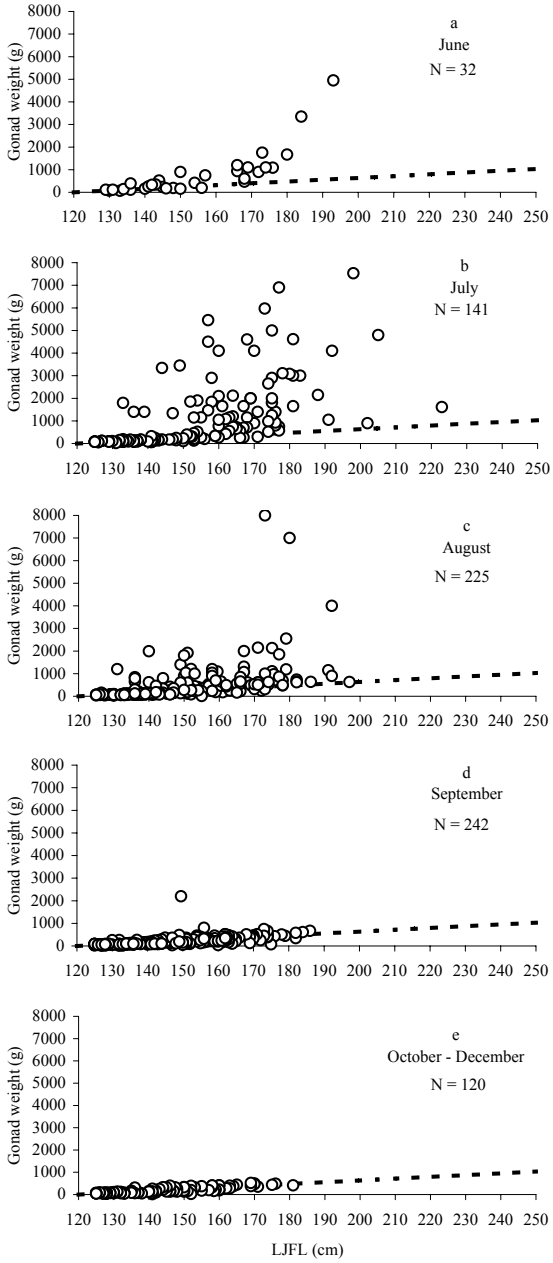

Fig. 4 - Ovarian weights in relation to female size during the fishing season. The dotted line indicates the resting conditions of the ovary in terms of the regression ovary weight / fish length which was obtained with the sample figured in the graph e.

Pesi degli ovari in relazione alla taglia delle femmine durante la stagione di pesca. La retta tratteggiata indica la quiescienza dell'ovario per mezzo della regressione peso dell'ovario / LJFL ottenuta col campione raffigurato nel grafico e.

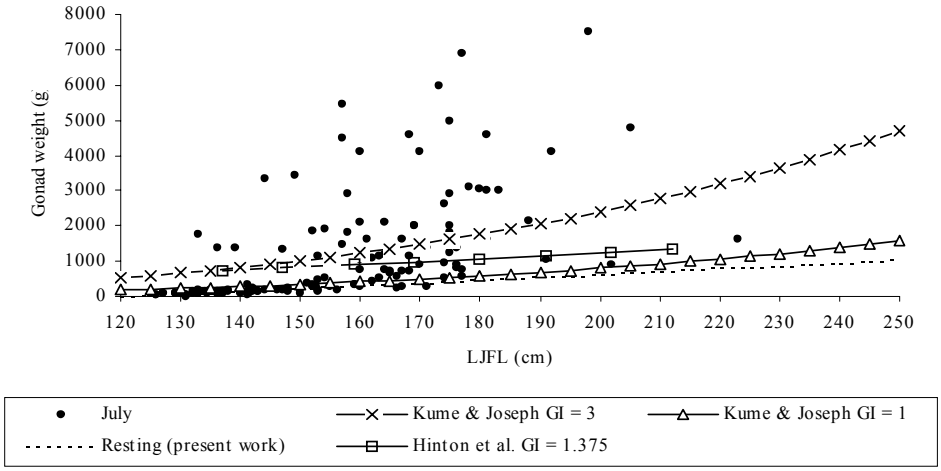

Fig. 5 - Ovarian weights recorded in July and limits proposed by different authors to separate active and resting females.

Confronto tra i pesi degli ovari rilevati in luglio ed i limiti proposti per separare gli ovari attivi da quelli in quiescenza.

At the beginning of the reproductive season, oocytes reach the starting of vitellogenesys with a KJGI value which is still low: Fig. 6a presents the case of a female, 141 cm LJFL, in which the main modal size of eggs is about 250 μm, while the KJGI is 0.9 and the HGI is 1.151.

Complete maturation is reached in July: oocytes exceed 1,500 μm, that is, they are ready to be ovulated. Given that swordfish are multi-spawners, the GIs are very different in fish sampled immediately before (Fig. 6b) or during the spawning (Fig. 6c). In the former case GIs can be very high: in the fish of Fig. 6b, a female of 157 cm LJFL, the most important group of eggs in the parenchyma was in the size range of 500-1,000 μm and the KJGI was 14.09, the HGI was 1.746.

In the Fig. 6c, a female of 174 cm LJFL, the ovarian parenchyma contained both large oocytes and a second batch in advanced vitellogenesys (size range 250-600 μm); the KJGI was 1.86 and the HGI was 1.368, that is apparently under the limit indicating spawning readiness: however, given the size of eggs, we consider this fish a spawner.

The two above-described ovarian patterns are also frequently found during August.

When the reproductive season is finished, the ovaries contain a main group of small-sized oocytes: in the case of Fig. 6d, a fish of 150 cm LJFL, the main mode was in the 100-150 μm range, few residual large eggs remained to bear witness to the previous spawning activity and the KJGI was 0.98 (HGI 1.189). The ovarian and weight patterns recorded at the beginning or at the end of the reproductive season can present difficulties in interpretation when identifying the spawners of the year in the sense that the time required to achieve the next complete maturation or the time elapsed from the last ovulation could be a matter of discussion. We will therefore calculate the following maturation ogive only on the basis of the July data, which represents the core of the reproductive season.

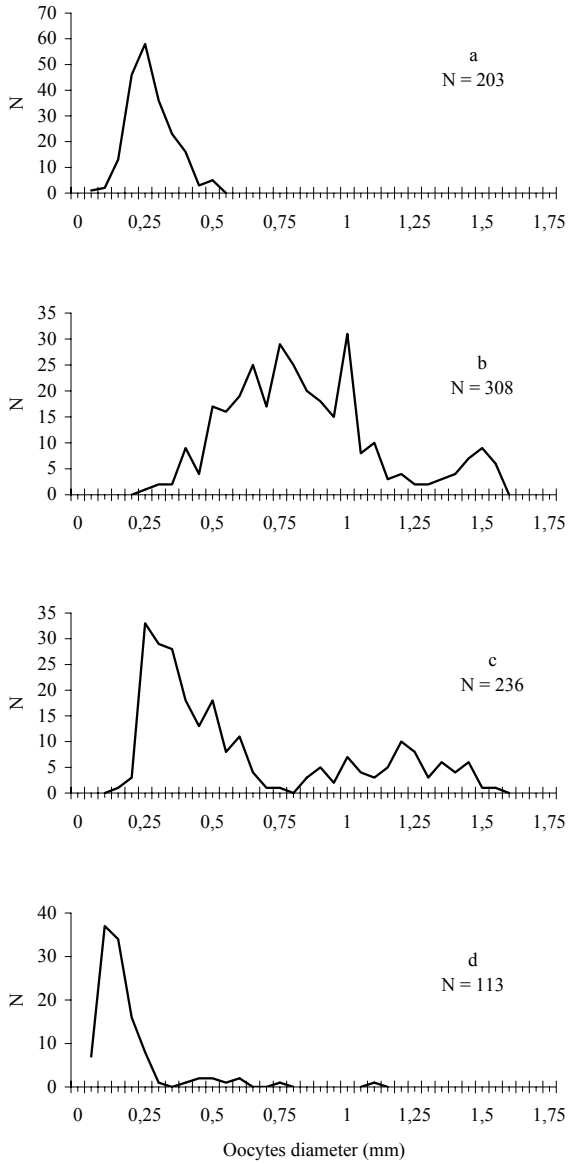

Fig. 6 - Frequency distributions of ovarian egg sizes found in different months (explanation in the text).
Distribuzioni di frequenza dei diametri degli oociti in mesi differenti (spiegazione nel testo).

f) Maturation ogive.

Assuming KJGI ≥ 1 as a reference point to identify spawners in the females sampled in July, 53.85% of the females larger than the minimum reproductive size are active.

In five size classes of females, from 130–139 to 170–179 cm LJFL, the numbers available were 30, 19, 24, 25, 20; sizes larger than 180 cm were all active spawners (12 individuals). We have already noted that the large females in which the 100% of spawners are found represent only 1.6% of the fished females.

The ogive is:

% mature = $100 / (1+ e^{(19,62783 - (0,13193 \times LJFL))})$ (Fig.7).

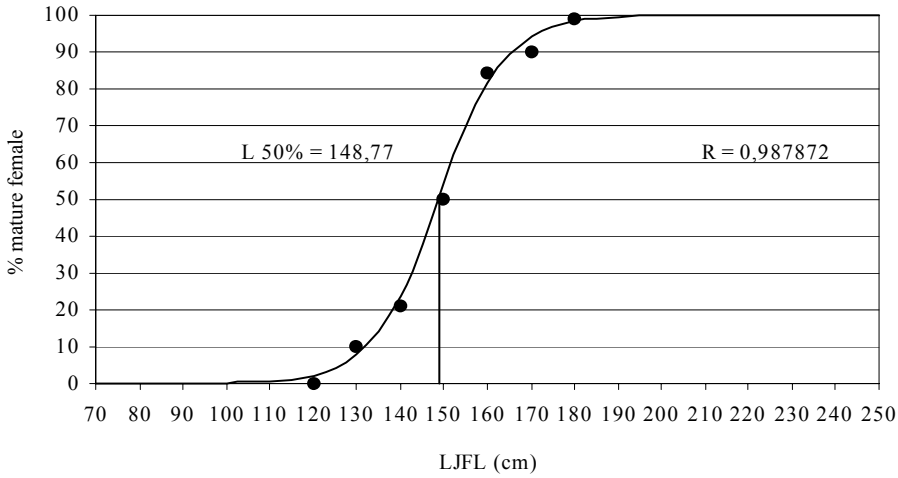

Fig. 7 - Female maturity at length ogive.
Ogiva di maturazione delle femmine di pesce spada.

The L_{50} is 148.8 cm LJFL, which on the basis of Von Bertalanffy growth functions derived in the Mediterranean (Megalofonou & De Metrio, 1989; Tserpes & Tsimenides, 1995; Orsi Relini *et al*., 1999) corresponds to age 4. Reproduction apparently starts with females younger than 4 (not less than three, see also Orsi Relini *et al.*, 1999) and becomes total at an advanced age (about 6-8 years). If the maturation ogive is obtained on the basis of KJGI ≥ 3 the L_{50} shifts to 170.3 cm LJFL; with HGI ≥ 1.375 it shifts to 160.2 cm LJFL.

Conclusions

The study of reproductive patterns in a time interval of seven months has shown that the reproductive season in the Mediterranean is very short and almost coincides with two summer months, while the resting season goes from October to May. This represents a difference from the reproduction times of the North Atlantic swordfish studied along the Eastern coast of the U.S. and Caribbean between 5° and 50° N. Full mature females were found in a tropical belt (18°-35° N) and spawning occurred from December to June, with some additions in August-November (Arocha & Lee, 1993, 1996; Arocha *et al.*, 1994). The reproduction of South Atlantic swordfish occurs in an equatorial belt all year long (Mejuto and Garcia, 1997).

The Mediterranean hosts northern spawning grounds, including our study area, the Ligurian Sea, where favourable surface temperatures are those of a temperate instead of a tropical sea; on the other side the Mediterranean swordfish live in mesopelagic waters which are warmer than the oceanic waters at the same latitude (Lacombe, 1990).

The existence of a resting period in the Mediterranean made it possible to derive the regression of the ovarian weight at rest in relation to fish length, an aspect not previously studied in oceanic populations owing to the length of their reproductive season. This function can be used to identify the active ovaries on the basis of simple weight and, after the corresponding micro-anatomical aspects have been verified, has suggested that, if a Kume and Joseph GI is used as a predictor of spawning readiness, the reference value should be 1 instead of 3.

Following these criteria, the L_{50} value was 148.77 cm LJFL. In the oceanic populations L_{50} is higher: in the North Atlantic it has been calculated as 182 cm LJFL (Taylor & Murphy, 1992) and 179 cm LJFL (Arocha and Lee, 1996). The growth curves of these fish show length at age larger than in the Mediterranean (Ehrhardt *et al.*, 1996). According to Taylor & Murphy (1992), the 182 cm size of the female corresponds to the age of 5.5 years. In the Hawaiian sector of the Pacific, L_{50} was 162 cm LJFL (De Martini *et al.*, 2000), with no indication of the corresponding age. The above-mentioned differences in time and place of spawning and, at least in part, in size and age of the mature females in the Atlanto-Mediterranean area, are in agreement with the distinction of three stock units at present recognized by the ICCAT (North Atlantic, South Atlantic and Mediterranean stock). However, the separation between Atlantic and Mediterranean fish is not so clear-cut and genetic studies gave contradictory interpretations.

According to one theory (Magoulas *et al.*, 1993; Kotoulas *et al.*, 1995), in terms of mitochondrial DNA, the Mediterranean swordfish is distinct from the Eastern Atlantic one, a fact that suggests fidelity to Mediterranean spawning areas, while, outside the reproductive season, fish can migrate to the adjacent ocean for trophic reasons. De facto, the migration of spawners to the Mediterranean has been verified in the waters of Gibraltar by Spanish researchers: they observed fishing activities both "towards" the Mediterranean and "back" to the Atlantic, as also occurs with tuna (De La Serna & Alot, 1990).

According to other genetic studies (Alvarado Bremer *et al.*, 1995; 1996; Rosel & Block, 1996), there are two main clades of swordfish, only one of which is to be found in the Pacific, while two are present both in the Atlantic and in the Mediterranean, albeit in different proportions. Chow *et al.* (1997) also indicate two main clusters, but with a different distribution: one in the Mediterranean – North Atlantic and one spread in the Pacific – Indian and South Atlantic Oceans. Are different clades of swordfish recognizable also on the basis of some morpho-physiological characteristics, for instance the reproductive parameters? In their studies of large Atlantic areas Mejuto & Garcia (1997) noted that the maximum KJGI values recorded were 19.8 for fish < 165 cm LJFL and 12.2 in fish > 165 cm LJFL (the sample size was 13,739 individuals) – a fact that suggests two kind of reproductive adaptations, that is apparently an affirmative answer to the previous question.

Is the Mediterranean population of swordfish mainly composed of a "small" fish which is outstanding in terms of size of its ovary?

The maximum ovarian weights recorded in the Mediterranean do in fact point to a very interesting question. Although many authors have only given average values, in the Mediterranean literature five specimens can be found with a KJGI > 20: four of them were fished in Spanish waters, on the basis of a sampling of 4,467 females effected in

1991 and 1992 (De La Serna *et al.*, 1996) and the last one in the Straits of Messina, Sicily (Cavallaro *et al.*, 1991). This fish represents the absolute maximum: the 192 cm LJFL and 130 kg weight female had a total weight of 15.7 kg of ovarian tissues, a KJGI 22.18 and 10.4 kg of running ova.

Maximum ovarian weights are directly related to batch fecundity, which can be very high: it was calculated as being in the range 1-10 millions ova, both in Mediterranean fish of 150-195 cm LJFL (De La Serna *et al.*, 1996) and in North Atlantic specimens of 155-250 cm LJFL (Arocha & Lee, 1996). So the Mediterranean swordfish seems to balance its smaller size and limited spawning time with a high level of fecundity achieved at a young age.

Riassunto

Monitorando la pesca del pesce spada nel Mar Ligure Occidentale nel periodo 1990-2001, sulle imbarcazioni delle flottiglie di Imperia e Sanremo sono stati raccolti 3558 campioni di gonadi dei due sessi, che hanno permesso di studiare i seguenti parametri riproduttivi:

Rapporto sessi.

Le femmine costituivano il 55% dell'insieme dei pesci sessati. Le taglie erano comprese tra 55 e 223 cm LJFL nelle femmine e tra 55 e 184 cm LJFL nei maschi.

Il rapporto sessi è vicino alla parità dalle taglie più piccole, fino a circa 130 cm LJFL; poi prevalgono le femmine, rappresentando il 75% a 145 cm LJFL, il 90% a 180 cm LJFL e il 100% a 190 cm LJFL.

Taglia riproduttiva minima.

La più piccola femmina matura è risultata di 131 cm LJFL.

Stagione riproduttiva.

In ciascuno dei sette mesi che formano la stagione di pesca, da giugno a dicembre, i pesi degli ovari sono stati messi in grafico in relazione alla lunghezza delle femmine. La stagione riproduttiva inizia a giugno, culmina a luglio-agosto e presenta una coda a settembre.

Il processo maturativo è stato studiato anche negli aspetti anatomo-microscopici del parenchima ovarico e sono state rilevate misure degli ovociti più avanzati. I diversi stadi del ciclo maturativo sono stati illustrati con istogrammi l/f dei diametri degli ovociti.

Stagione di quiescenza.

Nel materiale campionato, gli ovari risultano quiescenti da ottobre a dicembre, anche se verosimilmente questa fase di riposo si protrae per i successivi mesi invernali e primaverili in cui non c'è attività di pesca. E' stata calcolata la relazione tra il peso degli ovari e la lunghezza della femmina (Peso ovario (g) = 7,9734 LJFL (cm) - 959,84) nel periodo di quiescenza come termine di riferimento per separare le femmine attive da quelle quiescenti anche durante la stagione riproduttiva; in questo modo, con una semplice pesatura delle gonadi si può apprezzare lo stato riproduttivo della femmina. Tale regressione è molto simile a un indice di Kume e Joseph = 1; si può quindi ritenere un ovario attivo quello che supera il valore in peso indicato dalla predetta regressione oppure quello che presenta un indice di Kume e Joseph superiore a 1.

Ogiva di maturazione.

La percentuale di femmine mature in funzione della taglia è data dalla seguente equazione:

% mature = $100/(1+e^{(19,62783 - (0,13193 \times LJFL))})$

L_{50} è pari a 148,8 cm LJFL, lunghezza che nelle curve di crescita derivate da materiale mediterraneo, corrisponde a un'età di circa quattro anni.

La predetta L_{50} risulta inferiore a quelle calcolate nel Nord Atlantico occidentale e nel Pacifico tropicale; particolarmente nel primo caso, è noto che i pesci a parità di età sono più grandi di quelli mediterranei.

Infine si nota come gli indici gonadosomatici dei pesci del Mediterraneo possano raggiungere valori particolarmente elevati, verosimilmente come risposta adattativa alla brevità della stagione riproduttiva.

References

ALVARADO BREMER J.R., BAKER A.J., MEJUTO J. (1995) – Mitochondrial DNA control region sequences indicate extensive mixing of swordfish (*Xiphias gladius*) populations in the Atlantic Ocean. *Can. J. Fish. Aquat. Sci.*, **52**: 1720-1732.

ALVARADO BREMER J.R., MEJUTO J., GREIG T.W., ELY B. (1996) – Global population structure of the swordfish (Xiphias gladius L.) as revealed by analysis of the mitochondrial DNA control region. *J. Exp. Mar. Biol. Ecol.*, **197**: 295-310.

AROCHA F. (2002) – Oocyte development and maturity classification of swordfish from the North – Western Atlantic, *J. Fish Biol.,* **60**: 13–27.

AROCHA F., LEE D.W. (1993) – Preliminary observation on sex ratio and maturity stages of the swordfish, *Xiphias gladius*, in the Northwest Atlantic. *ICCAT Coll. Vol. Sci. Pap*., **40** (1): 425–432.

AROCHA F., LEE D.W. (1996) – Maturity at size, reproductive seasonality, spawning frequency, fecundity and sex ratio in swordfish from the Northwest Atlantic. *ICCAT Coll. Vol. Sci. Pap.,* **45** (2): 350-357.

AROCHA F., LEE D.W., GRUBICH J.R. (1994) – Observations on sex ratio, maturity stages, and fecundity of swordfish, *Xiphias gladius*, in the Northwest Atlantic Ocean. *ICCAT Coll. Vol. Sci. Pap.,* **42** (1): 309-318.

CAVALIERE A. (1962) – Studi sulla biologia e pesca di *Xiphias gladius* L. Nota I. *Bollettino di pesca, Piscicoltura e Idrobiologia.,* **17** (2): 123-143.

CAVALLARO G., CEFALI A., POTOSCHI A. (1990) – Aspetti biologici di *Xiphias gladius* L. 1758 dei mari meridionali italiani. *FAO Fish. Rep*., **394**: 91–102.

CAVALLARO G., POTOSCHI A., CEFALI A. (1991) – Fertility, gonado-somatic index and catches of eggs and larvae of *Xiphias gladius* L. 1758 in the Southern Tyrrhenian Sea. *ICCAT Coll. Vol. Sci. Pap.,* **35** (2): 502–507.

CHOW S., OKAMOTO H., UOZUMI Y., TAKEUCHI Y., TAKEYAMA H. (1997) – Genetic stock structure of the swordfish (*Xiphias gladius*) inferred by PCR-RFLP analysis of the mitochondrial DNA control region. *Mar. Biol.*, **127** (3): 359-367.

DE LA SERNA J. M., ORTÌZ DE URBINA J. M., MACÌAS D. (1996) – Observations on sex ratio, maturity and fecundity by length class for swordfish (*Xiphias gladius*) captured with surface longline in the Western Mediterranean. *ICCAT Coll. Vol. Sci. Pap.,* **45** (1): 115–139.

DE LA SERNA J.M., ALOT E. (1990) – Consideraciones relativas a los desplazamientos efectuados por el pez espada (*Xiphias gladius*) en el area del Estrecho de Gibraltar y otras observaciones relacionadas con la biologia de la reproduccion. *ICCAT Coll. Vol. Sci. Pap.,* **32** (2): 353–359.

DE MARTINI E.E., UCHIYAMA J.H., WILLIAMS H.A. (2000) – Sexual maturity, sex ratio, and size composition of swordfish, *Xiphias gladius*, caught by the Hawaii-based pelagic longline fishery. *Fish. Bull*., **98**: 489–506.

DE METRIO G., MEGALOFONOU P. (1987) – Catch, size distribution, growth and sex ratio of swordfish (*Xiphias gladius* L.) in the Gulf of Taranto. *FAO Fish. Rep*., **394**: 91–102.

DE METRIO G., GIACCHETTA F., SANTAMARIA N. (1995) – Sex ratio ed indice gonado somatico del pesce spada (*Xiphias gladius* L.) dello Ionio settentrionale e dell'Adriatico meridionale. *Biol. Mar. Medit*., **2** (2): 479–481.

EHRHARDT N.M., ROBBINS R.J., AROCHA F. (1996) – Age validation and growth of swordfish, *Xiphias gladius*, in the Northwest Atlantic. *ICCAT Coll. Vol. Sci. Pap.,* **45** (2): 358–367.

GARIBALDI F., PALANDRI G., ORSI L. (2004) - Documentazione della riproduzione del pesce spada, *Xiphias gladius* L., in Mar Ligure. Biol Mar. Medit., **11** (1): in stampa.

HINTON M.G., TAYLOR R.G., MURPHY M.D. (1997) – Use of gonad indices to estimate the status of reproductive activity of female swordfish, *Xiphias gladius*: a validate classification method. *Fish. Bull.,* **95**: 80–84.

KOTOULAS G., MAGOULAS A., TSIMENIDES N., ZOUROS E. (1995) – Marked mitochondrial DNA differences between Mediterranean and Atlantic populations of the swordfish, *Xiphias gladius*. *Molec. Ecol.*, **4**: 473-481.

KUME S., JOSEPH H. (1969) – Size composition and sexual maturity of billfish caught by the Japanese longline fishery in the Pacific Ocean East of 130° W. *Bull. Far Seas Fish. Res. Lab. (Shimizu),* **2**: 115-162.

LACOMBE H. (1990) – Water, salt, heat, and wind in the Mediterranean. *Oceanus*, **33** (1): 26-36.

MAGOULAS A., KOTOULAS G., DE LA SERNA J.M., DE METRIO G., TSIMENIDES N., ZOUROS E. (1993) – Genetic structure of swordfish (*Xiphias gladius*) populations of the Mediterranean and the Eastern side of the Atlantic: analysis by mitochondrial DNA markers. *ICCAT, Collect. Vol. Sci. Pap.*, **40**: (1): 126-136.

MEGALOFONOU P., DE METRIO G. (1989) – Stima dell'età e dell'accrescimento di *Xiphias gladius* L. del Mar Egeo mediante lo studio dei raggi spiniformi della pinna anale. *Nova Thalassia,* **10** (Suppl. 1): 437–436.

MEJUTO J., GARCIA B. (1997) – A preliminary analysis of gonadal indices of the swordfish (*Xiphias gladius* L.) in the Atlantic Ocean. *ICCAT, Coll. Vol. Sci. Pap.,* **46** (3): 336-344.

ORSI RELINI L., PALANDRI G., GARIBALDI F., CIMA C. (1996) - Accrescimento e maturazione del pesce spada. Nuove osservazioni in Mar Ligure. *Biol. Mar. Medit.,* **3** (1): 352-359.

ORSI RELINI L., PALANDRI G., GARIBALDI F., CIMA C., RELINI M., TORCHIA G. (1999) - Biological parameters of the Mediterranean swordfish derived from observations in the Ligurian Sea. *ICCAT, Coll. vol. Sci. Pap.,* **49** (1): 397-406.

REY J. C. (1987) – Comentarios sobre las areas de reproducion del pez espada (*Xiphias gladius*) en el Atlantico y Mediterraneo. *ICCAT, Coll. Vol. Sci. Pap.,* **27**: 180–193.

ROSEL P.E., BLOCK B.A. (1996) – Mitochondrial control region variability and global population structure in the swordfish, *Xiphias gladius*. *Mar. Biol.*, **125**: 11-22.

SANZO L. (1910) – Uovo e larva di pesce spada (*Xiphias gladius*). *Riv. Mens. Pesca Idrobiol.,* **12**: 206-209.

SANZO L. (1922) – Uova e larve di *Xiphias gladius* L. *R. Com. Talassogr. Ital.,* Mem. 79: 17 pp.

SANZO L. (1930) – Giovanissimo stadio larvale di *Xiphias gladius* L. di mm 6.4. *R. Com. Talassogr. Ital.,* Mem. 170: 8 pp.

SELLA M. (1911) – Contributo alla conoscenza della riproduzione e dello sviluppo del pesce spada (*Xiphias gladius* L.). *R. Com. Talassogr. Ital.,* Mem. **2**: 1–16.

TAYLOR R. G., MURPHY M. D. (1992) – Reproductive biology of the swordfish *Xiphias gladius* in the Straits of Florida and adjacent waters. *Fish. Bull.,* **90**: 809–816.

TSERPES G., TSIMENIDES N. (1995) – Determination of age and growth of swordfish, *Xiphias gladius* L., 1758, in the Eastern Mediterranean using anal fin spines. *Fish. Bull.,* **93**: 594–602.