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ABSTRACT

Swordfish is widely distributed along the Venezuelan coast. Until 1987, swordfish was a by-catch product of the tuna longline fishery. By this time the swordfish fishery in the southern United States had expanded their range to less utilized fishing areas of the Caribbean, including Venezuela. The significant increase in the catches of this resource led to the development of a swordfish fishery. Since swordfish in the North Atlantic is managed as a single stock by the International Commission for the Conservation of Atlantic Tunas, it was necessary to determine the population structure in Venezuela and adjacent waters. A total of 2,580 specimens have been collected between May 1991 and June 1994. Seasonal female sexual maturity is assessed from 646 ovaries using a gonadal index (GI). Results indicate that the catches are comprised of animals with mean size of 135.1 cm LJFL for females and 123.4 cm LJFL for males and 50% of the catch is made up of specimens less than 130 cm LJFL. Seasonal sex ratio show an increased proportion of females (60%), except in March and June where the proportion of males increases (55-65%). Mean female gonadal indices show little variation throughout the season(GI<1.0), sexually mature females show some prespawning activity towards the fourth quarter of the year. Only one specimen with hydrated oocytes was obtained in the samples. These results indicate that the population structure of the swordfish catch in Venezuela and adjacent waters is mainly comprised of sexually immature females and young sexually mature males. Occasional spawning is restricted to the last quarter of the year.
Key words: Population Structure, sexual maturity, spawning, swordfish.

INTRODUCTION

Swordfish is widely distributed along the Venezuelan coast. Until 1987, swordfish was a by-catch product of the tuna longline fishery (Alio et al.,1993). By this time the swordfish fishery in the southern United States had expanded their range to less utilized fishing areas of the Caribbean, including Venezuela (Tobias, 1989). The significant increase in the catches of this resource led to the development of a swordfish fishery. Most of the swordfish landings in Venezuela are exported to the United States with a value between $200,000 - $500,000 for the period of 1989 - 1994 (Habron et al., 1994). Stock assessments of swordfish which incorporate knowledge of the species population structure provides a basis for improving advise to managers about current and future prospects of stock production. Swordfish size structure, sex ratio, spawning season and area, and fecundity estimates, all are important elements to consider in stock assessment. Since swordfish in the North Atlantic is managed as a single stock by the International Commission for the Conservation of Atlantic Tunas (ICCAT), it was necessary to determine the population structure in Venezuela and adjacent waters. A study was initiated in 1991 with the Centro de Investigaciones Pesqueras (Cumaná, Venezuela) due to the lack of information on the population structure of swordfish in Venezuela and adjacent waters.

Very little information is known on the population structure in Venezuela, Alio et al. (1993) estimated 50% maturity of females at 127 cm LJFL and suggested that the southern Caribbean region is a spawning ground based on the high incidence of juveniles in the area. In other areas of the Northwest Atlantic the population structure is well studied (Guitart, 1964; Mejuto et al.,1990; Hoey, 1991). Although reproductive information was only limited to portions of the swordfish stock in the Northwest Atlantic Ocean (Tibbo et al., 1961; Taylor & Murphy, 1992). Recently, Arocha and Lee (1994) expanded the knowledge on swordfish reproduction in the Northwest Atlantic. They found that swordfish spawn in distinct geographical areas at different periods of time within the subtropical area of the Northwest Atlantic.

The information obtained from the research carried out in Venezuela and adjacent waters will contribute to the overall knowledge of the biological characteristics of swordfish in the Northwest Atlantic.

MATERIALS AND METHODS

Specimens were obtained from the FONAIAP longline observer program that cover the longline fleet with operations based in the ports of Guanta, Cumaná and Güiria located in the northeastern coast of Venezuela. Swordfish were sampled from May 1991 to June 1994, from which a total of 2,580 specimens were collected aboard commercial fishing vessels (Fig. 1). The data were classified in quarters or months for all years combined. The method of collection of the reproductive material for this study along with the associated morphometric data are given by Lee (1991). Lower jaw - fork length (LJFL) was measured to the nearest cm and dressed weight (DWT) to the nearest 100 g.

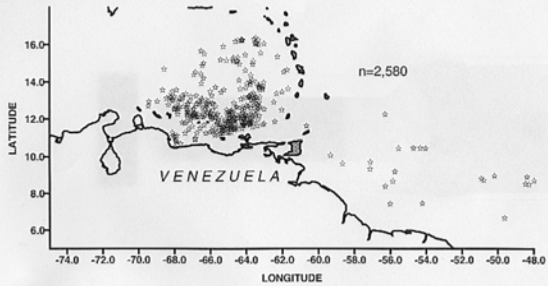

Figure 1. Location of swordfish samples during the sampling season (May 1991-June 1994.

A total of 646 paired ovaries (65-280 cm LJFL) were used for the assessment of sexual maturity. In the laboratory, ovaries were thawed and weighted to the nearest 0.1 g. Whole oocyte were obtained from a wedge of tissue extending from the periphery to the lumen of the ovary from three different sections in each ovary lobe. Oocyte diameter (in microns, m) was measured at random using a video analyzing system linked by a video camera to a dissection microscope.

Size frequency distributions of whole oocyte within ovaries at different maturity stages was determined. We used whole oocyte staging to assess maturity in all active ovaries, i.e. with signs of vitellogenesis. A subsample of 10 immature and regressing ovaries was used to assess maturity of inactive ovaries. Maturity stages were categorized as immature, maturing, mature, ripe and regressed (Table 1). A gonadal index (GI) as described by Arocha and Lee (1993) was calculated as GI = (gonad weight/LJFL3)x1000 and used as a measurement of relative reproductive development. Batch fecundity was determined using the gravimetric method (Hunter et al., 1985) by which counts are made of the number of hydrated oocyte present in a thawed oocyte subsample of known weight. Batch fecundity was calculated as BF=HO OW, where BF is batch fecundity, HO is the number of hydrated oocyte per unit of weight and OW is the ovary weight.

Maturity at size for females was defined as the smallest length at which 50% of the females sampled had maturing stage ovaries with yolked oocyte (Stage 3 and GI>2). Male maturity was defined as the smallest length at which 50% of the males sampled had milt present when pressure was exerted on the testis. A logistic function of the form: $Mature = 1/(1+e(-a(LJFL-b)))$, was used to predict a maturity schedule that best described the relationship between proportion of mature fish and fish length, the function was fitted to the data using maximum likelihood estimation.

RESULTS

Size distribution

The size distribution of the swordfish in Venezuela and adjacent waters when analyzed by quarters, show that 50 % of the specimens caught by the longline fleet during the first and second quarter consists of animals that are around 130 cm LJFL (Fig. 2). During the third and fourth quarter, 50% of the animals caught were below 125 cm LJFL, which falls bellow the minimum size allowed by ICCAT (ICCAT,1991). The average size of females during the sampling season was 135.1 cm LJFL and the males was 123.4 cm LJFL (Table 2). For both sexes, the average size of specimens by quarters showed no marked differences between quarters, except in the third quarter where the mean size of the specimens caught were smaller (Table 2).

Proportion of sexes

Examination of the proportion of females by quarters (Fig. 3) shows strong dominance of females toward sizes larger than 200 cm LJFL throughout the season. At small sizes, there is an uneven proportion of sexes for the size classes between 65 - 100 cm LJFL, followed by an even trend in the proportion of males and females in size classes between 100 and 125 cm LJFL in all quarters. For size classes between 125 - 150 cm LJFL, males dominate in all but the third quarter (Fig. 2), where females predominate in most of the size classes in that range. For specimens larger than 150 cm LJFL, females tend to increase its proportion gradually towards larger sizes, markedly in the second and fourth quarter. The monthly pattern in the proportion of females for all sizes combined, showed a marked decline in March and June and a 1:1 proportion in July and October (Fig. 4). During the reminder part of the year the proportion of females remain higher than 50%. Although from October through December the proportion of females does not depart far from the 1:1 ratio.

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Maturation of ovaries

Size frequency distribution and stage of whole oocyte in active ovaries representing the developmental sequence of maturation indicated that the size of oocyte is correlated with their stage of development but there is considerable overlap between stages (Fig. 5). The observed pattern of oocyte development is asynchronous, indicating that there are several batches of oocyte to be spawned in a season. Immature fish have only unyolked oocyte (50 ~ 180 m). Swordfish with ovaries showing frequency distribution of this type of oocyte, had a mean GI of 0.24 and range between 0.01-0.96. Maturing swordfish has yolked oocyte (500 ~ 700 m) as the most advanced group of oocyte in the ovary. This stage had a mean GI of 1.87 with range between 0.76-5.34. Mature swordfish has advanced yolked oocyte (1,000 ~ 1,200 m) in their most advanced group of oocyte with mean GI of 5.34 with ranges from 3.03-6.53. The only female in the ripe stage (166 cm LJFL) in the samples had migratory nucleus (1,200 - 1,400 m) and hydrated oocyte (1,400 - 1,750 m).

At this point the hydrated oocyte will be ovulated and spawning is presumed to occur in less than 24 hours. The GI for this specimen was 7.18. Only one post-spawning female was obtained (238 cm LJFL), characterized by having a large mode for sizes between 1,000 - 1,200 m. The internal appearance of this type of ovary is bloodshot and the follicular tissue appears loose, which is an indication of recent spawning. The GI for this specimen was 0.96. Regressed ovaries showed a thick tunic and a compact follicular tissue with occasionally yolked oocyte imbedded in it. The mean GI found for this ovary condition was 0.57 with ranges from 0.22-1.42.

Size at maturity

It was observed that male swordfish mature at a smaller size than females. The smallest mature male observed was 110 cm LJFL and the smallest mature female was 150 cm LJFL (Fig. 6). The proportion of mature males increases gradually with size after reaching 50 % maturity, and all males are mature by 180 cm LJFL. In contrast, the proportion of mature females increases rapidly, and all females are mature by 175 cm LJFL. The predicted length at 50 % maturity was estimated by fitting the data to a logistic function using maximum likelihood estimation:

for females, $\text{Mature} = 1/(1+e(-0.1765(\text{LJFL}-167)))$

for males, $\text{Mature} = 1/(1+e(-0.0737(\text{LJFL}-143)))$.

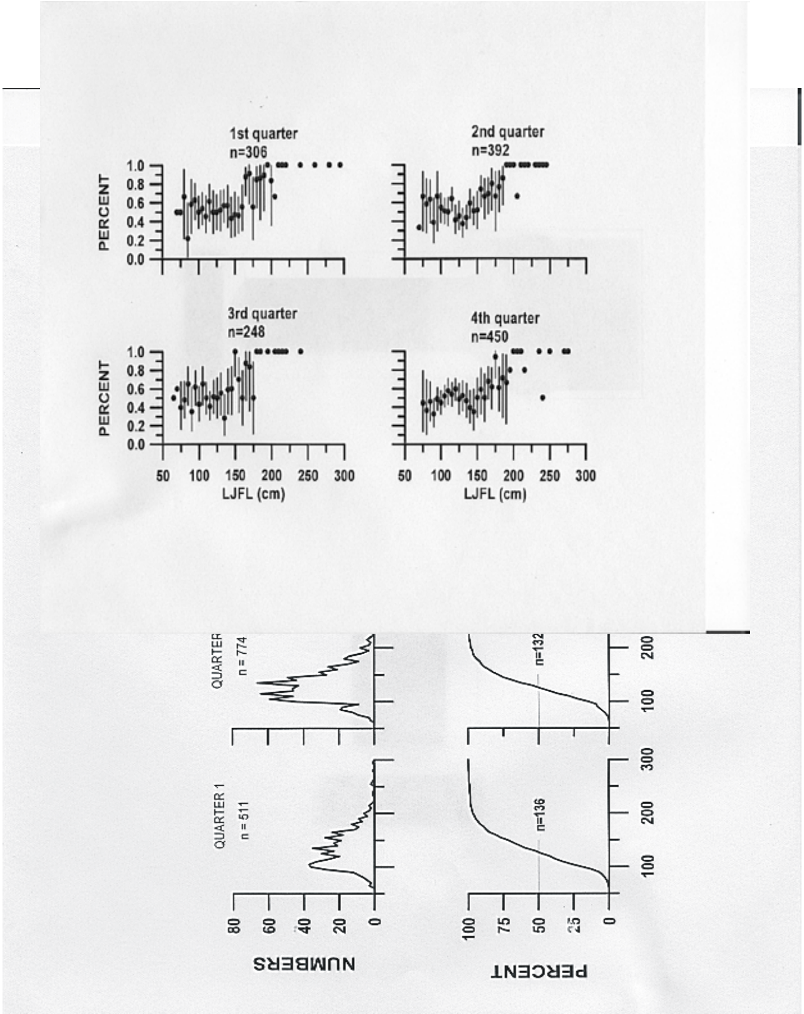

Figure 2. Seasonal frequency distribution and cumulative distribution of swordfish during May 1991-June 1994

Figure 3. Seasonal proportion of female swordfish (with 95% binomial C.I.) In Venezuela and adjacent waters.

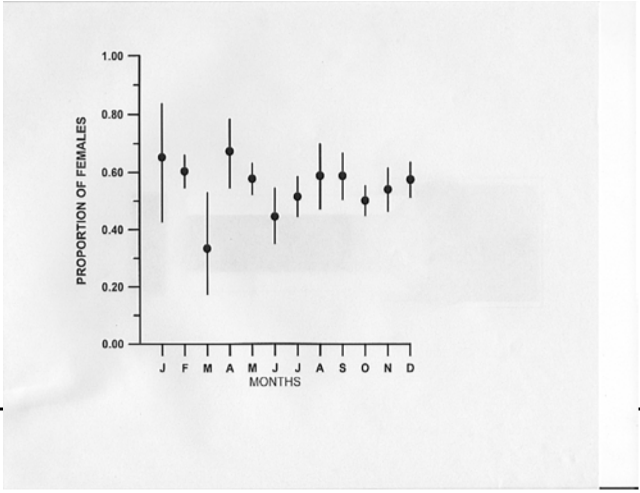

Figure 4. Monthly evolution of the proportion of female swordfish (95 % C.I.) During the sampling period, all months combined

Spawning season and area of spawning

Female gonad index (GI) for specimens of all sizes combined and for mature females (>150 cm LJFL) along with ovarian assessment (Fig. 7), suggest that swordfish may not spawn regularly in the study area based on the low GI values observed. Mean GI show a consistent annual trend, they do not reach GI values of 1.0 and ovarian assessment indicates that most of the females in the area are immature or in a regressed stage (Fig. 7). Only four specimens show GI > 3.0, suggesting some spawning activity from September through December.

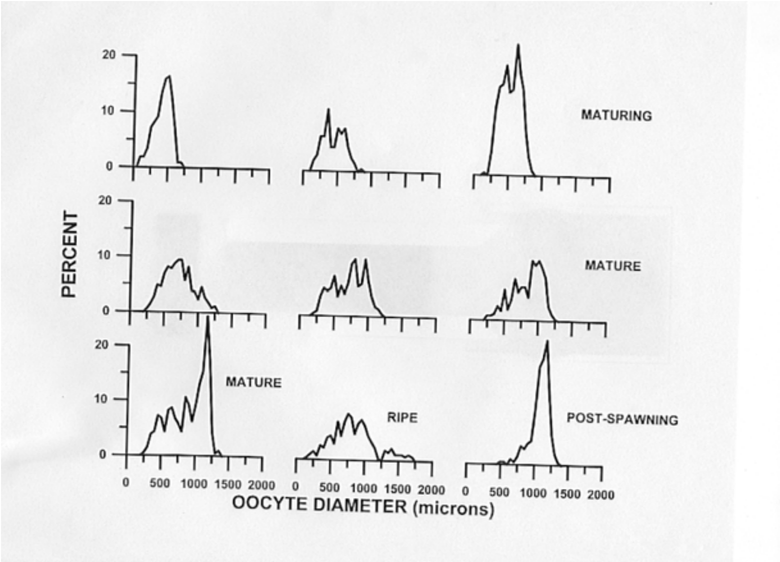

Figure 5. Frequency distribution of vitellogenic oocytes in maturing, mature ripe and post-spawning swordfish in Venezuelan and adjacent waters

Reproductively active specimen (n=9) were only obtained during the last four months of the year, of which 3 were in Maturing stage (208-220 cm LJFL), 4 were in a Mature stage (157-170 cm LJFL) and one was in a Ripe stage (166 cm LJFL). Mean batch fecundity was estimated from the only specimen displaying hydrated oocyte. Batch fecundity for this specimen was 995,067 oocyte (SE=44363.31). The highest spawning activity seemed to occur in December, when 3 specimens with the highest levels of oocyte development were obtained. This event occurred during the same year (1992) and all specimens were caught off the northeastern coast of Venezuela (Fig. 8). The other specimens were obtained in the preceding months, off the leeward islands in the Lesser Antilles and off the northcentral coast of Venezuela.

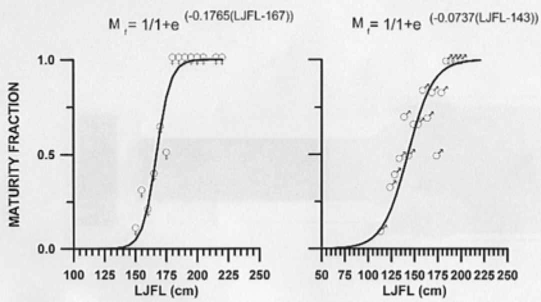

Figure 6. Maturity schedules for swordfish in Venezuela and adjacent waters

DISCUSSION

The size composition of the catches in the sampling area consists mainly of small immature fish that may be considered to form part of the new recruits to the Northwest Atlantic portion of the swordfish stock. This new recruits probably have two origins, one can be from the occasional spawning occurring in the sampling area and the other, from the spawning grounds located south of the Sargasso Sea (Arocha and Lee, 1994). The possibility of new recruits from south of the Sargasso comes from the fact that the main spawning season for swordfish occurs in that area from December through March (Arocha and Lee, op.cit.). Juveniles can enter the Caribbean Sea through passages in the Leeward Islands that bring south Sargasso and subtropical Atlantic waters into the Caribbean basin (Kleckner and McCleave, 1988). This new recruits will show up in the catches during the third quarter, when 50% of the catch is formed of specimens of 118 cm LJFL. At this point, the animals will feed during the upwelling season that starts in the last quarter of the year (Anon., 1989) and gain sufficient energy reserves that will help them migrate north, to waters off the southeast coast of the U.S., as based on reports of tagged and recaptured swordfish (Brown, 1994).

The seasonal variation of sexes do not show the characteristic patterns when spawning females are observed. In other areas of the Atlantic a consistent drop in the proportion of females for size classes between 125 and 170 cm LJFL is highly correlated with the presence of females with high gonad indices. In the subtropical area of the Northwest Atlantic (18° - 35°N), a drop to about 30% in the proportion of females between 125 - 175 cm LJFL was observed in combination with spawning females and high gonad indices (Arocha and Lee, 1994).

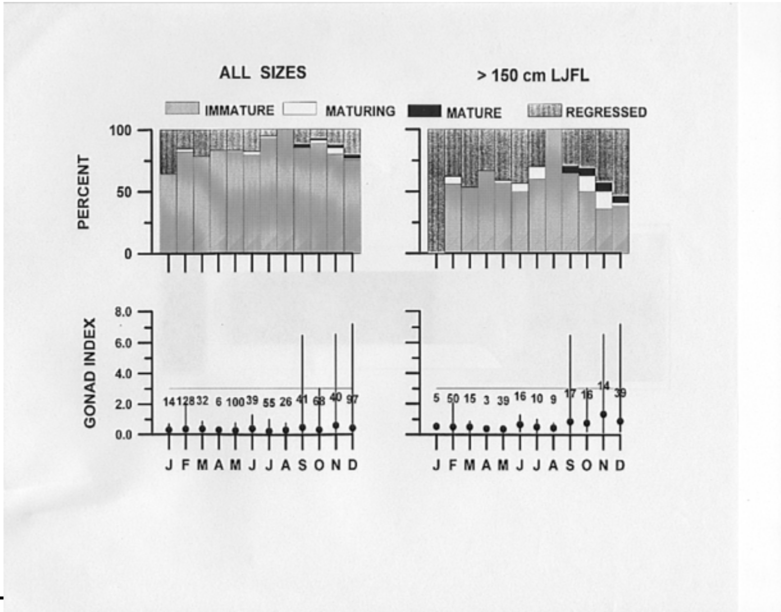

Figure 7. Monthly proportion of maturity stages and mean gonad indices for swordfish in the study area.

Also, in the tropical waters of the West Atlantic (5°N - 10°S) and in the West Indian Ocean (5°N - 10°S) a similar pattern was observed by Mejuto et al. (1994), where the proportion of females dropped to less than 20% for sizes between 130 and 165 cm LJFL and coincided with females showing high gonad indices. The seasonal variation observed in samples obtained in this study give no indication of a major spawning activity in the Caribbean as observed for other parts of the West Atlantic and West Indian Oceans.

The smallest mature female observed in the samples was 150 cm LJFL, which is similar to the smallest mature female obtained by Arocha et al. (1993), but much smaller than those observed by Taylor and Murphy (1992). The size at 50% maturity for swordfish in the subtropical area of the Northwest Atlantic is 189 cm LJFL, much larger than the one obtained in this study (167 cm LJFL). However, in recent analyses carried out by the senior author, it was found that maturity schedules differed between spawning areas in the subtropical area of the Northwest Atlantic. It was found that 50% of the females were mature at 170 cm LJFL in the area south of the Sargasso, which is in close agreement with the observed maturity schedules obtained in this study and gives added support to the idea that the population structure in Venezuela may be conformed of recruits coming from the Sargasso spawning grounds.

Based on the reproductively active females obtained in this research, a spawning season can be proposed for the last quarter of the year. This event may be restricted to this time of the year by the high concentration of primary productivity in the northeastern Venezuelan shelf (Anon., 1989). In other areas of the Northwest Atlantic, spawning occurs from December to March in the Sargasso area and from April through June in Straits of Florida and adjacent waters (Taylor and Murphy, 1992; Arocha and Lee, 1994). It is considered that the areas mentioned are the major spawning grounds for swordfish in the Northwest Atlantic Ocean. Where as the spawning activity observed off the northeastern shelf of Venezuela may be an occasional event.

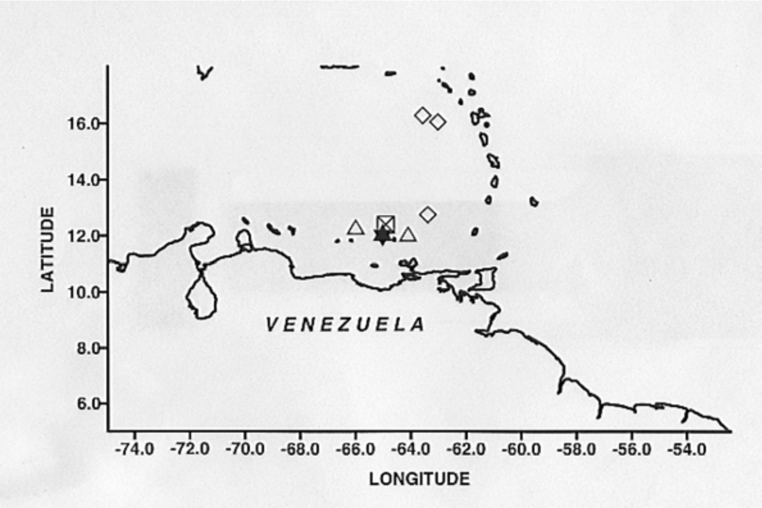

Figure 8. Location of maturing (triangles), mature (rhombus), ripe (star) and post-spawning (crossed square) swordfish in the sampling area

During the three years of sampling, of the 9 reproductively active specimen, only five were obtained off the northeastern shelf of Venezuela and two of the remaining four were caught off the Leeward Islands (near the Anegada Passage). This two specimens (157 and 166 cm LJFL) were in a mature stage and were caught in September and November of 1993. A situation that puts these specimens within range of two spawning sites. This condition would add further support to the possibility that the population structure in Venezuela is linked to the

spawning population in south of the Sargasso Sea.
Research continues to try to establish if there are differences in growth rates between the different spawning areas in the Northwest Atlantic that will help distinguish different populations.

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Table 1. Maturity stages of swordfish in Venezuela and adjacent waters based on macroscopic appearance of ovaries and whole oocyte stages of the most advance group of oocyte in the frequency distribution.

MATURITY STAGES	MACROSCOPIC STAGE	WHOLE-OOCYTE STAGE
IMMATURE	Round in cross-section, lumen well developed no vascularization present. Pale pink in color (<250 g)	Unyolked oocytes transparent (<150µ m in diam.)
MATURING	Vascularization well defined, granular appearancedue to presence of vitellogenic oocytes (400-1500 g)	Oocytes with yolk deposition, completly opaque, except perivitelline border (200-700 µm in diam.)
MATURE	Oocytes visible through ovarian wall, pale yellow-orange in color (1000-3000 g)	Oocytes with opaque yolk material and oocytes with yolk globules with part of the yolk translucent (1000-1200 µm in diam.)
RIPE	Ovaries very swollen, translucent and hydrate oocytes visible through a thin almost transparent ovary wall; ovary weight:>3000g	Hydrate oocytes, translucent with single oil globule (1250-1800 µm in diam.)
POST-SPAWNING	Ovary flaccid, empty in appearance, deep red in color; ovigerous folds separable with loose oocytes in lumen	Deformed hydrated oocytes with opaque yolk material, some oocytes of advanced stages loose in lumen
REGRESSED	Ovary with thick wall, no separable follicular tissue (350-900 g)	Opaque oocytes found occasionally imbedded within the compact mass of the follicular tissue.

Table 2. Summarized analysis of the length of swordfish samples collected in Venezuela and adjacent waters during May 1991- June 1994.

PERIOD	SEX	SAMPLE SIZE	MEAN	S.E.

ALL SEASON	FEMALES	1396	135.10	1.03
	MALES	1186	123.40	0.85
QUARTER 1	FEMALES	306	142.27	2.68
	MALES	205	130.55	2.33
QUARTER 2	FEMALES	392	138.31	1.91
	MALES	382	128.00	1.63
QUARTER 3	FEMALES	248	126.47	2.14
	MALES	201	115.48	1.66
QUARTER 4	FEMALES	450	134.26	1.68
	MALES	396	122.10	1.35