PRELIMINARY OBSERVATIONS ON SEX RATIO AND MATURITY STAGES OF THE SWORDFISH, *XIPHIAS GLADIUS*, IN THE NORTHWEST ATLANTIC

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SUMMARY

Information on sex ratio at size and sexual maturity at size by areas is presented. A total of 3,293 swordfish gonads from the northwest Atlantic between 6°N and 55°N have been collected since April, 1990. Sexual maturity by time and area is assessed from 1,382 ovaries using a gonadal index (GI). Results indicate that spatial-temporal variation in the sex ratio in different areas may be associated with spawning migration and/or with differential migratory behavior between sexes for different size classes. The presence of female swordfish with relatively high gonadal index values associated with mature gonads during the winter months between 18°N-35°N. These results are indicative of a winter-time spawning season for swordfish in the northeast Atlantic.

RESUME

L'information sur le sex-ratio par taille et la maturité sexuelle par taille par zone est présentée. En tout, 3.293 gonades d'espadon de l'Atlantique nord-ouest entre 6ºN et 55ºN ont été prélevées depuis avril 1990. La maturité sexuelle par période et zone est évaluée à partir de 1.382 ovaires en utilisant l'indice gonado-somatique (GI). Les résultats indiquent que la variation spatio-temporelle du sex-ratio dans différentes zones peut être associée avec la migration reproductrice et/ou avec le comportement migratoire différentiel entre les sexes pour des classes de taille différentes. La présence d'espadon femelles avec un indice gonado-somatique assez élevé est associé avec des gonades matures pendant les mois d'hiver entre 18ºN-35ºN. Ces résultats indiquent qu'il existe une saison de frai de l'espadon dans l'Atlantique nord-ouest durant la période hivernale.

RESUMEN

Se presenta información sobre la proporción de sexos por talla y sobre madurez sexual por talla, y por zonas. Desde abril de 1990 se ha recogido un total de 3.293 gónadas de pez espada del Atlántico noroeste, entre 6°N y 55°N. La madurez sexual, por tiempo y zona, se estima en base a 1.382 ovarios, aplicando un índice gonadal (GI). Los resultados indican que la variación espacio-temporal en la proporción de sexos de las diferentes zonas, podría estar relacionada con la migración de desove y/o con las diferencias en el comportamiento migratorio entre los sexos de diferentes clases de talla. La presencia de hembras de pez espada con valores de índice gonadal relativamente altos, está asociada con gónadas maduras durante los meses de invierno, entre 18°N y 35°N. Estos resultados señalan la temporada invernal de desove del pez espada en el Atlántico noroeste.

INTRODUCTION

Sex ratio at size data for the Atlantic swordfish (*Xiphias gladius*) have been shown to present spatial-temporal variation (Hoey, 1991; Mejuto et al., 1990). Variations in the sex-ratio at different size classes might be attributed to reproductive migration in time and space as has been suggested for Eastern Atlantic in the area adjacent to the Strait of Gibraltar (de la Serna et al., 1992). Considering these views, sex ratio at size for the northwest Atlantic swordfish will be described and analyzed from different latitudinal areas based on the different temperature regimes that dominate in every area.

Additional information on the reproductive biology of Atlantic swordfish is needed. In the Northeastern Atlantic, north of 35°N no spawning activity has been observed (Garcia & Mejuto, 1988). In Atlantic waters adjacent to the Strait of Gibraltar, there appears to be a west-east spawning migration into the Mediterranean based on the high proportion of mature females for all size classes and the high gonadal indices in early summer (de la Serna et al., 1992). In the Northwestern Atlantic spawning season and area of spawning have been inferred based on spatial-temporal distribution of larvae and juveniles (Grall et al., 1983). A spawning season from early spring to mid summer has been proposed for the Straits of Florida and adjacent waters based on the presence of mature females with hydrated oocyte and post-ovulatory follicles (Taylor & Murphy, 1992).

In this preliminary report, sexual maturity will be analyzed based on a gonadal index related to the most advanced oocyte diameter. Additional research will focus on detailed maturity studies from histological observations of maturing, mature and spent ovaries, and will provide fecundity estimates from swordfish sampled (Lee & Arocha, 1992).

MATERIALS AND METHODS

A total of 3,293 gonads (2,284 ovaries and 1,009 testes) have been collected from swordfish sampled aboard commercial fishing vessels from April 1990 to June 1992 in the northwest Atlantic Ocean between 6°N and 55°N (Fig. 1). The method of collection of the reproductive material for this study along with associated morphometric data was described by Lee (1991). Sex ratio was estimated from 3,867 specimens sampled during this period. The region has been divided into three areas (Fig. 1), i.e. Temperate (35°N-55°N), Subtropical (18°N-35°N) and Tropical (6°N-18°N).

Sex was confirmed from gonad samples brought to the Southeast Fisheries Science Center - Miami Laboratory, where all samples were kept frozen until analyzed. A total of 1,382 paired ovaries were used for the assessment of sexual maturity. The experimental approach for the assessment of ovarian development and maturity stages for females based on microscopic examination of whole oocyte have been defined previously (Lee & Arocha, 1992).

A gonadal index (GI) was used as a numeric index to show the maturity stage of the ovaries and is described by the expression:

$$GI = (Ow/L^3)*10^4$$

where Ow: Thawed ovary weight in grams (precision of 0.1 g for ovaries less than 1,000 g, precision of 1.0 g for ovaries over 1,000 g)
L: LJFL in centimeters

To establish when females are considered mature and capable of spawning, 16 paired ovaries from specimens of LJFL 180-261 cm were subsampled as described in Lee & Arocha (1992).

RESULTS AND DISCUSSION

The observed overall proportion of males and females for the total area is greater for females (69.49%), and is consistent for the temperate (76.37%) and the tropical areas (61.61%). However, for the subtropical area, the proportion of females (50.06%) is not different from the 1:1 ratio (Table 1).

The total numbers of males and females swordfish sampled during the period of this study (Fig.2a) shows that females are more frequent in the samples beyond the 120 cm LJFL size class. It is evident that sex ratio shows a tendency with size (Fig. 2b). At sizes below 120 cm the sex ratio is variable, although it appears to be that males and females are in equal proportions (Fig 2b,c). At sizes greater than 120 cm the proportion of females increases, reaching 100% for specimens greater than 250 cm (Fig. 2b,c).

The size distribution by areas (Fig. 3) reveals the difference in maximum size classes between the areas observed. In temperate and subtropical areas males reach 250 cm and females 290 cm size classes (Fig. 3a,b). In the tropical area (Fig. 3c) male and female maximum sizes observed are greatly reduced, where males and females sampled ranged to the 185 cm and 245 cm size classes, respectively.

The proportion of females by size differs between the three areas defined (Figs. 4 and 5). Females are consistently more abundant for sizes greater than 120 cm LJFL in the temperate area (Figs. 4a,5a). The proportion of males at sizes greater than 100 cm LJFL is higher in the subtropical and tropical areas than in the temperate area (Figs. 4 and 5). In the subtropical area, males are predominant between 120 cm and 170 cm LJFL (Figs. 4b and 5b).

Monthly changes in the sex ratio during the period of April 1990 to June 1992 are variable for the three areas (Fig. 6). Sex ratio in the temperate area maintains a constant trend, females are over 65% more abundant in all months sampled (Fig. 6a). During the winter months (Dec-Feb) sex ratio in the subtropical area changes to a predominance of males up to 60% (Fig. 6b), there is also an apparent late spring predominance of males. In the tropical area (Fig. 6c), the general trend shows a higher ratio of females for the period sampled.

Results from the gonadal index analyses revealed that females with GI $\geq$ 3.0 have mean oocyte diameters greater than 1.0 mm (Table 2, Fig. 7), where these oocyte are in an advanced yolked stage when compared to the size of ripe oocyte (Fig. 8). Based on these results it is proposed that females with GI $\geq$ 3.0 are mature and capable of spawning within a relatively short period of time.

Monthly gonadal index (GI) for the subtropical area (Fig. 9b, note different Y-axis scale) reflects an apparent spawning seasonality in the area. GI values increase during the winter months (Dec.- Feb.) with mean GI greater than 3.0 and then decreased in April - May. In the temperate and tropical areas the monthly gonadal index suggests that no spawning activity occurs in those areas, where mean GI during the sampled months does not exceed 1.0 (Fig. 9a,c).

Mean GI at size for the subtropical area shows an increasing trend for size classes beyond 150 cm LJFL after which the maximum observed GI is over 12 (Fig. 10b, note different Y-axis scale). In temperate and tropical areas (Fig. 10a,c) mean GI at size (and maximum range) does not reach mature gonadal index (GI $\geq$ 3.0). In both areas, there appears to be an increasing trend in mean GI's that tends to level off at the 175 cm size class. In the subtropical area, the mean GI appears to increase beyond values of 3.0 to over 5.0 at the 230 cm size class and drops there after (Fig. 10). Sample size for fish > 230 cm LJFL from the region are small and were generally obtained outside the winter period.

These results indicate that spawning activity may be centered in the subtropical area (Fig. 11) where the proportion of males in this sample exceeds that of females for size classes between 150 cm and 175 cm along with an increased proportion of large males (245-250 cm LJFL). Also the presence of mature females (GI $\geq$ 3.0) with mature and ripe ovaries during the winter months (Dec - Feb) in both winter periods (90-91 and 91-92) along with males bearing mature testes (based on the external appearance, very enlarged and creamy) concentrated off northeast of Puerto Rico where most of the mature swordfish were caught, is indicative of a spawning season during the winter months (Fig.11). This behavior may be associated with a temperature range for breeding as has been suggested by previous authors (Taning,1955; Markle,1974).

It has been suggested that female swordfish in the Straits of Florida attain 50% maturity at an estimated size of 182 cm and males at 112 cm (Taylor & Murphy, 1992). Maturing (advanced vitellogenic ovaries) and mature female swordfish samples caught northeast of Puerto Rico during the winter months (Dec-Feb) appear to attain 50% maturity (based on advanced yolked oocyte 0.80-1.25 mm) at about the same size as the ones in the Florida Straits (Fig.12) when compared to the maturity ogive proposed by Taylor & Murphy (op.cit.). Considering all the information present it is possible that there are several spawning areas in the warm waters of the Northwestern Atlantic. Two areas that appear to have been documented include a nearshore (Florida Straits and adjacent waters) area and another offshore (off northeast Puerto Rico) area. The degree of contribution to stock-wide spawning success from each of these areas is unknown.

Reproductive analyses will continue at the Miami Laboratory to enhance our knowledge of the reproductive behavior of the swordfish (*Xiphias gladius*) in the northwestern Atlantic Ocean. Future analyses will include processing all samples in storage at the Miami Laboratory as well as more closely monitoring collection efforts in areas of limited sampling (i.e. Gulf of Mexico and Straits of Florida).

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TABLE 1. Number of samples and proportion of sexes of swordfish from April 1990 to June 1992.

AREAS	FEMALES		MALES	
	NUMBERS	%	NUMBERS	%
Temperate	2,072	76.37	641	23.63
Subtropical	416	50.06	415	49.94
Tropical	199	61.61	124	38.39
Total	2,687	69.49	1,180	30.51

TABLE 2. Observed mean and range of most advanced whole oocyte of 16 swordfish from different areas and different months related to their Gonadal Index (GI). TEMP= Temperate area, SUBTR= Subtropical area.

SAMPLE	DATE	AREA	LJFL (cm)	Ow (g)	OOCYTE (mm)	GI
92SW0206	01/92	SUBTR	233.7	15,846	0.88-1.57-2.36	12.42
92SW0205	01/92	SUBTR	231.1	8,604	0.60-0.92-1.48	6.97
92SW0192	01/92	SUBTR	195.6	3,931	0.72-1.03-1.52	5.25
92SW0190	01/92	SUBTR	261.5	5,351	0.76-1.07-1.64	2.99
92SW0187	01/92	SUBTR	185.4	5,639	0.76-1.04-1.72	8.35
92SW0186	01/92	SUBTR	208.3	6,637	0.76-1.00-1.28	7.35
91SW0263	07/91	TEMP	222.3	1,228	0.24-0.27-0.32	1.13
91SW0252	07/91	TEMP	230.0	653	0.20-0.23-0.24	0.54
91SW0226	07/91	TEMP	151.0	109	0.12-0.16-0.20	0.32
90SW1750	08/90	TEMP	182.9	290	0.20-0.24-0.28	0.47
90SW1788	09/90	TEMP	213.4	628	0.20-0.27-0.32	0.65
90SW1766	09/90	TEMP	195.6	610	0.20-0.24-0.28	0.63
90SW1757	09/90	TEMP	236.2	433	0.20-0.31-0.44	0.58
90SW1768	09/90	TEMP	236.2	853	0.28-0.39-0.96	0.65
90SW1718	10/90	TEMP	182.9	321	0.36-0.41-0.48	0.53
90SW1793	10/90	TEMP	180.3	305	0.20-0.36-0.44	0.52

FIGURE 1. Map of the Northwest Atlantic Ocean indicating (A) Temperate (35°N - 55°N), (B)Subtropical (18°N - 35°N) and (C) Tropical areas (6°N - 18°N), shaded area indicate where samples were collected.

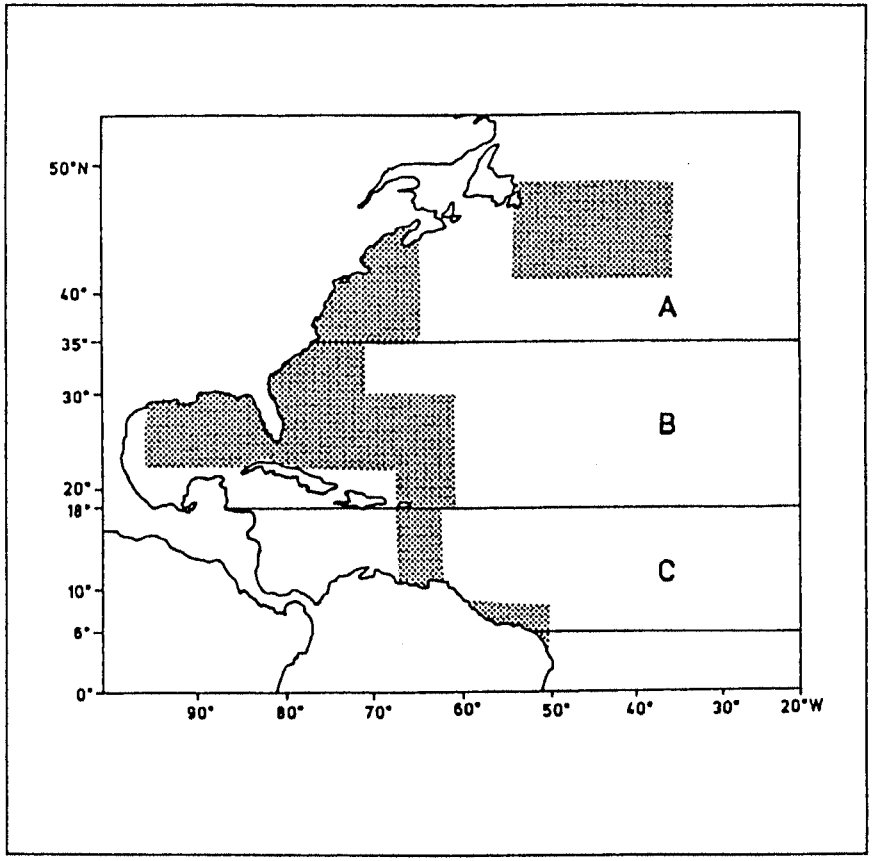

FIGURE 2. (A) Size frequency distribution of males (N=1,180,dashed) and females (N=2,687,line); (B) Sex-ratio at size(♂ ,♀); (C) Mean proportion of females (with 95% binomial conficence limits) grouped by 5 cm intervals for all areas sampled in the Northwest Atlantic from April 1990 to June 1992.

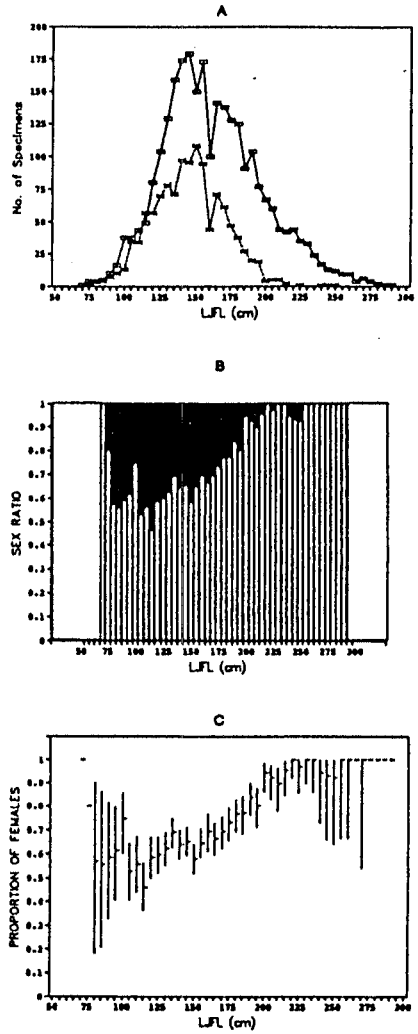

FIGURE 3. Size frequency distribution of Northwest Atlantic swordfish in numbers grouped in 5 cm intervals. (A) Temperate area(♂=641;♀=2,072); (B) Subtropical area (♂=415; ♀=416); (C)Tropical area(♂=124; ♀=199).

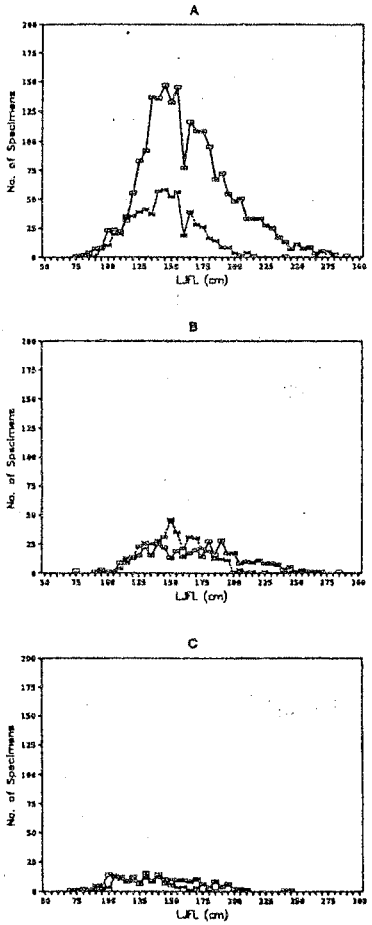

FIGURE 4. Sex-ratio at size of Northwest Atlantic swordfish grouped in 5 cm intervals (♂ ; ♀). (A) Temperate area (♂=641; ♀=2,072); (B) Subtropical area (♂=415; ♀=416); (C) Tropical area (♂=124; ♀=199).

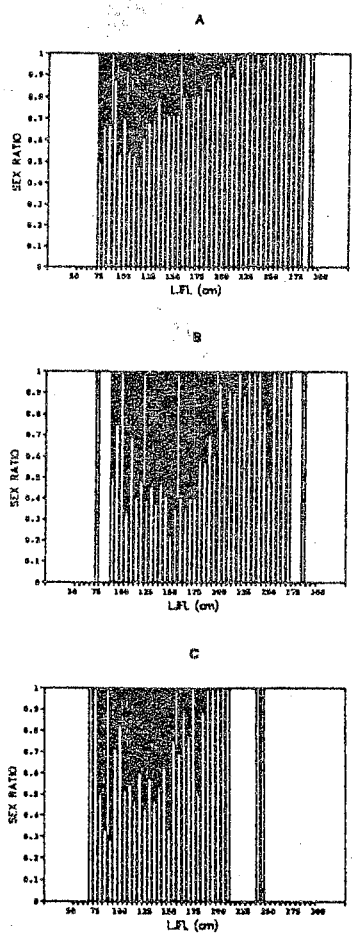

FIGURE 5. Mean proportion of female Northwest Atlantic swordfish (with 95% binomial confidence limits) grouped in 5 cm intervals (no confidence limits are shown for size classes with fewer than 5 specimens observed). (A) Temperate area (N=2,072); (B) Subtropical area (N=416); (C) Tropical area (N=199).

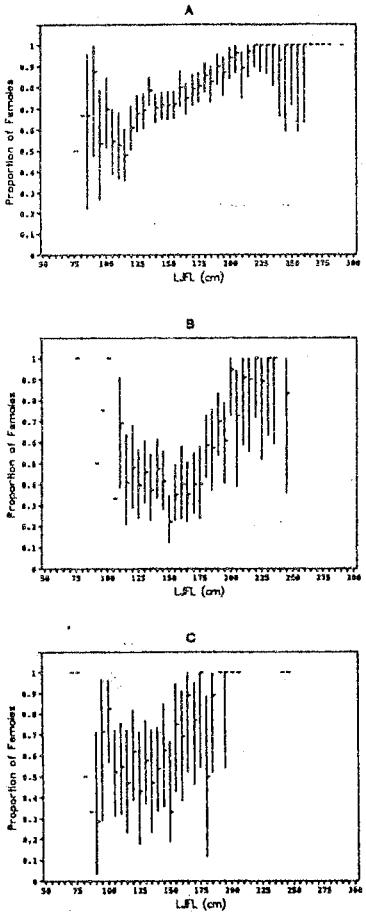

FIGURE 6. Monthly evolution of Northwest Atlantic swordfish sex ratio from April 1990 to June 1992 (♂ ; ♀). (A) Temperate (♂=641; ♀=2,072); (B) Subtropical area (♂=415; ♀=416);(C) Tropical area (♂=124; ♀=199).

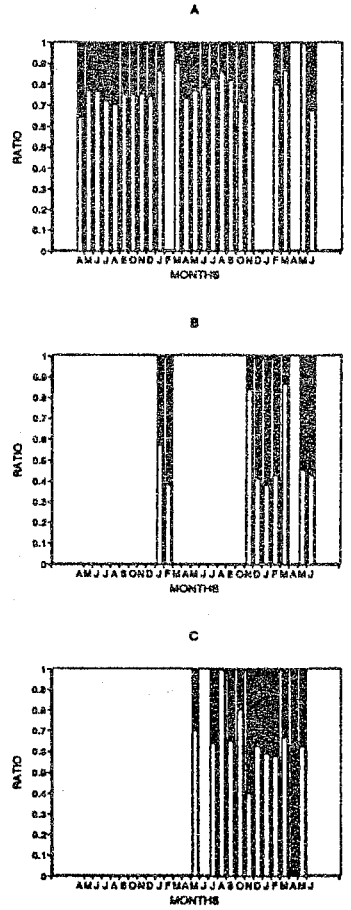

FIGURE 7. Mean and range of most advanced whole oocyte related to the gonadal index (GI) of 16 Northwest Atlantic swordfish (180-261 cm LJFL).

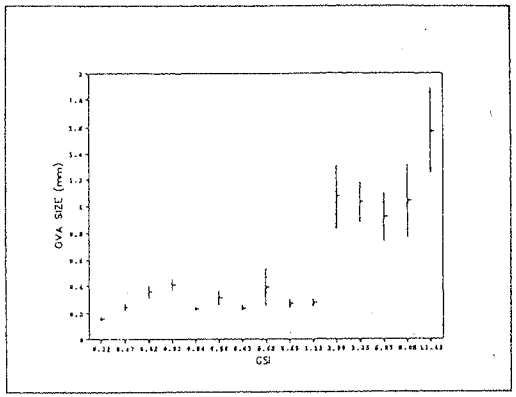

FIGURE 8. Video image of ripe(r) 1.28 mm, advanced yolked(ay) 0.80-1.00 mm, and yolked(y) 0.50-0.80 mm oocyte from a 221.0 cm LJFL swordfish specimen collected in the Northwest Atlantic. (Bar=0.5 mm).

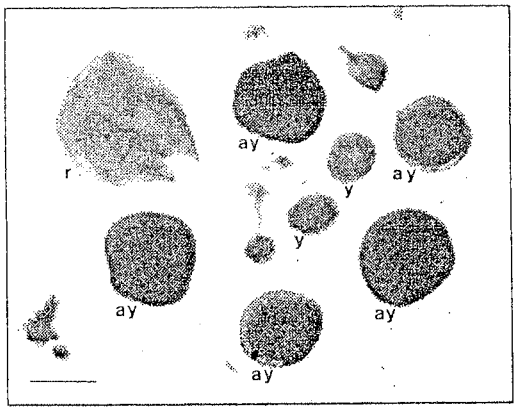

FIGURE 9. Monthly evolution of mean (and range) gonadal index (GI) of Northwest Atlantic female swordfish. (A) Temperate area (N=883); (B) Subtropical area (N=344); (C) Tropical area (N=155).

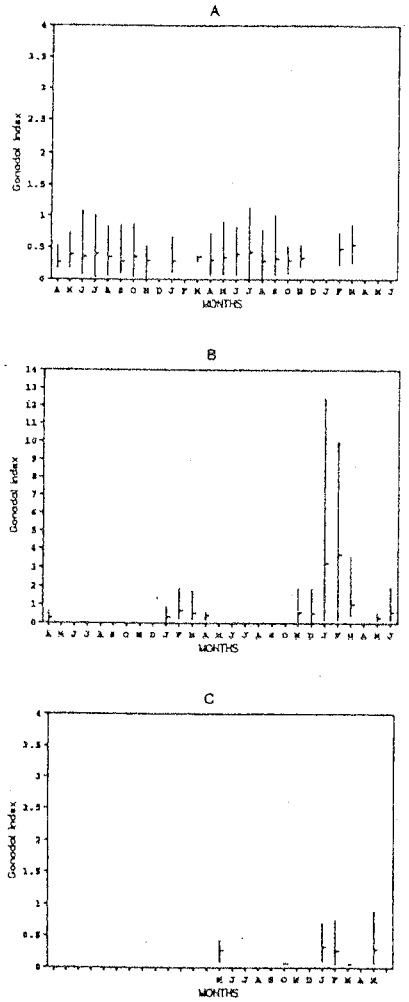

FIGURE 10. Mean (and range) of gonadal index (GI) at size grouped in 5cm intervals of Northwest Atlantic female Swordfish. (A) Temperate area (N=883); (B) Subtropical area (N=344); (C) Tropical area (N=155).

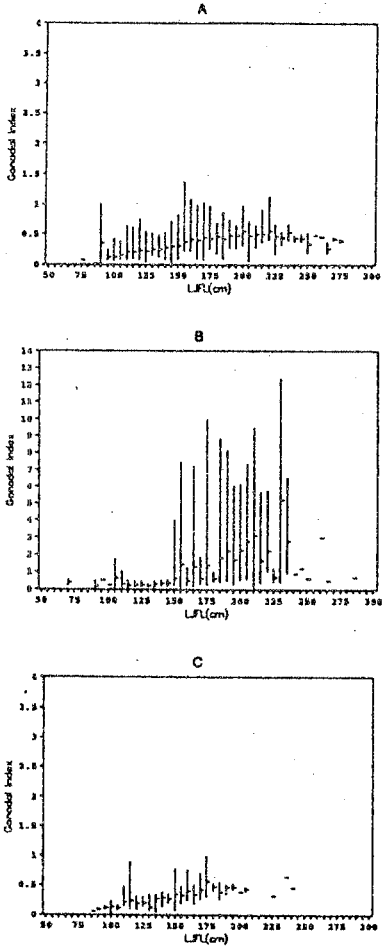

FIGURE 11. Map of the Northwest Atlantic Ocean indicating (A) Temperate (35°N - 55°N), (B) Subtropical (18°N - 35°N) and (C) Tropical areas (6°N - 18°N), shaded area indicate where samples were collected. Area labeled 1 indicates proposed spawning grounds off northeast Puerto Rico. Area labeled 2 indicates proposed spawning grounds in the Straits of Florida.

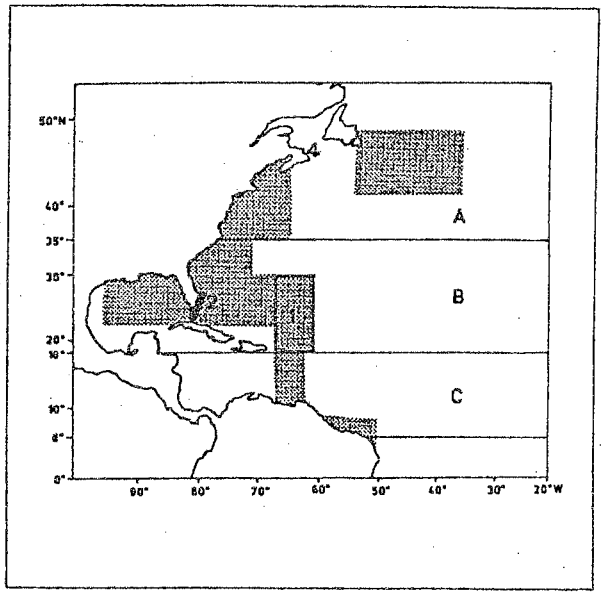

FIGURE 12. Estimated maturity ogive for females from the Straits of Florida and adjacent waters (Taylor & Murphy, 1992) and proportion of maturing and mature females (▓) from off northeast Puerto Rico during winter months.