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

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SUMMARY

Information on sex ratio at size and sexual maturity at size by area is presented. A total of 6,137 swordfish gonads from the northwestern Atlantic Ocean between 5°N and 55°N have been collected since April, 1990. Analysis of the gonadal material continues. Female sexual maturity by time and area is assessed from 2,398 ovaries using a gonadal index (G). Results continue to substantiate that the spatial-temporal variation in sex ratio in the region is associated with spawning migration and probably with differential migratory behavior between sexes for different size classes. Female swordfish with relatively high gonadal index values associated with mature gonads are present during the winter months between 18°N-35°N. Results are indicative of a winter-time peak spawning season for swordfish in the northwestern Atlantic Ocean. Maturity ogives by length and preliminary fecundity estimates are also presented.

RESUME

L'information sur le sex ratio par taille et la maturité sexuelle par taille par zone est présentée. En tout, 6.137 gonades d'espadon provenant de l'océan Atlantique nord-ouest, entre 5ºN et 55ºN, ont été prélevées depuis avril 1990. L'analyse de gonades se poursuit. La maturité sexuelle femelle spatio-temporelle est évaluer sur 2.398 ovaires en utilisant un indice gonadal (GI). Les résultats continuent à justifier que la variation spatio-temporelle du sex ratio dans le secteur est associée à la migration reproductrice et vraisemblablement présente un comportement migratoire différent entre les sexes de différentes classes de taille. L'espadon femelle avec des valeurs d'indice gonadal élevées associées avec des gonades matures est présent durant les mois d'hiver entre 18ºN - 35ºN. Les résultats indiquent une saison reproductrice importante durant la période hivernale pour l'espadon de l'océan de l'Atlantique nord-ouest. Les estimations d'ogives en état de maturité par longueur et la fécondité préliminaire sont également présentées.

RESUMEN

Se presenta información sobre proporción de sexos por clases de talla y madurez sexual por clases de talla por área. Desde abril de 1990, se ha recopilado un total de 6.137 gónadas de pez espada del Océano Atlántico Noroeste, entre 5°N y 55°N. Se continúa efectuando análisis de tejido gonadal. Se evalúa la madurez sexual femenina por tiempo y área a partir de 2.398 ovarios utilizando un índice gonadal (IG). Los resultados continuan mostrando que la variación espacio temporal en la proporción por sexos en la región está asociada a la migración reproductora y probablemente a un comportamiento migratorio diferenciado entre sexos para las diferentes clases de talla. Durante los meses de invierno entre 18°N y 35°N se presentan hembras de pez espada con valores de referencia gonadales relativamente altos asociados a gónadas maduras. Los resultados son indicativos de una estación de desove pico en el invierno para el pez espada en el Océano Atlantico noroeste. También se presentan las ojivas de madurez por talla y estimaciones preliminares de fecundidad.

INTRODUCTION

A reproductive study was initiated in 1990 by the National Marine Fisheries Service (NMFS), Miami Laboratory due to the lack of information on the reproductive biology of swordfish in the Northwest Atlantic Ocean. Most of the studies carried out in the past have been limited to portions of the stock represented by small sample sizes and confined to isolated geographical areas of the Northwest Atlantic (Tibbo *et al.*, 1961; Guitart, 1964; Wilson, 1984; Taylor & Murphy, 1992). Preliminary analyses were carried out to confirm if sex ratio at size showed spatial-temporal variation (Arocha & Lee,1993) as has been proposed in the recent years (Hoey, 1991; Mejuto *et al.*,1990) and if the variability could be attributed to a migratory reproductive behavior, as has been suggested for the area adjacent to the Strait of Gibraltar (de la Serna *et al.*,1992). In addition, Arocha and Lee (1993) also indicated that there was a spawning migration to the warmer areas of the Northwest Atlantic; offshore (off northeast Puerto Rico) and inshore (Florida Straits) spawning areas were proposed for the subtropical area.

In this report, the information on seasonal sex ratio and sex ratio at size for the three areas in the Northwest Atlantic is updated based on the samples obtained from commercial fishermen and observer programs of the NMFS (U.S.) and Fondo Nacional de Investigaciones Agropecuarias (FONAIAP, Venezuela) since 1990. Maturity ogives and batch fecundity estimates are presented for the spawning fraction of the Northwest Atlantic swordfish stock.

MATERIALS AND METHODS

From April 1990 to March 1993, a total of 6,137 swordfish were sampled aboard commercial fishing vessels in the Northwest Atlantic between 5°N and 55°N. The method of collection of the reproductive material for this study along with the associated morphometric data was described by Lee (1991). The Northwest Atlantic sampling region, was divided latitudinally into three areas based on the different temperature regimes that characterize each area (Fig.1) as proposed by Arocha and Lee (1993).

Sex ratio at size was estimated from 4,038 female (65-290 cm LJFL) and 2,099 male (65-278 cm LJFL) specimens. Sex ratio data for the proportion of females was fitted using simple LOWESS regresion (Wilkinson, 1990). The data sets analyzed were the totals sampled so far in this study for each of the three areas, plus the total samples for all areas combined. No attempt was made to further partition the data into annual or smaller time strata.

A total of 2,398 paired ovaries (70-275 cm LJFL) were used for the assessment of sexual maturity. Relative reproductive development of mature female swordfish was assessed as described by Arocha and Lee (1993) with a gonadal index (GI) calculated as GI = (gonad weight/$LJFL^3$)x1000, where gonad weight is in g and Lower Jaw Fork Length (LJFL) is in cm.

Maturity at size for females was defined as the smallest length at which 50% of the females sampled had advanced vitellogenic ovaries with yolked oocytes (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: $\% \text{ Mature} = 100/(1+e^{(-a(LJFL-b))})$, 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.

Batch fecundity was determined using the gravimetric method (Hunter *et al.*,1985) which counts the numbers of hydrated oocytes present in a weighted subsample of thawed ovarian tissue. Each subsample consisted of a wedge of tissue extending from the periphery to the lumen of the ovary. Batch fecundity was calculated as $B_f = H_e \times O_w$, where B_f is batch fecundity, H_e is the number of hydrated oocytes per unit of weight (1 g) in the tissue sample and O_w, is the ovary weight.

RESULTS AND DISCUSSION

The demographic structure of the swordfish in the Northwest Atlantic when analyzed by areas, shows a strong dominance of females towards sizes larger than 115 cm LJFL in the temperate area, while a somewhat lower dominance of females was observed at sizes <200 cm LJFL in the subtropical and tropical areas (Fig. 2). Likewise, the variation in the sex ratio at size (Fig. 3) for the three areas observed continues to show females being consistently dominant for larger sizes (>200 cm LJFL).

Examination of the proportion of females (Fig.4) also indicates the dominance of females for sizes greater than 120 cm LJFL in the temperate area. Within the subtropical area, males between 115 and 175 cm LJFL are in higher numbers as revealed from the drop in the proportion of females in those size classes (Figs. 3 and 4). In the tropical area, there is an increased proportion of males (Fig. 3) in the smaller size classes (75 - 95 cm LJFL) followed by an even trend in the proportion of males and females in size classes between 100 and 170 cm LJFL (Figs. 3 and 4). For size classes larger than 170 cm LJFL, females tend to dominate again (Fig. 4). These results are in close agreement to those reported previously by Arocha and Lee (1993).

LOWESS fits to the proportion of females at size are shown in figure 4. A three line regression model on the proportion of female at size data available in the North Atlantic up to 1991 was used by Restrepo *et al.*(1992). Their choice of a three line model was based upon visual examination of the data (Victor Restrepo, University of Miami, pers.comm.). The data available for this study did not show similar trends when observed by areas. Consequently, no model structure was deemed to be appropiate for the fits and a simple LOWESS regression (Wilkinson, 1990) was carried out for the female proportions at size (Table 1). This allows separation of swordfish catch at size by sex for the three areas, which could be used in swordfish stock assessments.

From April 1990 to March 1993, the seasonal patterns in sex ratio for all sizes combined vary markedly between the three areas (Fig. 5 a,b,c). In the temperate area, the proportion of females is greater (70%) than that of the males. In the subtropical area, the trend seems to indicate that males and females are evenly distributed during the winter months, yet vary in proportions during late spring and early fall. In the tropical area, the trend is somewhat similar as in the temperate area; however, there are occasions when the proportion of males increases, as seen in some fall months of 1991 and 1992. When seasonal sex ratio is observed for mature specimens (♂ > 115 cm LJFL and ♀ > 185 cm LJFL), the overall observed trend is the predominance of males throughout the three areas (Fig. 5 d,e,f). This trend is more evident in the subtropical and tropical area. It appears that sexually mature females are less accesible to the fishery during the months of spawning incidence (Dec.,Jan.,Feb.,May,Jun.,Aug) in the subtropical area and to a lesser degree in the tropical area. This changes can be observed during the winter of 90-91, 91-92 and from May to August 1992. However, the sex ratio changes for the winter of 92-93, where sexually mature females become more frequent (Fig. 5e). These results confirm a spatial-temporal variation in sex ratio within the subtropical area which could indicate mating aggregations limited for this area.

Female gonadal index (GI) for sexually mature specimens (>185 cm LJFL) and ovarian assessment indicates that swordfish spawn regularly during the winter months in the subtropical area. High seasonal mean GI's (≥ 3.0) were observed only in the subtropical area which occurred during January and February of 1992 and 1993. Higher GI range values (≥ 5.0) were also observed (Fig. 6) for the same area and those occurred in late spring and late summer in 1992. The low monthly mean GI values (< 1.0) in the temperate and tropical areas show a consistent annual trend (Fig. 6), which are indicative of a lack of spawning activity in these areas. Although specimens with mature gonads and high GI values were observed in the temperate and tropical areas on three occasions (Figs. 6 and 7), these occurrences were uncommon.

Mean GI at size for the three areas for all months combined (Fig. 7 a,b,c) show little variation from those reported previously by Arocha and Lee (1993). In the subtropical area, high mean GI values (≥ 3.0) are observed for size classes 175-250 cm LJFL with peak mean values between 230-250 cm LJFL. In the temperate and tropical areas, mean GI at size rarely reach the level of the mature gonadal index (GI>3.0). However, when GI at size is observed for sexually mature females in the months of spawning incidence (Dec.,Jan.,Feb.,May,Jun.,Aug.) the trend in the temperate and tropical areas give no indication of spawning activity (Fig. 7 d,f). The subtropical area continues to show evidence of increased spawning activity due to the high mean GI values observed (Fig. 7e).

These results indicate that spawning activity is centered in localized areas in the subtropical area based on the increased proportion of mature males for size classes between 115 and 175 cm LJFL and the presence of mature females (GI ≥ 3.0) with hydrated oocytes in their ovaries. The proposed spawning grounds are localized south of the Sargasso Sea, the Windward Passage, the Yucatan Strait and the Florida Straits (Fig. 8).

It was observed that male swordfish mature at a smaller size than females in the subtropical area where spawning activity occurs. The smallest mature male observed was 105 cm LJFL and the smallest mature female was 150 cm LJFL (Fig. 9). The proportion of mature males increases rapidly with size after reaching 50 % maturity, and all males are mature by 185 cm LJFL. In contrast, the proportion of mature females increases gradually, and all females are mature by 220 cm LJFL. The predicted length at 50 % maturity was estimated by fitting the data to a logistic function using maximum likelihood estimation:

for females, $\% \text{ Mature} = 100/(1+e^{(0.06778(LJFL-189))})$

for males, $\% \text{ Mature} = 100/(1+e^{(0.03844(LJFL-116))})$.

The predicted length estimated from our samples, at which 50 % of the females ($L_{0.5}$=189 cm) and males ($L_{0.5}$=116 cm) reach maturity are comparable to estimates of maturity for the Florida Straits (Taylor & Murphy,1992), where 182 cm LJFL was predicted for females and 112 cm LJFL was for males.

Batch fecundity estimates for eight females displaying oocyte hydration throughout the entire ovaries ranged from 0.8 million to 5.0 million oocytes (Table 2). Batch fecundity in swordfish increased with increasing size (Fig. 10). However, there was no statistically significant relationship between our estimates of batch fecundity and weight, most likely due to of the small number of observations. The relationship between fish length (LJFL) and batch fecundity (B_f) was best described by the equation:

$$B_f = 365{,}791\ e^{LJFL\ 0.03824}; \qquad (r^2 = 0.784,\ n=8).$$

CONCLUSIONS

Our results add significant information to the reproductive biology of the swordfish in the Northwest Atlantic Ocean. It has become apparent that swordfish migrate to spawn in the warmer waters of the Northwest Atlantic (Fig. 8). The observed seasonal changes in sex ratio in the subtropical area, to a higher proportion of males than observed in other areas and a high incidence of gravid females, gives indications of a spawning migration. It has also been noted from tag-recaptured specimens that there is a consistent north-south migration of swordfish along the eastern coast of North America (Bayley *et al.*, 1992). The area of the lower Caribbean Sea might serve as nursing grounds for swordfish based on the high incidence of immature specimens (low GI values) that appear seasonally during the period of highest primary productivity in the area (Anon. 1989); and the temperate area may serve as main feeding grounds for swordfish (Stillwell & Kohler, 1985).

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The maturity schedules presented in this study are similar to those estimated for the Straits of Florida (Taylor & Murphy, 1992); however, batch fecundity estimates differ (Table 2). Our highest batch fecundity estimates were obtained during the peak of the spawning season (winter months) south of the Sargasso Sea; our lowest estimates were obtained late in the spawning season (late spring) in the Florida Straits. However, in serial spawners, a decrease in batch fecundity is expected as the spawning season progresses (Hunter & Leong, 1981; DeMartini & Fountain, 1981). It is possible that batch fecundity in the Florida Straits peaks from the middle of the spawning season onward (April - June) for late older females spawners and young animals that tend to spawn late in the spawning season. This could explain the relatively high fecundity estimates for smaller specimens and the low estimates for larger fish. Improved estimates of batch fecundity should come from specimens obtained throughout the spawning season along with information on spawning frequency to obtain a reliable estimate of potential annual fecundity for the spawning stock. This is an objective of our continuing research.

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TABLE 1. Number of specimens, proportions (P) and smoothed proportions (SP) of female swordfish sampled in the Northwest Atlantic.

SIZE	TEMPERATE AREA				SUBTROPICAL AREA				TROPICAL AREA				TOTAL AREA			
LJFL	F	M	P	SP	F	M	P	SP	F	M	P	P	F	M	P	SP
65									1	2	0.33	0.37	1	2	0.33	0.42
70	1	1	0.50	0.66					1	2	0.33	0.38	2	3	0.40	0.43
75	3	1	0.75	0.67	2		1.00	0.60	7	8	0.47	0.40	12	9	0.57	0.45
80	5	2	0.71	0.67	1	1	0.50	0.59	6	10	0.38	0.41	12	13	0.48	0.46
85	7	1	0.88	0.67				0.58	11	15	0.42	0.43	18	16	0.53	0.47
90	8	8	0.50	0.67	1	1	0.50	0.56	11	22	0.33	0.44	20	31	0.39	0.49
95	23	11	0.68	0.68	4	1	0.80	0.55	38	28	0.58	0.46	65	40	0.62	0.50
100	25	25	0.50	0.68	1	1	0.50	0.54	46	46	0.50	0.47	72	72	0.50	0.52
105	25	26	0.49	0.68	4	3	0.57	0.52	53	51	0.51	0.48	82	80	0.51	0.53
110	36	41	0.47	0.68	11	6	0.65	0.51	47	29	0.62	0.50	94	76	0.55	0.54
115	60	41	0.59	0.69	12	16	0.43	0.49	50	40	0.56	0.51	122	97	0.56	0.56
120	104	49	0.68	0.69	17	19	0.47	0.48	44	37	0.54	0.52	165	105	0.61	0.57
125	115	53	0.68	0.69	24	40	0.38	0.47	33	34	0.49	0.54	172	127	0.58	0.58
130	154	45	0.77	0.70	45	49	0.48	0.45	31	31	0.50	0.55	230	125	0.65	0.59
135	157	67	0.70	0.71	44	66	0.40	0.44	45	34	0.57	0.56	246	167	0.60	0.60
140	166	63	0.72	0.72	49	65	0.43	0.43	28	30	0.48	0.58	243	158	0.61	0.61
145	162	64	0.72	0.73	46	57	0.45	0.42	22	27	0.45	0.59	230	148	0.61	0.62
150	168	65	0.72	0.74	33	87	0.28	0.42	31	17	0.65	0.61	232	169	0.58	0.64
155	92	36	0.72	0.76	34	55	0.38	0.43	28	19	0.60	0.63	154	110	0.58	0.65
160	149	51	0.75	0.77	26	37	0.41	0.45	17	15	0.53	0.66	192	103	0.65	0.67
165	127	37	0.77	0.79	33	50	0.40	0.47	41	17	0.71	0.68	201	104	0.66	0.68
170	140	34	0.80	0.81	34	44	0.44	0.49	24	9	0.73	0.71	198	87	0.69	0.70
175	117	22	0.84	0.82	23	36	0.39	0.53	19	6	0.76	0.74	159	64	0.71	0.73
180	83	16	0.84	0.84	38	33	0.54	0.57	24	9	0.73	0.77	145	58	0.71	0.75
185	94	12	0.89	0.86	33	29	0.53	0.61	12	3	0.80	0.80	139	44	0.76	0.78
190	71	14	0.84	0.88	51	22	0.70	0.65	15	2	0.88	0.82	137	38	0.78	0.80
195	66	4	0.94	0.90	27	16	0.63	0.70	7	1	0.88	0.85	100	21	0.83	0.83
200	64	4	0.94	0.91	30	4	0.88	0.75	16		1.00	0.87	110	8	0.93	0.85
205	50	4	0.93	0.93	24	4	0.86	0.79	7	1	0.88	0.89	81	9	0.90	0.87
210	51		1.00	0.94	16	2	0.89	0.83	3		1.00	0.90	70	2	0.97	0.89
215	42	2	0.95	0.95	21	1	0.95	0.86	5	1	0.83	0.92	68	4	0.94	0.91
220	34	1	0.97	0.96	16	1	0.94	0.89	3		1.00	0.93	53	2	0.96	0.92
225	32		1.00	0.97	11	1	0.92	0.91				0.93	43	1	0.98	0.94
230	21		1.00	0.98	18		1.00	0.92				0.94	39		1.00	0.95
235	17		1.00	0.99	13		1.00	0.93	2		1.00	0.94	32		1.00	0.96
240	9		1.00	0.99	5		1.00	0.94	2	1	0.67	0.95	16	1	0.94	0.96
245	16		1.00	0.99	8	2	0.80	0.95				0.95	24	2	0.92	0.97
250	10		1.00	0.99	2	1	0.67	0.95	1		1.00	0.95	13	1	0.93	0.97
255	12		1.00	1.00	3	1	0.75	0.96	2		1.00	0.96	17	1	0.94	0.98
260	3		1.00	1.00	3		1.00	0.97				0.96	6		1.00	0.98
265	6		1.00	1.00	1		1.00	0.97				0.96	7		1.00	0.98
270	4		1.00	1.00	1		1.00	0.98	2		1.00	0.96	7		1.00	0.99
275	3		1.00	1.00	1		1.00	0.98		1		0.97	4	1	0.80	0.99
280				1.00	1		1.00	0.99	1			0.97	2		1.00	1.00
285	1		1.00	1.00	1		1.00	1.00					2		1.00	1.00
290	1		1.00	1.00									1		1.00	1.00

F, FEMALES; M, MALES

TABLE 2. Estimates of swordfish batch fecundity in the spawning areas of the Northwest Atlantic Ocean.

THIS STUDY

LENGTH LJFL(cm)	WEIGHT DWT(k)	BATCH FECUNDITY (MILLIONS)	DATE	AREA
210	107.3	0.862	JUN.1993	OFF MIAMI
221	115.5	1.503	DEC.1991	S SARGAS.
224	147.3	2.766	JAN.1993	S SARGAS.
226	103.6	1.416	JAN.1993	S SARGAS.
228	79.5	1.883	FEB.1993	S SARGAS.
233	102.7	2.311	JAN.1993	S SARGAS.
241	124.5	5.082	DEC.1991	S SARGAS.
251	133.2	4.871	FEB.1993	YUC. STRAIT

TAYLOR & MURPHY, 1992

LENGTH LJFL(cm)	BATCH FECUNDITY (MILLIONS)
177	3.071
207	2.838
233	3.125
252	2.184
256	1.398
256	4.220
281	4.220

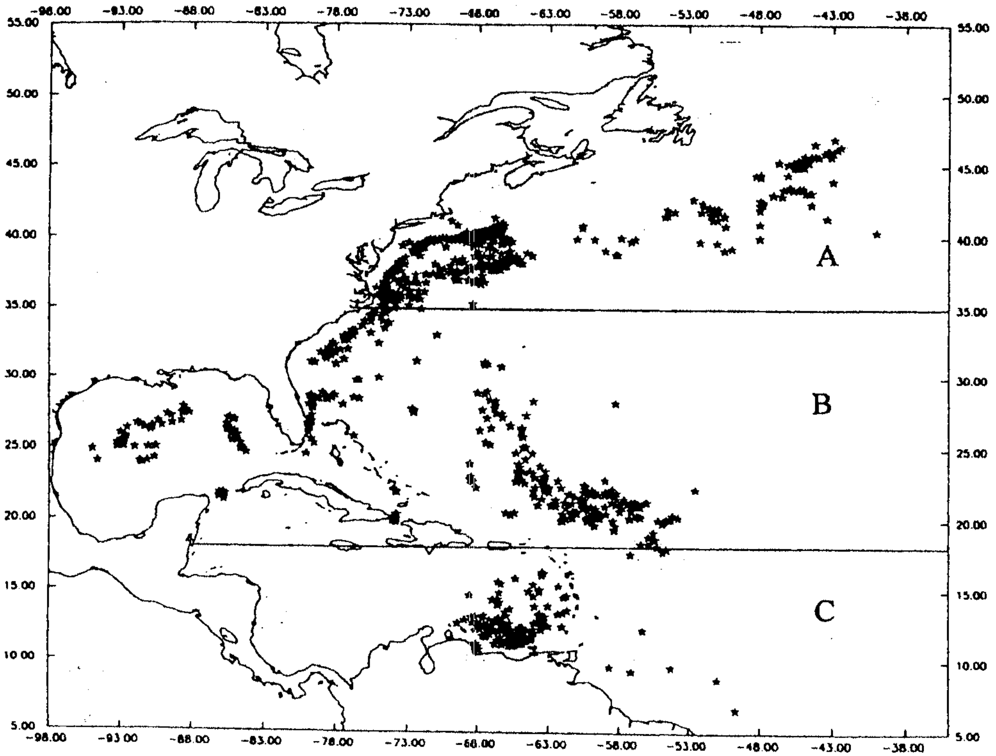

Figure 1. Map of the Northwest Atlantic Ocean indicating the geographical areas, A, Temperate, B, Subtropical and C, Tropical, and the distribution of the sampled specimens.

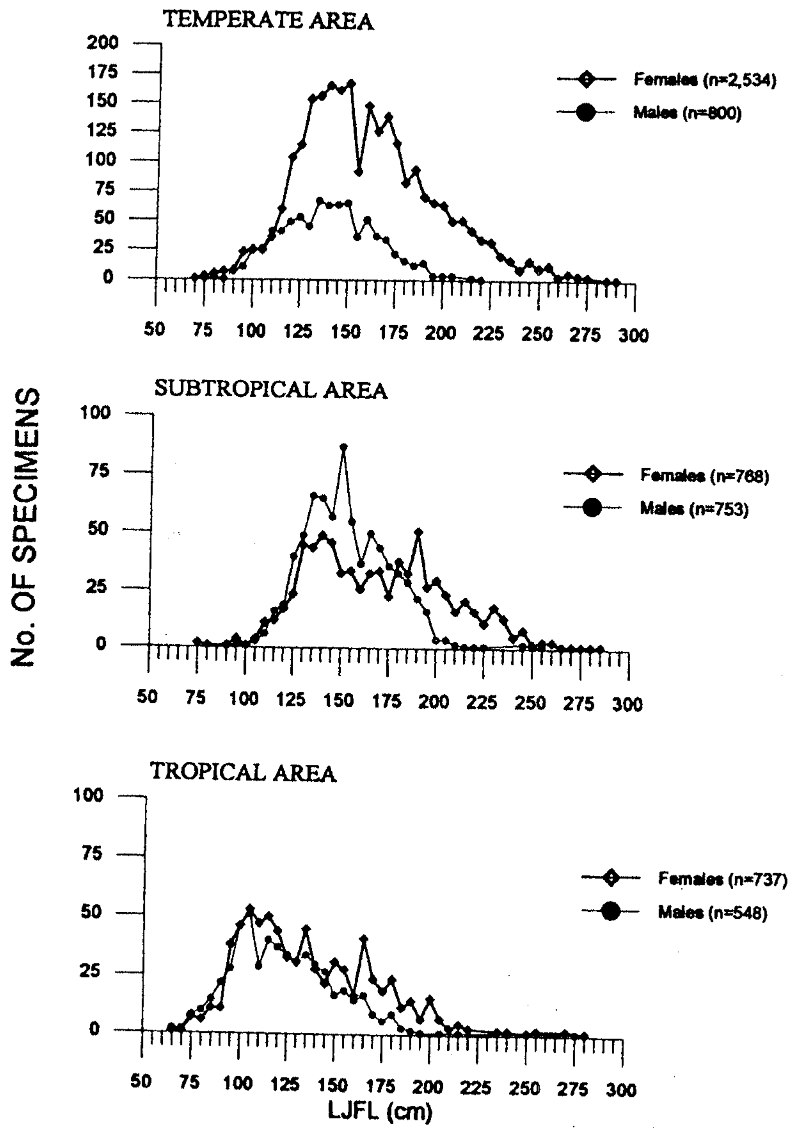

Figure 2. Frequency distribution of Northwest Atlantic swordfish grouped by areas in 5 cm intervals.

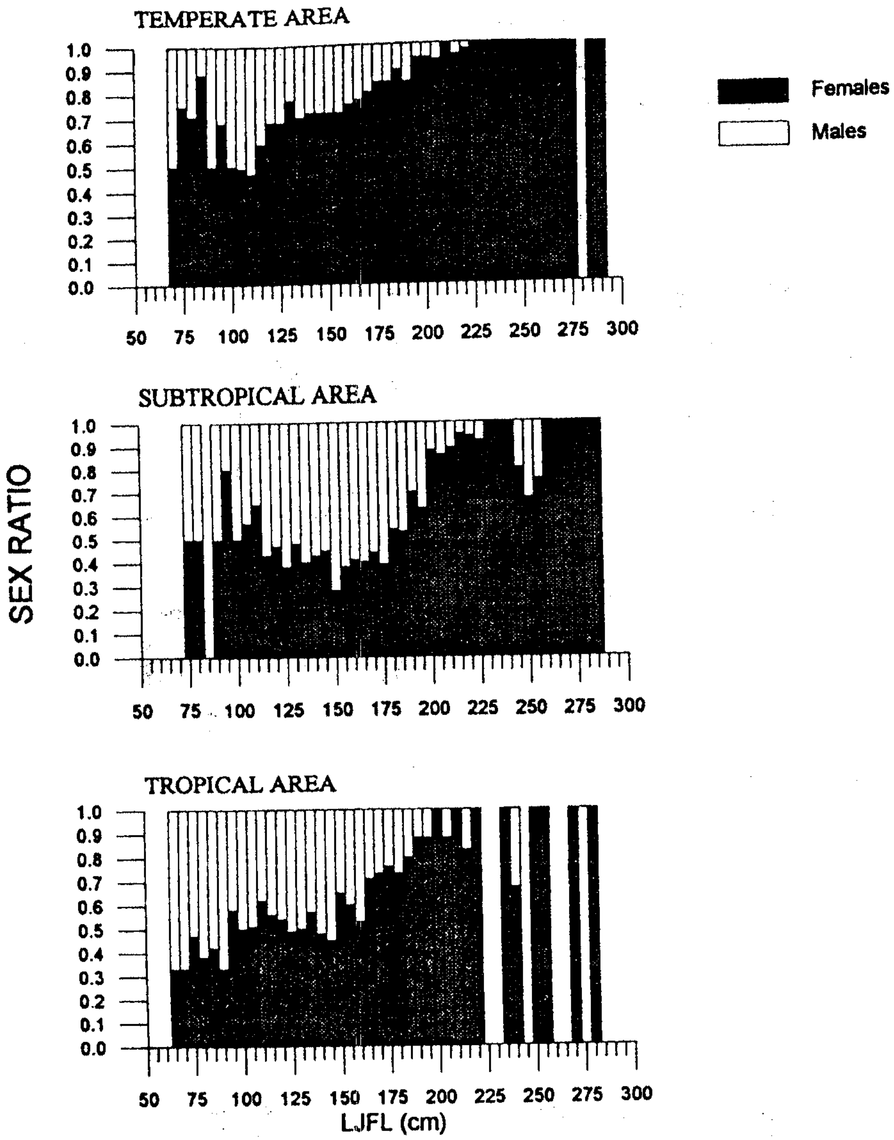

Figure 3. Sex ratio at size for Northwest Atlantic swordfish grouped by areas in 5 cm intervals.

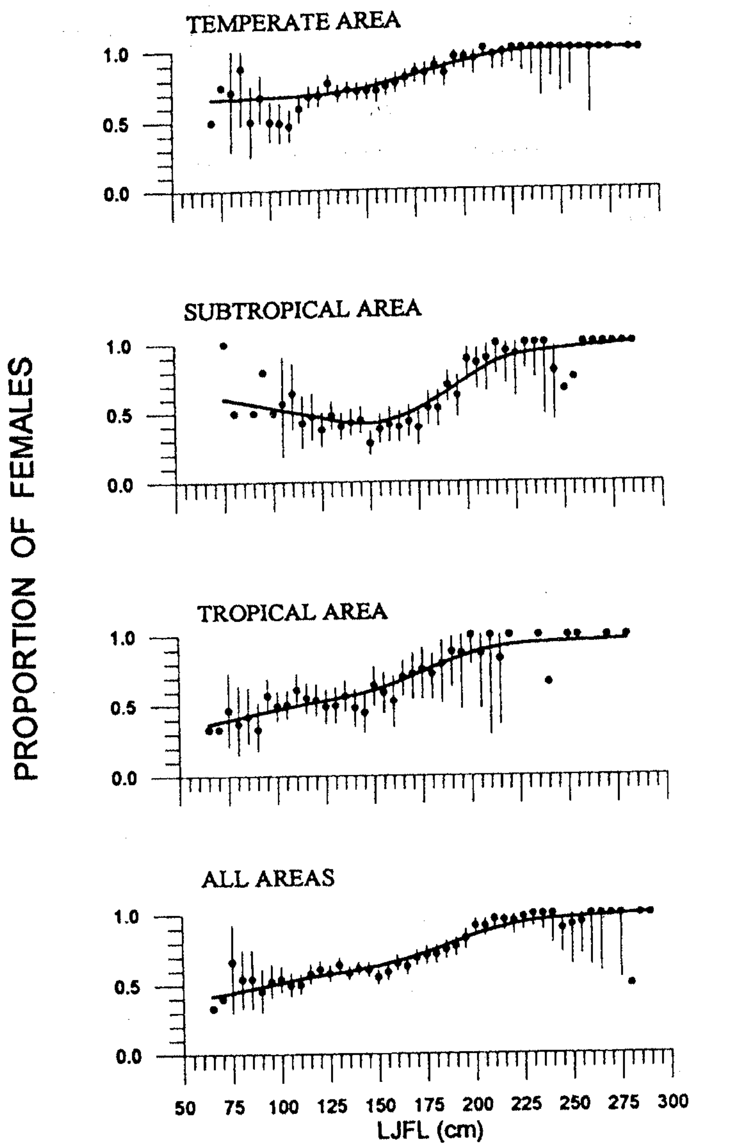

Figure 4. Mean proportion of females (with 95% binomial c.l.) and simple LOWESS smoothing for Northwest Atlantic swordfish grouped by area and all areas combined in 5 cm intervals.

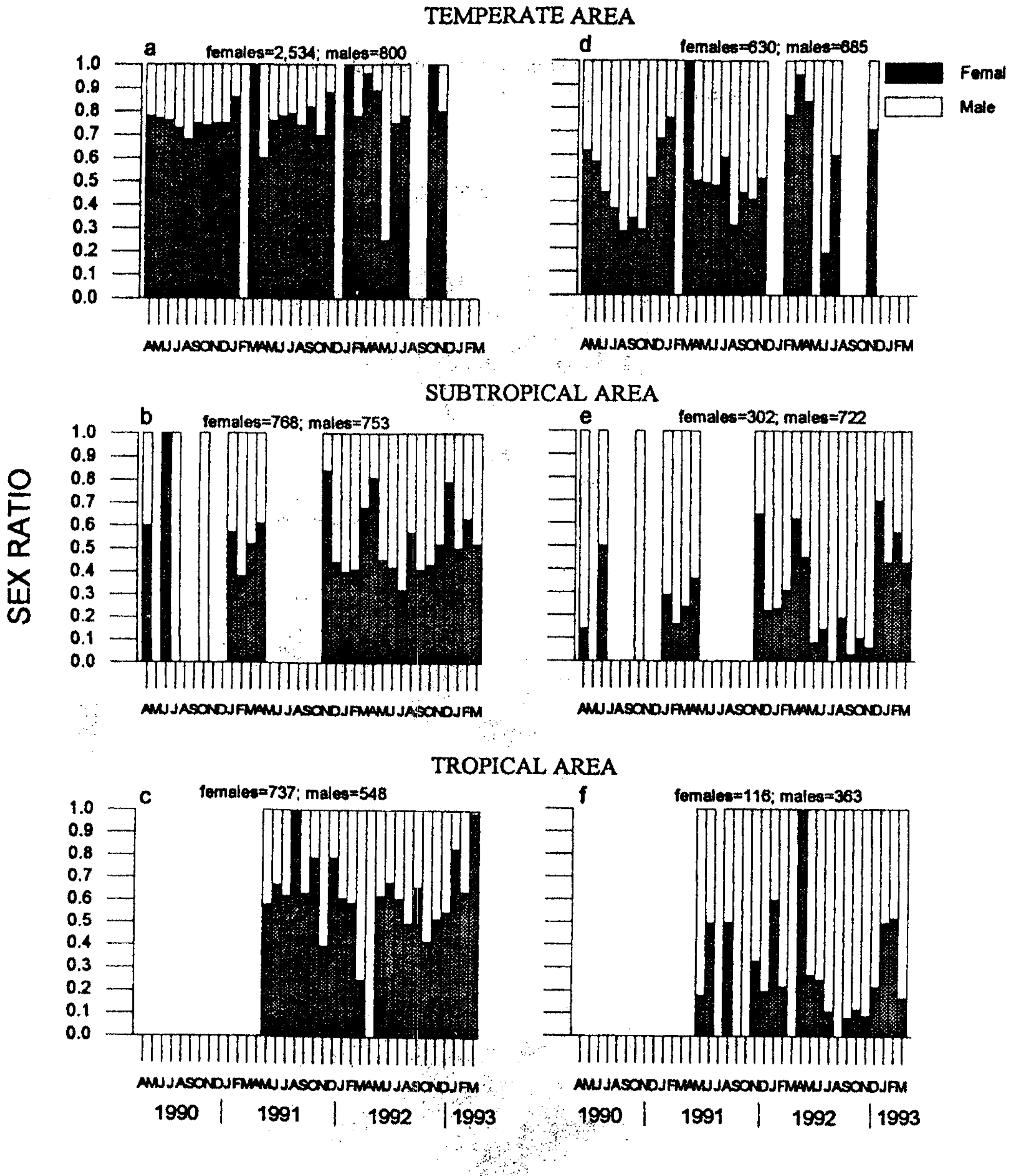

Figure 5. Monthly evolution of Northwest Atlantic swordfish sex ratio by area, from April 1990 to March 1993.
a,b,c. All sizes combined.
d,e,f. Sexually mature specimens.

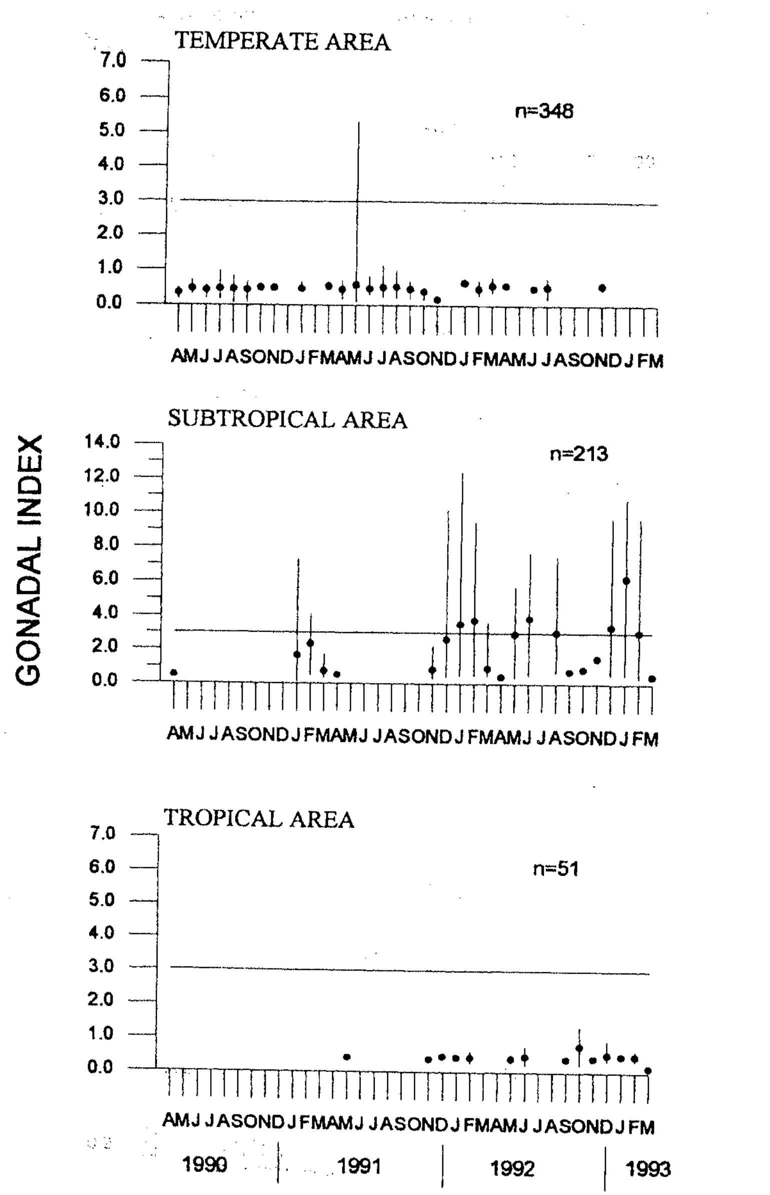

Figure 6. Monthly evolution of mean (and range) gonadal index of Northwest Atlantic mature female swordfish (>185cm LJFL) by areas, from April 1990 to March 1993.

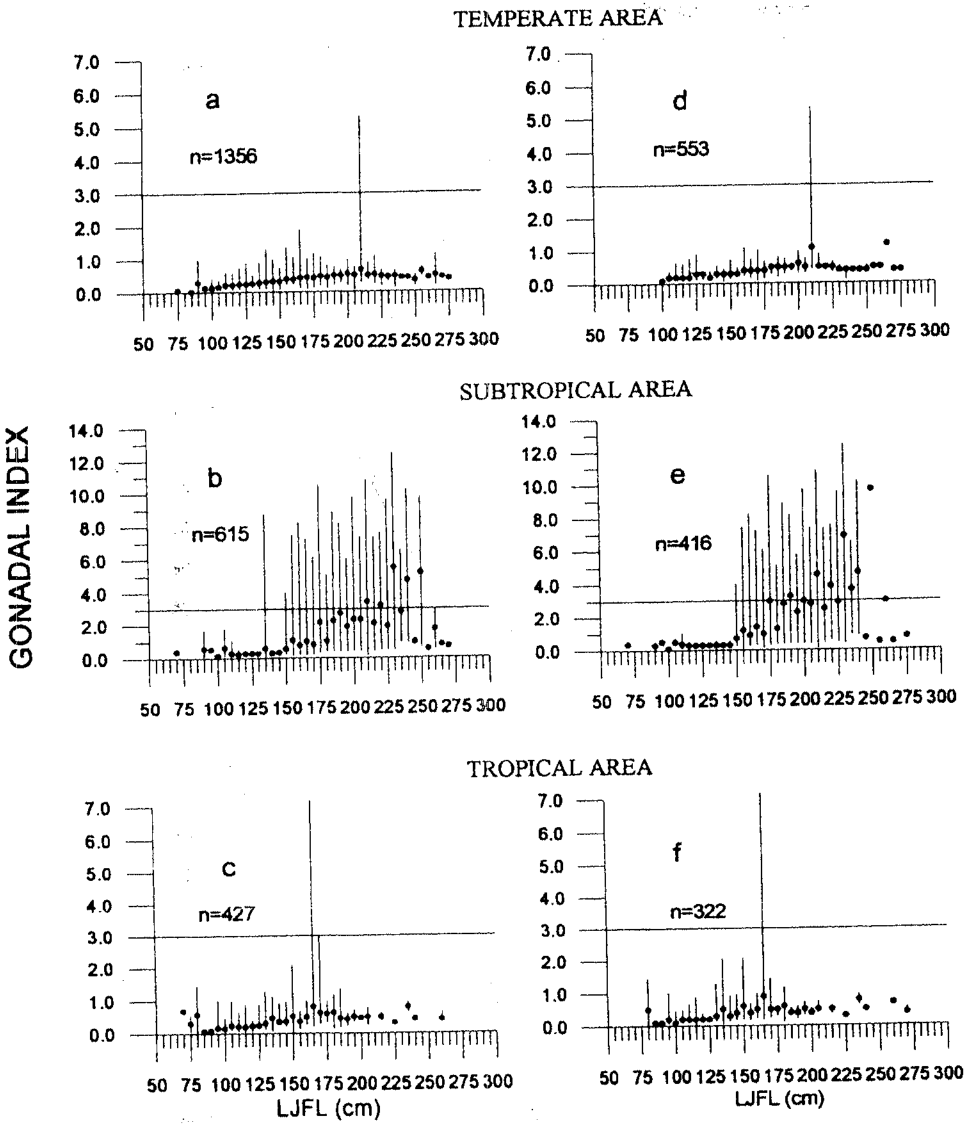

Figure 7. Mean (and range) of gonadal index at size grouped in 5 cm intervals of Northwest Atlantic swordfish by area.
a,b,c. All months combined.
d,e,f. Only months where spawning incidence is observed.

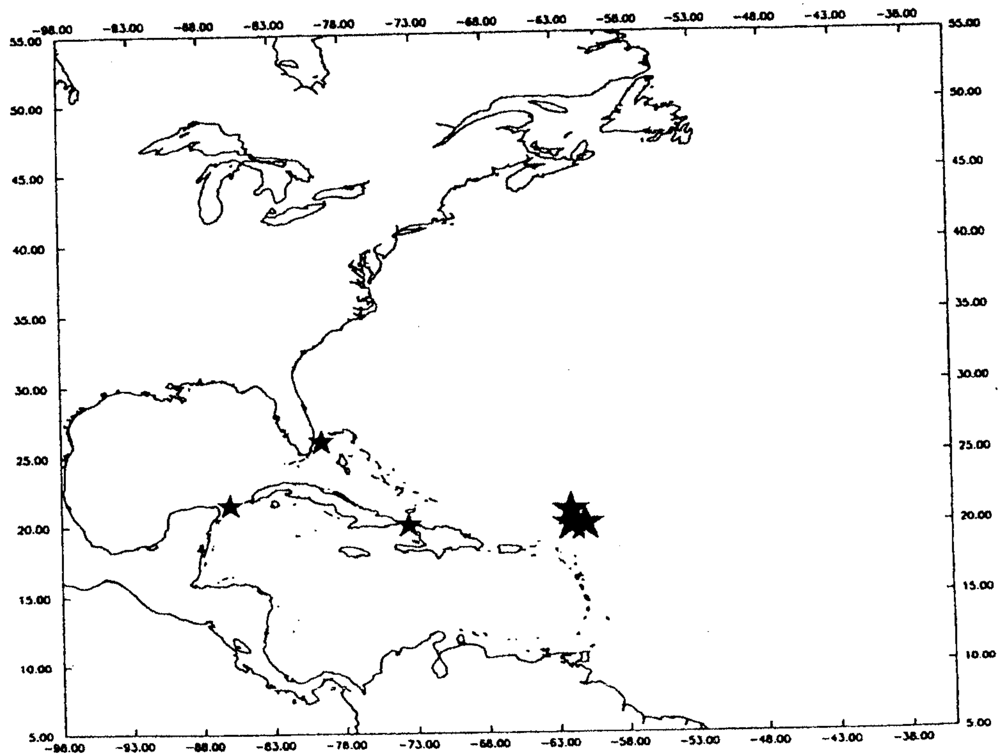

Figure 8. Map of the Northwest Atlantic Ocean indicating swordfish spawning grounds.

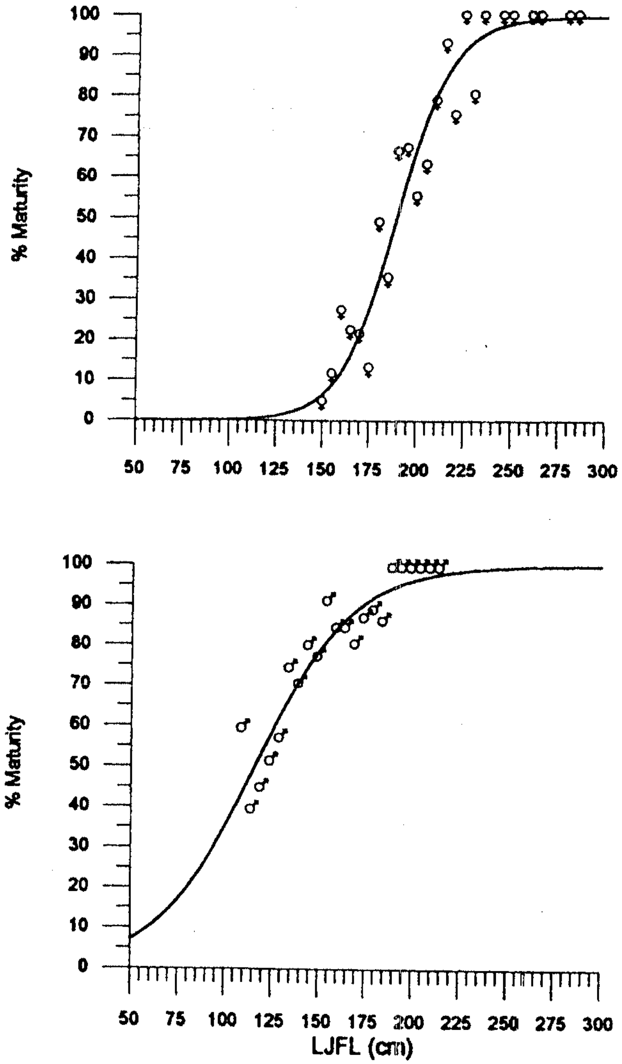

Figure 9. Maturity schedules for female (top) and male (bottom) swordfish in the spawning areas of the Northwest Atlantic Ocean. Symbols= observed mature proportions based on 5 cm groupings

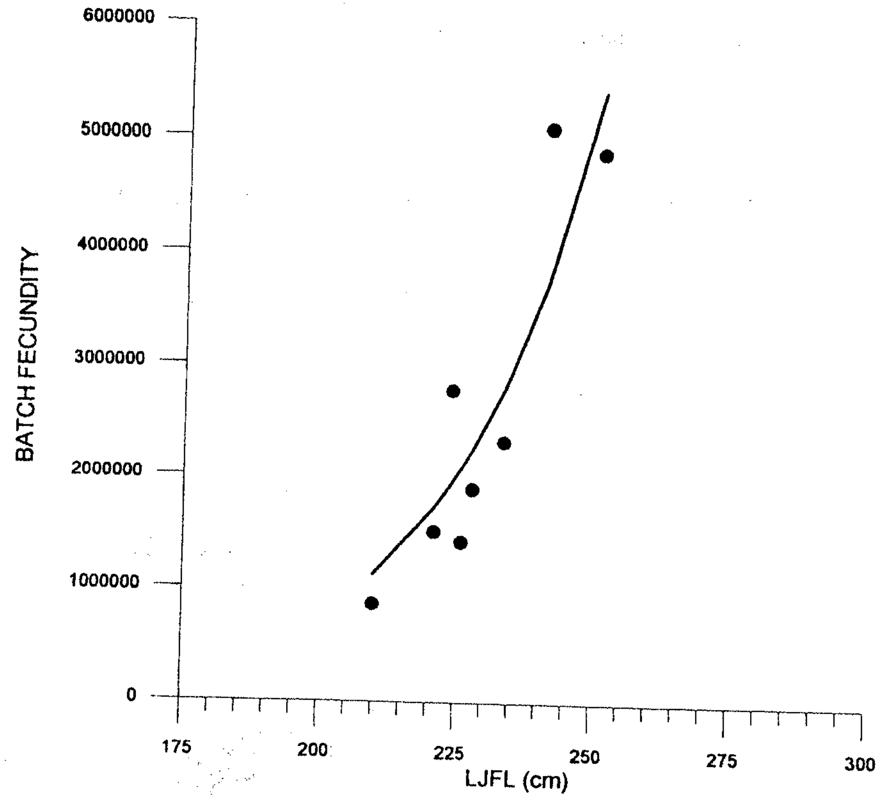

Figure 10. Relationship between batch fecundity and length for swordfish in the Northwest Atlantic Ocean during the period 1991-1993.