

SWORDFISH, XIPHIAS GLADIUS, DYNAMICS IN THE STRAITS OF FLORIDA

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SUMMARY

Estimates of stock parameters and a preliminary yield-per-recruit analysis were carried out on the fast-developing longline fishery for swordfish in the Straits of Florida. Age and growth were determined from apparent annular marks on anal fin spines. Swordfish are relatively slow-growing, long-lived fishes. The best population parameter estimates are $K = 0.0949$, $L_{\infty} = 309$ cm, $Z = 0.41$ and $M = 0.20$, from which $F = 0.21$ and $E = 0.51$ were derived. Female swordfish grow to a larger asymptotic size than do males and apparently have lower natural mortality rates and longer total lifespans. At all reasonable values of M for presently exploited sizes, yield per recruit could be increased with small to moderate increases in F .

RESUME

Les auteurs ont analysé préliminairement le rendement par recrue et ont estimé les paramètres du stock pour la pêche à l'espadon effectuée à la palangre dans les Détroits de Floride. L'âge et la croissance ont été déterminés à partir de marques annulaires apparentes sur les épines de la nageoire anale. Les espadons montrent une croissance relativement lente durant une longue vie. Les meilleures estimations du paramètre de population sont $K = 0.0949$, $L_{\infty} = 309$ cm, $Z = 0.41$, et $M = 0.20$, d'où $F = 0.21$ et $E = 0.51$ ont été dérivés. Les femelles atteignent une taille asymptotique plus grande que celle des mâles, et de plus présentent apparemment des taux de mortalité plus bas, et peuvent vivre plus longtemps. A toutes les valeurs raisonnables de M pour les tailles couramment exploitées, le rendement par recrue pourrait être augmenté avec des augmentations modérées de F .

RESUMEN

Se efectuaron estimaciones de los parámetros de stock, y un análisis preliminar del rendimiento por recluta, para pez espada, en las pesquerías de palangre en los estrechos de Florida. Se determinó edad y crecimiento por unas marcas anulares situadas en los radios de las aletas anales. Los peces espada son animales de crecimiento lento, que suelen alcanzar larga vida. Las mejores estimaciones de los parámetros de población son $K = 0.0949$, $L_{\infty} = 309$ cm, $Z = 0.41$ y $M = 0.20$, de

los cuales $F = 0.21$ y $E = 0.51$ han sido derivados. Las hembras llegan a tener un tamaño asintótico superior al de los machos y, aparentemente, tienen un tasa de mortalidad más baja, alcanzando una vida más larga que estos. En todos los valores razonables de M para los tamaños actualmente explotados, el rendimiento por recluta podría incrementarse con aumentos de pequeños a moderados en F .

INTRODUCTION

A relatively small but valuable United States longline fishery for swordfish has developed in the western Atlantic in the past 15 years. A significant part of the total effort takes place in the Florida Straits, in all months by local fishermen and seasonally by longliners based in New England ports. A management plan for swordfish is being developed by United States regional fishery management councils, but lack of data on stock structure and dynamics, particularly age and growth, has hampered plan development. We have estimated growth rates, sizes at age and total mortality rates for swordfish caught in the Florida Straits. Using these estimates and what we believe to be reasonable assumptions about other stock parameters, we also have conducted a preliminary yield per recruit analysis.

Swordfish have been fished commercially in the northwest Atlantic since the 19th century. Until 1962 virtually all swordfish were harpooned and fishing was confined to waters between New York and Canada during summer. In 1960 the estimated total catch of swordfish in the northwest Atlantic was 2800 metric tons (Caddy, 1976). In the early 1960's longline gear was introduced into the fishery, mostly by Canadian fishermen. In 1963 the estimated total catch had increased to 8800 m.t. It declined the next year and stabilized at about 5000 m.t. until 1971. With the introduction of longlining the range of the fishery expanded. By the middle 1960's it extended from Canada to the Gulf of Mexico and operated year round. In 1971, as a result of United States Food and Drug Administration guidelines that prohibited sale of swordfish with more than 0.5 ppm tissue mercury content, the swordfish fishery collapsed (Caddy, 1976). Some Canadian and United States boats continued fishing clandestinely although total effort was greatly reduced. Reported total catches from the western North Atlantic (FAO Zones 21 and 31) declined to 800 m.t. in 1971 (FAO, 1976). In 1978, the permissible level of mercury was raised to 1.0 ppm. This resulted in rejuvenation of both the Canadian and the United States fisheries. FAO (1979) reported 7077 metric tons landed from the western North Atlantic (Zones 21 and 31) in 1978. The catches almost certainly have increased in 1979 and 1980, but good landings data are not presently available. The

reported catch from Florida in 1979 was at least 777 m.t., which is probably a gross underestimate of actual landings. Presently there are approximately 200 boats in the Florida fishery and the number continues to increase. The success of Florida longliners has encouraged entry of more vessels into the fishery from Gulf of Mexico and south Atlantic States. Regional Management Councils are concerned that the great increase in effort, with little knowledge of stock dynamics, could eventually lead to a decline in the fishery.

AGE AND GROWTH

Fin spines of swordfish have marks that we believe are annuli. Artuz (1963) reported what he believed to be annual marks on the dorsal fin spines of Sea of Marmara swordfish. We have found the best marks on anal fin spines. Marks can be counted on thin sections of the second anal spine under a dissecting scope. There is a direct correlation between number of marks on the spines and fish size. To date we have successfully aged approximately 200 south Florida swordfish by this method. A good linear relationship exists between fork length and fin spine radius:

$$L = 59.58 + 23.98S \quad r = .94$$

L + lower jaw to fork length (cm)
 S = anal fin spine radius (mm)
 r = correlation coefficient.

The fork length - fin spine radius relationship is the same for males and females. Using the relationship and the measured radii to each presumed annulus, mean lengths at each annulus were back-calculated.

Points plotted on Figure 1 are the mean back-calculated lengths for male, female and both sexes combined of swordfish 1 to 8 years old. Older fish have been aged (XI+) but because sample sizes are small they were not included in the present analysis. Lengths were converted to weight (from our length-weight relationships) to give estimated weights at age (Table 1). Beckett (1974) using modal size frequencies and tagging data roughly estimated weights at age of fish from the Canadian fishery in the northwest Atlantic. His estimate

indicated a faster growth rate than that which we have obtained. He estimated that fish weighed only 4 kg at age 1 but 110 kg at age 5.

Male and female swordfish do not grow at the same rate. Females grow faster after age 2 and reach a larger size than males (Figure 1). The largest females in Florida catches weigh more than 300 kg (>11 years old) while the largest males weigh less than 140 kg.

The von Bertalanffy growth model was fitted to our fork length at age data for males and females combined. The result is represented by the dotted line in Figure 1.

The equation is:

$$L_t = 309.0 (1 - e^{-0.0949(t + 3.091)})$$

Parameter estimates are:

$$\begin{aligned} L &= 309.0 \text{ cm} \\ K &= 0.0949 \\ t_0 &= -3.091 \text{ yr} \end{aligned}$$

Back-calculated lengths at age and those predicted by the von Bertalanffy model are nearly identical (Table 2).

Separate fits of the von Bertalanffy model for male and female lengths at age also were attempted. The parameter estimates are:

Males		Females	
L	= 199.8 cm	L	= 373.7 cm
K	= 0.2359	K	= 0.0741
t ₀	= -1.846 yr	t ₀	= -3.203 yr

Despite the small sample sizes upon which the fits were based, the preliminary parameter estimates clearly show differences in growth dynamics between the sexes. In Florida, males predominate in catches by nearly a 2 to 1 ratio until age VII when more females than males are landed.

AGE COMPOSITION OF THE CATCH

Fish in age-classes 0 to >XI have been observed in south Florida longline catches. Based on our weight at age analysis,

fish between 1 and 4 years old are most common in the catch. (Figure 2). More than 50% of the catch consists of 1-4 year-old individuals. Age-classes 0-VIII include more than 85% of the landed fish. The estimated total weights contributed by the age-classes, based on the Figure 2 weight frequency distributions, were nearly evenly distributed among age-classes 0-IV (34.6%), IV-VIII (31.8%) and >VIII (33.6%). The fishery, while dominated by catches of relatively small swordfish (mostly males), depends to a significant extent on the relatively infrequent catches of large, old fish (mostly females), which contribute more than 30% of the landed weight in the Florida Straits' fishery.

MORTALITY

Total mortality rates have been estimated by several methods, all of which depend on the accuracy of our aging technique. Based on a sample of 175 aged fish the maximum likelihood estimate (Robson and Chapman, 1961) of the instantaneous mortality coefficient, with .95 confidence limits, is $Z = 0.41 \pm 0.07$. A second estimate, obtained from the expected relationship between growth and annual mortality rate (Beverton and Holt, 1956) was obtained from:

$$Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L_c}$$

where $L_c = 135$ cm (the length at full recruitment), $L_\infty = 309$ cm and $\bar{L} = 174$ cm. The estimate is $Z = 0.33$

Total mortality was estimated for males and females, based on the Robson and Chapman (1961) method. Males probably have a higher total mortality, but the .95 confidence limits on the estimates from our small samples overlap: Males, $Z = 0.52 \pm 0.13$; Females, $Z = 0.35 \pm 0.10$.

Using the proposed relationship between the natural mortality coefficient (M) and maximum age (T_m) (Tanaka, 1960), and, based on our age data, assuming that the lifespan of swordfish is between 12 and 20 years, then the natural mortality coefficient lies between $M = 0.13$ and 0.23 . The estimated fishing mortality coefficient (F) then ranges from 0.10 to 0.35 and the rate of exploitation $E = \frac{F}{Z}$ lies within the range 0.21 to

1.00. The best point estimates are $M = 0.20$, $F = 0.21$, $E = 0.51$. The possible range of the ratio M/K is approximately 1.25 to 2.50, using our estimate of $K = 0.0949$ from the von Bertalanffy equation. The best point estimate of $M/K = 2.11$.

YIELD PER RECRUIT ANALYSIS

The estimated mean length at entry into the Florida longline fishery (L_c) is 118 cm fork length, which corresponds to estimated length at age II when whole weight is 18.6 kg. For that L_c and $K = 0.0949$ a preliminary yield per recruit analysis was carried out using the Beverton and Holt (1966) yield tables and allowing M/K to vary from 1.25 to 2.50 ($M = 0.12$ to 0.24). Figure 3 gives the relationship between yield per recruit (in kg) and the fishing mortality coefficient for four values of M . As expected, the predicted yields per recruit decline with increasing M and maximum yields per recruit can be taken at increasingly higher fishing mortality rates as M increases. Under present circumstances, at estimated $M = 0.20$ and $L_c = 118$ cm, F_{max} is approximately 0.35, while estimated present F is only 0.21.

If our best estimates of Z , M and L_c are approximately correct, the swordfish fishery in the Florida Straits can continue to expand. The present rate of exploitation $E = 0.51$ could be increased to $E = 0.64$ to maximize yield per recruit under current conditions of growth, natural mortality and size at recruitment into the fishery. An increase in yield per recruit of 0.9 kg might be realized by increasing effort to $F_{max} = 0.35$, which corresponds to $E = 0.64$. If M actually is near the low end of our estimated range, then the fishery is presently operating close to F_{max} . If M is near the high end of our range then effort could be increased considerably to

maximize yield per recruit, but the realized increase would be small because the yield curve is flat-topped for high values of M .

DISCUSSION

The success of a stock dynamics analysis on swordfish depends on a knowledge of stock structure and the validity of the aging analysis. To date there is little information from tagging to define stocks of swordfish. The species is found throughout the world oceans between $45^{\circ}N$ and $45^{\circ}S$ (Palko *et al.*, 1979). Complex seasonal migrations, with differential distribution of the sexes, are thought to occur and all spawning is believed to take place in tropical and subtropical seas. A few tag returns indicate that adult females may return to the same summer feeding grounds each year (Beckett, 1974). Relatively high catches of males are believed to occur in low latitudes of the western North Atlantic (Beckett, 1974; Guitart, 1964). Stock identification is beyond the scope of our present work, but stocks must be defined eventually to best understand population dynamics and to use the knowledge to manage the fishery.

All of the parameters that were estimated and yield models that were applied in the stock dynamics analysis are dependent upon the aging analysis. Rings on fin spines provide clear marks that appear to be annuli and give reasonable estimates of age at size. These marks have not yet been validated as indicators of age. Jolley (1977) used dorsal fin spines of sailfish (*Istiophorus platypterus*) in an age and growth analysis that gave good results. Tagging studies and an independent means of aging swordfish (e.g. otoliths) could provide the validation of our aging technique that eventually will be required. Examination of modal size frequencies is unlikely to provide a good analysis of age and growth because of apparent great individual variability in growth rates and the possible complex stock structure of the species. Because males and females grow and die at different rates, any analysis of age and growth, as well as stock dynamics, must eventually consider the sexes separately.

The Canadian, summer longline fishery, which developed in

the 1960's, provided evidence that the size structure of the stock was changed and abundance of fish was reduced after only a few years of intense fishing (Caddy, 1976). Mean weights of dressed fish in the Florida longline fishery, based on our samples, have not declined since 1975, despite a considerable influx of new effort. The weight-frequency distribution of swordfish in 1979 Florida catches (Figure 3) is nearly identical to that for the 1970 Canadian longline fishery (Beckett, 1974). In both fisheries approximately 65% of the landed fish were ≤ 100 lbs dressed weight (45 kg). If the two fisheries exploit the same stock of swordfish there is no evidence of any significant change in population age structure since 1970. Based on a sample of 242 swordfish caught off northwest Cuba in the early 1960's, 64% were ≤ 100 lbs dressed weight (Guitart, 1964). However, fish between 100 and 200 lbs (45-91 kg) dressed weight constituted a higher percentage of the catch (31%) than in the Florida fishery (25%). Fish ≥ 200 lbs constituted only 5.4% of the Cuban catch compared to 10.3% of the Florida catch. There has been no sign of a decline in catch per unit effort in the Florida longline fishery. Gears and methods have evolved and changed in the past five years, possibly masking any decline in abundance that might have occurred.

At present, the mean length of swordfish entering the exploited phase in the Florida longline fishery (L_C) is 118 cm fork length, the length at 2 years of age. At the present estimated rate of exploitation ($E = 0.51$) some benefits, through increased yield per recruit, could be obtained by increasing L_C . If our best estimate of natural mortality is accurate ($M = .20$), then an increase of L_C to approximately 143 cm would maximize yield per recruit (Y/R) and provide a relative increase in Y/R of approximately 3.8% over the present level. If $M = 0.13$, the lower boundary of our range of estimated M, then an approximate 9.5% relative increase in Y/R is possible by increasing L_C to the size that maximizes Y/R, but this would require $L_C = 167$ cm, the size at 5 years of age. Incorporating such a measure in a management plan would require that the mean weight at first capture increase from the present 18.6 kg to approximately 55 kg. If $M = 0.23$, the upper boundary of our range of M, no significant increase in Y/R would be achieved by increasing L_C .

Results of the yield per recruit analysis indicated that rate of exploitation is still below the level that would maximize Y/R in the Florida longline fishery. Given that result, combined with our best population parameter estimates, and considering the preliminary nature of the data, there is no urgent need to regulate the commercial longline fishery at present. But, the effort level is increasing rapidly and rate of exploitation may surpass the optimum level in the near future.

Various management options are possible. One way to increase L_C to achieve a higher Y/R would be to restrict fishing in certain areas or at certain times. Because most small fish are males that grow quickly toward asymptotic size and die at relatively fast rates, this might be a wasteful regulation. There is a suspicion in the fishery that small fish are caught in low latitudes (e.g. Florida and the Gulf of Mexico), but our comparison of the present size-frequency distribution of landed fish from Florida with that for the 1970 Canadian fishery indicated no differences. Until better information on stock structure and on differential dynamics of males and females becomes available, there is no call for strict regulations on this fishery given present effort levels. Continued rapid increases in effort could change our view on management needs.

ACKNOWLEDGMENTS

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LITERATURE CITED

- Artuz, M.I. 1963. Contribution to the knowledge of the biology of the swordfish (Xiphias gladius L.) in the Sea of Marmara. Proc. Gen. fish. Coun. Medit., 7: 459-471.
- Beckett, J.S. 1974. Biology of swordfish, Xiphias gladius L., in the northwest Atlantic Ocean. pp. 103-106. In: Shomura, R.S. and F. Williams (editors). Proceedings of the International Billfish Symposium Kailua-Kona, Hawaii, 9-12 August 1972. Part 2. Review and Contributed Papers. NOAA Tech. Rep. NMFS SSRF-675.
- Beverton, R.J.H. and S.J. Holt. 1956. A review of methods for estimating mortality rates in exploited fish populations,

- with special reference to sources of bias in catch sampling. Rapp. P.-v. Reun. Cons. perm. int. Explor. Mer, 140: 67-83.
- Beverton, R.J.H. and S.J. Holt. 1966. Manual of methods for fish stock assessment Part II. Tables of yield functions. FAO Fish. Tech. Paper 38(Rev. 1), 10 pp. plus 67 Appendix pp.
- Caddy, J.F. 1976. A review of some factors relevant to management of swordfish fisheries in the Northwest Atlantic. Canada, Fisheries and Marine Service Tech. Rep. 633, 36 pp.
- Food and Agriculture Organization. 1976. Yearbook of Fishery Statistics, Catches and Landings, 1975. FAO, Rome, Vol. 40, 417. pp.
- Food and Agriculture Organization. 1979. Yearbook of Fishery Statistics, Catches and Landings, 1978. FAO, Rome, Vol. 46, 372 pp.
- Guitart, D. 1964. Biología pesquera del emperador o pez de espada, Xiphias gladius Linnaeus (Teleostomi: Xiphiidae) en las aguas de Cuba. Poeyana 1, Ser. B: 1-37.
- Jolley, J.W., Jr. 1977. The biology and fishery of Atlantic sailfish Istiophorus platypterus, from southeast Florida. Fla. Mar. Res. Publ. 28, 31 pp.
- Palko, B.J., G.L. Beardsley and W.J. Richards. 1979. Synopsis of the biology of the broadbill swordfish, Xiphias gladius Linnaeus, 1758. ICCAT Working Document, SCRS/79.
- Robson, D.S. and D.G. Chapman. 1961. Catch curves and mortality rates. Trans. Am. Fish. Soc., 90: 181-189.
- Tanaka, S. 1960. Studies on the dynamics and the management of fish populations. Bull. Tokai Reg. Fish. Res. Lab., 28: 1-200.

Table 1. Estimated whole and dressed weights of swordfish from the Straits of Florida, based on back-calculated sizes at age from anal fin spine analysis.

Age	Whole Wt (kg)	Dressed Wt* (kg)
I	10.5	7.9
II	18.6	14.0
III	29.1	21.8
IV	40.9	30.7
V	55.9	41.9
VI	73.6	55.2
VII	88.2	66.2
VIII	105.9	79.4

* dressed wt = 0.75 whole weight

Table 2. Back-calculated lengths and lengths predicted from the fitted von Bertalanffy model for swordfish caught in the Straits of Florida.

Age	Back-Calculated Fork Length (cm)	Predicted Fork Length (cm)
I	98.95	99.42
II	117.66	118.39
III	135.01	135.35
IV	149.88	151.35
V	165.05	165.62
IV	179.48	178.60
VII	189.50	190.41
VIII	200.49	201.14

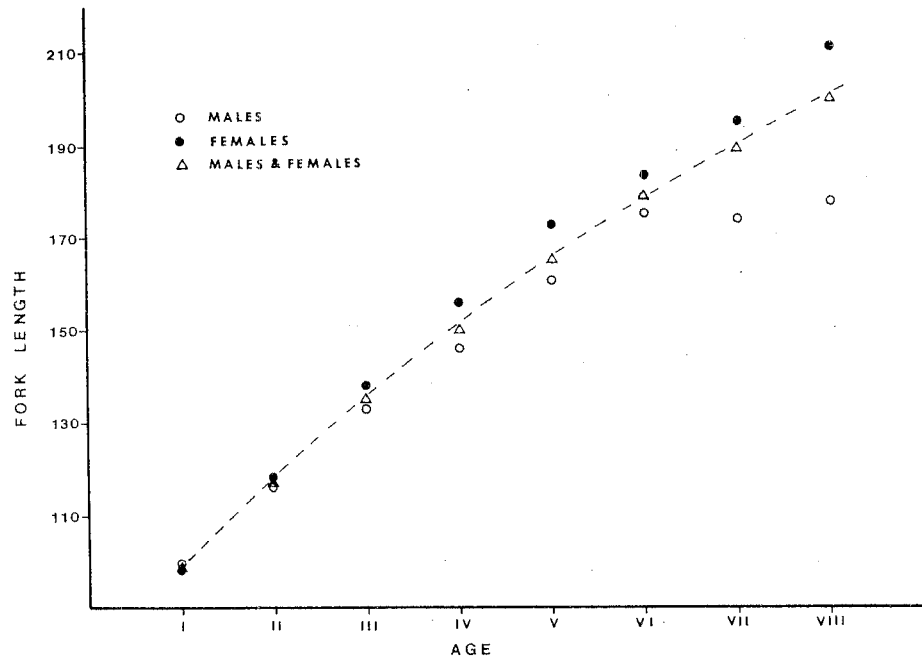


Figure 1. The relationship between fork length (cm) and age (yrs) for swordfish landed in south Florida. The data points are back-calculated lengths at annuli. The line is based on the von Bertalanffy model fitted to the combined male and female data.

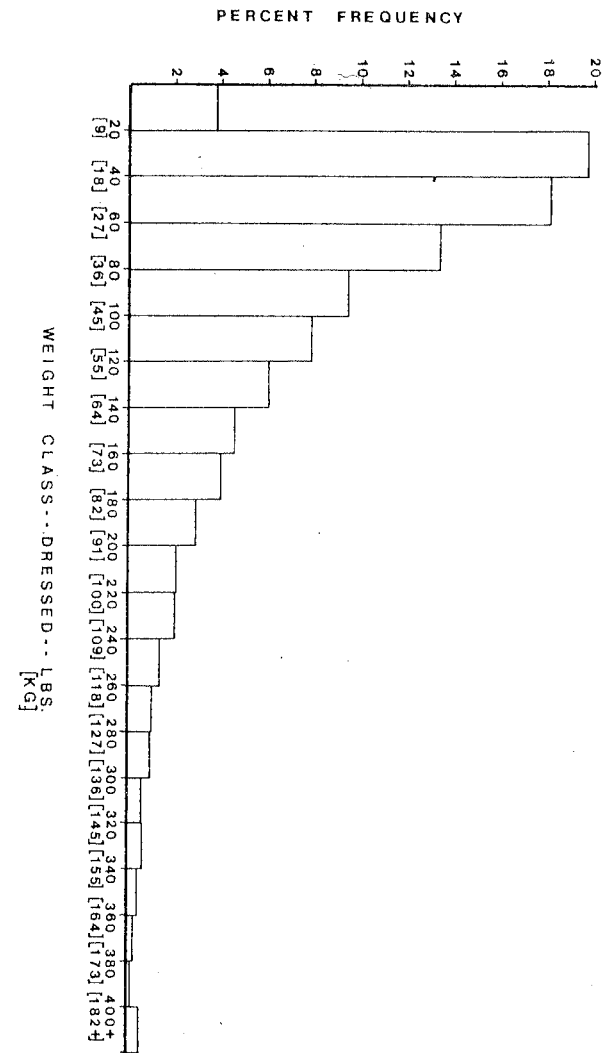


Figure 2. The weight-frequency distribution for 8753 swordfish landed in Florida from February 1979 through January 1980. Dressed weight equals whole weight X 0.75.

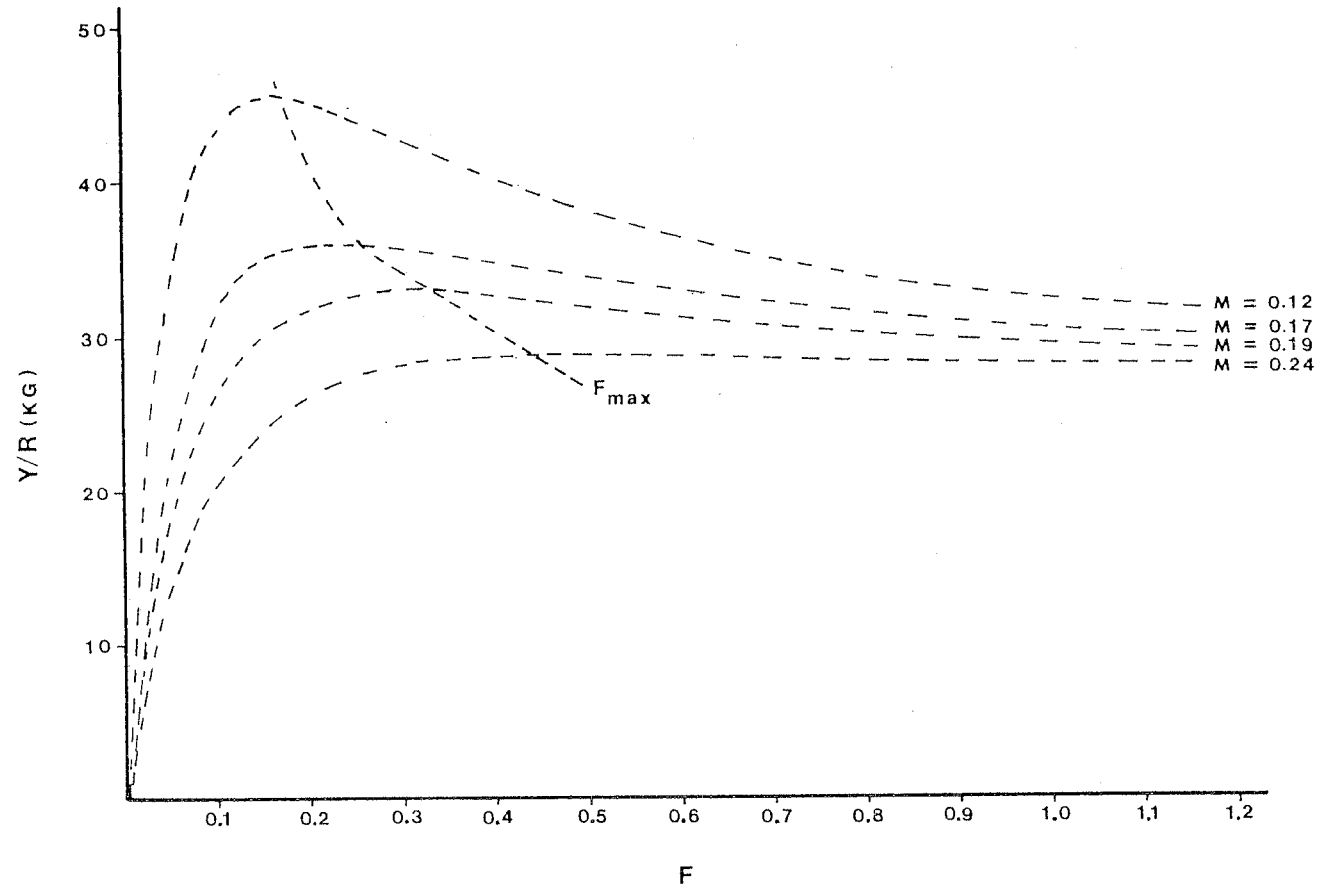


Figure 3. Yield curves for Florida swordfish. Yield per recruit (Y/R) is given in relation to the fishing mortality coefficient (F) for four possible values of natural mortality (M). For this analysis, the growth coefficient $K = 0.0949$ and the mean length at first capture $L_C = 118$ cm.