ANALYSES OF NORTH ATLANTIC SWORDFISH CATCH-AT-AGE DATA UNDER ALTERNATIVE HYPOTHESES ABOUT GROWTH AND SEX RATIO

V. R. Restrepo, G. P. Scott**, J. E. Powers***

**Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149, U.S.A.*

***NMFS-Southeast Fisheries Center, 75 Virginia Beach Drive, Miami, Florida 33149, U.S.A.*

SUMMARY

Information about differences in sex ratio at size and possible sexual dimorphism in growth have raised questions regarding likely biases that may be incurred during swordfish stock assessments. In this study we separated the 1978-89 catch-at-length data into sexes and converted it into catch at age using three growth curves (two sex-specific ones and the one used in the 1990 assessment). The U.S. and Spain CPUE data were treated similarly in order to derive age-specific indices of abundance for each sex-growth curve combination. We then carried out virtual population analyses (VPAs) of the resulting data sets in order to better understand how trends in population size and fishing mortality may differ depending on the growth hypothesis used.

Analyses of the status of Atlantic swordfish are routinely conducted under the assumption that males and females follow the same growth pattern. However, the sex ratio of the catches is clearly heterogeneous, with most large fish being females (Hoey 1991; Mejuto *et al.*, 1991). This gives support to the notion that growth may differ between males and females, although sex-specific mortality rates could explain part of the observed differences in sex ratio (Suzuki and Miyabe 1991).

There is concern that ignoring the possible sexual dimorphism in growth can bias the virtual population analysis (VPA) estimates of fishing mortalities and population sizes. Suzuki and Miyabe (1989) demonstrated that cohort analyses of the data separated by sex, and aged assuming a dimorphic growth pattern (from Berkeley and Houde 1983), resulted in fishing mortality estimates consistently lower than those obtained previously during the assessments at ICCAT. Restrepo (1990) further examined this issue by simulating a population with known characteristics, including sexual dimorphism in growth, and then carrying out VPAs as during the ICCAT assessments. Restrepo's (1990) results are largely dependent on the degree of mis-ageing caused as a result of differences between the population's "true" growth rate(s) (by sex), and the homogeneous growth model used in the assessments. Unfortunately, there is no scientific consensus as to what the "true" growth rate of North Atlantic swordfish is, partly because growth studies based on hard parts have not been validated.

In this study we re-analyze the 1978-89 catch-at-age data, separated by sex and aged according to either of three growth curves. Our objective is to better understand how last year's ICCAT swordfish assessment may have differed if sexual dimorphism in growth had been explicitly taken into consideration. The procedures used to obtain abundance indices and calibrate the VPAs are generally the same as those in last year's assessment which are documented in ICCAT (1991).

RESUME

L'information sur les différences du sex ratio selon la taille et un éventuel dimorphisme sexuel de la croissance a soulevé des question quant aux biais probables qui peuvent surgir dans les évaluations de stock de l'espadon. La présente étude sépare les données de prise par taille de 1978-89 par sexe et les convertit en prise par âge au moyen de trois courbes de croissance (deux spécifiques du sexe et celle qui a servi à l'évaluation de 1990). Les données de CPUE américaines et espagnoles ont été traitées de façon similaire pour calculer des indices d'abondance spécifiques de l'âge pour chaque combinaison sexe-croissance de la courbe. Nous avons ensuite effectué l'analyse des populations virtuelles (VPA) sur les jeux de donnés obtenus de façon à mieux appréhender comment les tendance de la taille de la population et de la mortalité par pêche peuvent différer selon l'hypothèse de croissance utilisée.

L'analyse de l'état de l'espadon atlantique est normalement menée en supposant que les mâles et les femelles ont le même rythme de croissance. Le sex ratio des prises est néanmoins nettement hétérogène, la plupart des grands poissons étant des femelles (Hoey, 1991; Mejuto *et al.*, 1991). Ceci renforce la notion d'une croissance différente entre mâles et femelles, bien que le taux de mortalité spécifique du sexe puisse justifier une partie des différences de sex ratio observées (Suzuki et Miyabe, 1991).

La possibilité de biais dans les estimations par VPA de la mortalité par pêche et de la taille de la population du fait de ne pas tenir compte d'un éventuel dimorphisme sexuel est une source d'inquiétudes. Suzuki et Miyabe (1989) ont démontré que l'analyse des cohortes des données séparées par sexe, et dont l'âge est déterminé en supposant un mode dimorphique de croissance (selon Berkeley et Houde, 1983), donnait des estimations de

la mortalité par pêche toujours plus faibles que celles qui avaient été obtenues antérieurement par les évaluations de l'ICCAT. Restrepo (1990) a étudié plus à fond cette question en simulant une population avec des caractéristiques connues, dont un dimorphisme sexuel de la croissance, puis a mené des VPA comme lors des évaluations de l'ICCAT. Les résultats de Restrepo (1990) indiquent que l'importance des biais dans les estimations de la VPA dépendent en grande partie du degré de détermination erronée de l'âge du fait de différences entre le taux de croissance "réel" de la population (par sexe) et le modèle de croissance homogène utilisé dans les évaluations. Malheureusement, il n'existe pas de consensus scientifique sur le taux de croissance "réel" de l'espadon nord-atlantique, en partie du fait que les études de croissance basées sur les structures osseuses n'ont pas été validées.

Cette étude analyse de nouveau les données de prise par âge de 1978-89, séparées par sexe et dont l'âge est déterminé selon l'une des trois courbes de croissance. Notre but est de mieux appréhender comment l'évaluation de l'an dernier de l'ICCAT sur l'espadon aurait pu différer s'il avait été tenu compte de façon explicite du dimorphisme sexuel de la croissance. Les méthodes utilisées pour obtenir les indices d'abondance et calibrer les VPA sont en général les mêmes que celles de l'évaluation de l'an dernier qui sont commentées dans le rapport ICCAT (1991).

RESUMEN

La información que se tiene sobre las diferencias en el sex ratio por talla y el posible dimorfismo sexual en el crecimiento, plantea ciertas preguntas acerca de los posibles sesgos que pueden introducirse en las evaluaciones del stock de pez espada. En el presente estudio, los datos de captura por talla del período 1978-89 se clasifican por sexos y se convierten en captura por edad por medio de tres curvas de crecimiento (dos por sexo y otra ya empleada en la evaluación de 1990). De manera similar se tratan los datos de CPUE de España y Estados Unidos, con el fin de obtener índices de abundancia por edad en cada una de las curvas de sexo-crecimiento. A continuación se analizan los datos resultantes por VPA para llegar a ver las diferencias que se producen en el tamaño de la población y en la mortalidad por pesca, de acuerdo con la hipótesis de crecimiento aplicada.

Por lo general, los análisis de la condición del pez espada atlántico se hacen bajo el supuesto de que los machos y las hembras siguen la misma pauta. Sin embargo, la sex ratio en las capturas es heterogénea y la mayor parte de los peces grandes son hembras (Hoey, 1991; Mejuto *et al*, 1991). Esto obra a favor de la idea de que el crecimiento de machos y hembras podría ser diferente, si bien, las tasas de mortalidad por sexo podrían aclarar en parte estas diferencias observadas en la sex ratio (Suzuki y Miyabe, 1991).

El hecho de ignorar el posible dimorfismo sexual en el crecimiento podría sesgar las estimaciones de mortalidades por pesca y tamaños de población del análisis de VPA, lo cual resulta preocupante. Suzuki y Miyabe (1989) demostraron que el análisis de cohortes de los datos clasificados por sexo y con edad estimada suponiendo un crecimiento dimórfico (de Berkeley y Houde, 1983), daba siempre estimaciones de la mortalidad por pesca inferiores a las obtenidas en anteriores evaluaciones hechas en ICCAT. Restrepo (1990) volvió a estudiar este hecho simulando una población de características dadas, incluyendo un crecimiento sexual dimórfico, y realizando después VPAs como se hace en ICCAT. Los resultados de Restrepo (1990) indicaban que la magnitud de los sesgos en las estimaciones por VPA dependen en gran parte del grado de error en la determinación de la edad provocado por las diferencias entre la tasa (o tasas) "auténticas" de crecimiento (por sexo) y el modelo de crecimiento homogéneo aplicado en la evaluación. Desafortunadamente, no hay acuerdo científico sobre cual es la "auténtica" tasa de crecimiento del pez espada en el Atlántico norte debido, en parte, a que los estudios sobre crecimiento basados en partes duras no han sido convalidados.

El presente estudio vuelve a analizar los datos de captura por edad del período 1978-1989, por sexos y con una edad determinada de acuerdo con una de las tres curvas de crecimiento. El objetivo es llegar a saber con más exactitud en qué se habría diferenciado la evaluación ICCAT del pez espada llevada a cabo el año pasado, de haber tenido en cuenta de forma explícita el dimorfismo sexual del crecimiento. Los procedimientos empleados para obtener índices de abundancia y calibrar los VPAs son, en general, los mismos empleados en la evaluación del año pasado, documentados en ICCAT (1991).

METHODS

The analyses were carried out using either one of three sets of growth curves (the formulations and parameters used for these can be found in Restrepo, 1991):

a) The "Gompertz" curve, estimated from tagging. Under this model, males and females have identical growth. This is the curve adopted by ICCAT during the past few years.
b) The "Berkeley-Houde" curves, estimated from anal fin spine rings. Under this model (Berkeley and Houde, 1983), males and females exhibit very different growth patterns.
c) The "Ehrhardt" curves, also estimated from anal fin spine

data. In this model (Ehrhardt, 1991), the curves do not differ as much between sexes as they do with the preceding model.

For the VPAs, the catch-at-length data were assigned ages with either of the above growth curves, after being separated into sexes. The CPUE data used to generate the indices of abundance for calibrating the VPAs were treated in the same fashion. The sections below give a more detailed account of these analyses.

Sex Ratios
Swordfish sex ratios are known to vary over time and areas (Mejuto *et al.* 1991). We did not attempt to quantify sex ratios by time-area strata because historical data appear to be insufficient for analyses of this kind throughout the entire time series. Nevertheless, the available data are indicative of similar patterns throughout the North Atlantic: the sex ratio is close to unity up to an intermediate size (about 150 cm LJFL), and then increasingly favors females up to about 250 cm. Generally, all fish larger than 250 cm are females. Based on this, we fitted a three-line model with the lines constrained to join at sizes that were directly estimated. Letting P_L denote the fraction of females at size L, the model we used can be written as

$$(1) \qquad P_L = \begin{cases} A+BL, & \text{for } L<L_1 \\ A+BL_1+D(L-L_1), & \text{for } L_1\le L<L_2 \\ 1 & \text{for } L\ge L_2 \end{cases}$$

where A, B, D, L_1 and L_2 are parameters.

Considering the binomial nature of the data (i.e., a fish either is or is not a female), we estimated the parameters by maximizing the log-likelihood

$$(2) \qquad \ln(\Lambda) = \sum_{L=\min}^{\max} r_L \ln(P_L) + (n_L - r_L)\ln(1-P_L) \quad ,$$

where n and r denote the total number of fish and the number of females in each size, respectively. The data used were basically those in ICCAT (1991) (Fig. PARM 2, p. 359).

CPUE Indices
Eleven CPUE indices were used to calibrate the VPAs during the 1990 assessment: U.S. longline catch rates for ages 1, 2, 3, 4, and 5+; Spanish longline catch rates for the same ages, and Japanese longline catch rates for age 5+. For this study, we did not modify the index from Japanese longliners. The age-specific catch rates from the Spanish and U.S. fleets were re-estimated with the same methods used in the ICCAT assessment (see Scott and Bertolino, 1991), after the original CPUE data were separated into sexes and assigned ages with the appropriate model.

VPAs
All VPAs were conducted with the 1978-1989 time series, ages 1 to 9+. The tuning differed from that in the 1990 Assessment (see ICCAT 1991, Appendix 6) in that index weights in the objective function were not estimated by calibrating to the catch data one index at a time. Instead, solutions were obtained with iterative reweighing scheme (differences between the two approaches are usually minor; see Powers and Restrepo, SCRS/91/40, this volume). Parameters that were directly estimated in the search were the population sizes for ages 3, 4, 5, and 6 in 1990. Terminal year selectivities for ages not directly estimated were obtained from the ratio of the age-specific selectivity predicted by separable virtual population analysis (SVPA, Pope and Shepherd, 1982), to that directly estimated for age 5. Input parameters to the SVPAs were as in last year's assessment.

For the purpose of comparing estimates of population sizes amongst the various models, we summarized the results by age groups (age 1, ages 2 to 4, and age 5+). Estimated fishing mortalities are only reported for the 5+ age group. These were calculated as

$$F_{5+,t} = -\ln\left(\frac{\sum_{j=6}^{9+} N_{j,t+1}}{\sum_{j=5}^{9+} N_{j,t}}\right) - M$$

RESULTS AND DISCUSSION

The parameters estimated for the three-line model used to separate the data into sexes (equation 1) were:

A = 0.60575,
B = −0.001213,
D = 0.0071,
L_1 = 153.47, and
L_2 = 246.09.

Thus, this model predicts a proportion of females close to 0.5 for small fish up to 153 cm LJFL, which then increases steeply so that all animals above 246 cm are females.

Standardization of the CPUE data after sexing and re-ageing, resulted in estimates of relative abundance that were very similar between sexes and growth models (e.g., Figure 1). In all cases the same pattern observed in the 1990 ICCAT analysis were similar: a strong increase in the abundance of one-year olds, relatively stable numbers of two-year olds, and a decline in the remaining ages, most notably in the 5+ age group.

VPA estimates of population sizes by sex are presented in Figure 2. The trends are very similar in all cases but the magnitude of the estimates varies considerably for older fish, depending on the growth model used. For the 5+ group, females exhibit a steeper decline in numbers than do males, and the magnitudes are quite different specially with the Gompertz model (open circles, Figure 2).

Fishing mortality rates by sex also differ depending on the growth model used (Figure 3). In general, males were estimated to suffer higher mortalities than females, with the difference being most accentuated when the Gompertz model was assumed (open circles). Analyses using the Berkeley-Houde model resulted in F estimates that did not differ as much between the sexes (open triangles). Analyses with the Ehrhardt model fell between these two extremes (open squares).

Figure 4 shows the population size and fishing mortality estimates with sexes pooled together after analysis, together with those obtained with the base analysis. The base analysis (solid squares) is that carried out as in the 1990 ICCAT assessment (i.e., with the Gompertz curve and assuming a sex ratio of 1:1). Trends and levels of population sizes for recruits and young fish are very similar in all cases with the exception of the last 2 or 3 years, in which the base analysis results in lower population sizes. For the 5+ age group, the aggregate population size estimated with the Gompertz curve separately by sex is nearly identical to that with the base analysis (open circles and solid squares, respectively). The total population size from the Berkeley-Houde model results in higher numbers (open triangles, Figure 4).

Trends in fishing mortality rates with sexes pooled together are similar in all cases, with the base analysis indicating a steeper increase over time (Figure 4).

It is interesting to note that although trends in the estimates from the VPAs were not strikingly different between sexes, some of the magnitudes were. The most extreme results were obtained for older fish (ages 5 and above) by ageing the data with the Gompertz model (see Figures 2 and 3). While not necessarily intuitive, this finding seems obvious after examination of the results. As noted by Suzuki and Miyabe (1991) and by Restrepo (1991), sexually dimorphic growth appears to be a necessary condition to explain the observed differences in the sex ratios of the catch. In the context of VPAs, if the sex ratios are accounted for by conducting separate analyses by sex and the same growth model is assumed for males and females, then differences in sex ratios will be largely attributable to differential mortality. This is the reason for the F values for males being much higher than those for females (Figure 3). By analogy, estimates obtained with growth curves that exhibit sufficient dimorphism to explain the observed heterogeneous sex ratios should result in similar fishing mortality estimates (the Berkeley-Houde and Ehrhardt models move closer in this direction).

Based on the results from this study and those of Suzuki and Miyabe (1989) and Restrepo (1991), it is possible that much could be gained from assessing swordfish stocks without ignoring the heterogeneity of sex ratios in the catch. However, there is a need for more studies and continuing data collection before some of the existing doubts on how to best carry out the analyses can be resolved. Of primary importance are the validation of, and agreement on, the growth curves that will be used. Ideally, annual age-length keys could be constructed if a valid method for ageing were found. Also important is the continuing compilation of sex information from the catches so that annual sex ratios by size can be obtained more precisely than with a coarse model like that used in these analyses.

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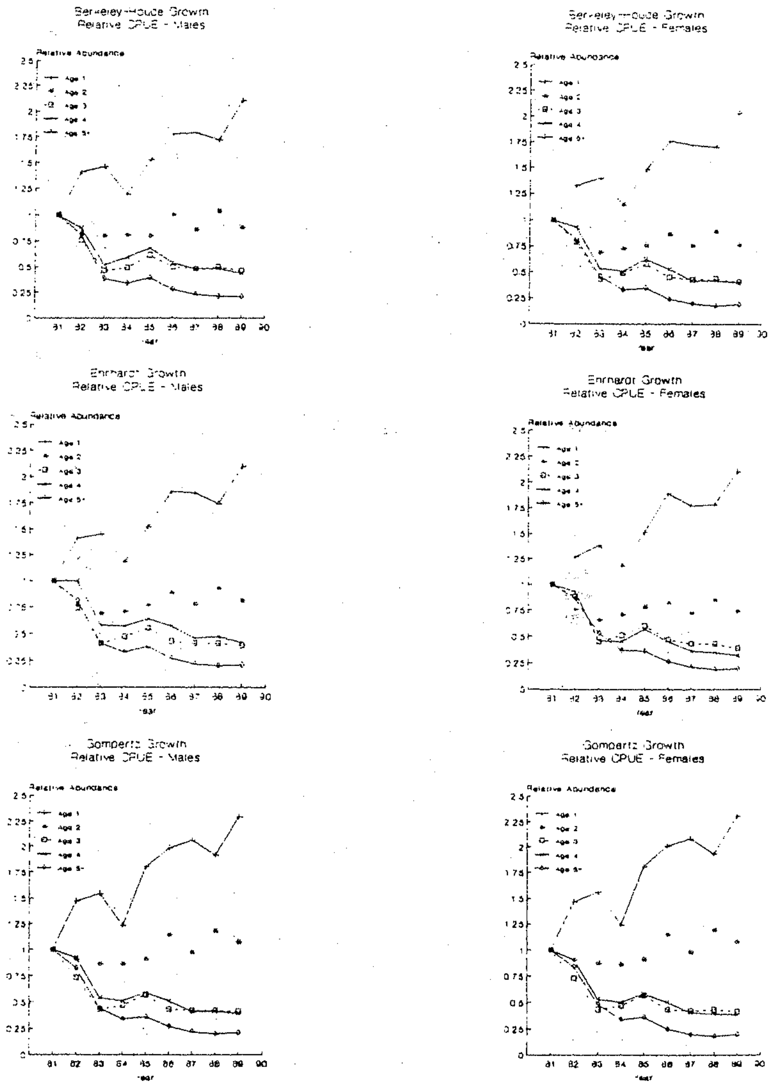

Figure 1: Indices of abundance, by sex and growth assumption, from US longline data.

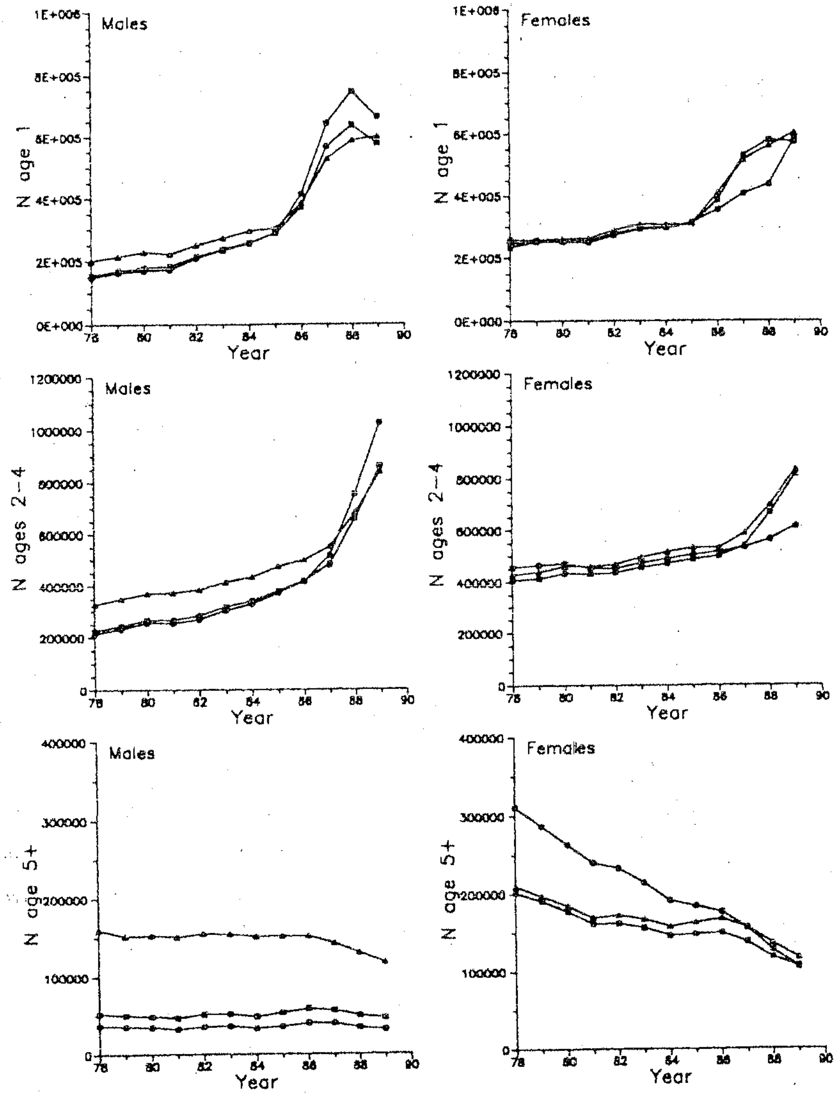

Figure 2: Sex-specific estimates of population size, obtained with three growth models: Gompertz (circles), Ehrhardt (squares) and Berkeley-Houde (triangles).

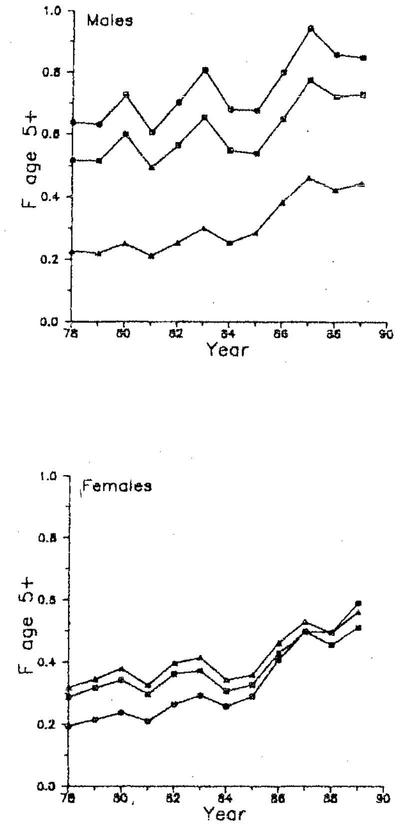

Figure 3: Sex-specific estimates of fishing mortality obtained with three growth models. Symbols are as in Figure 2.

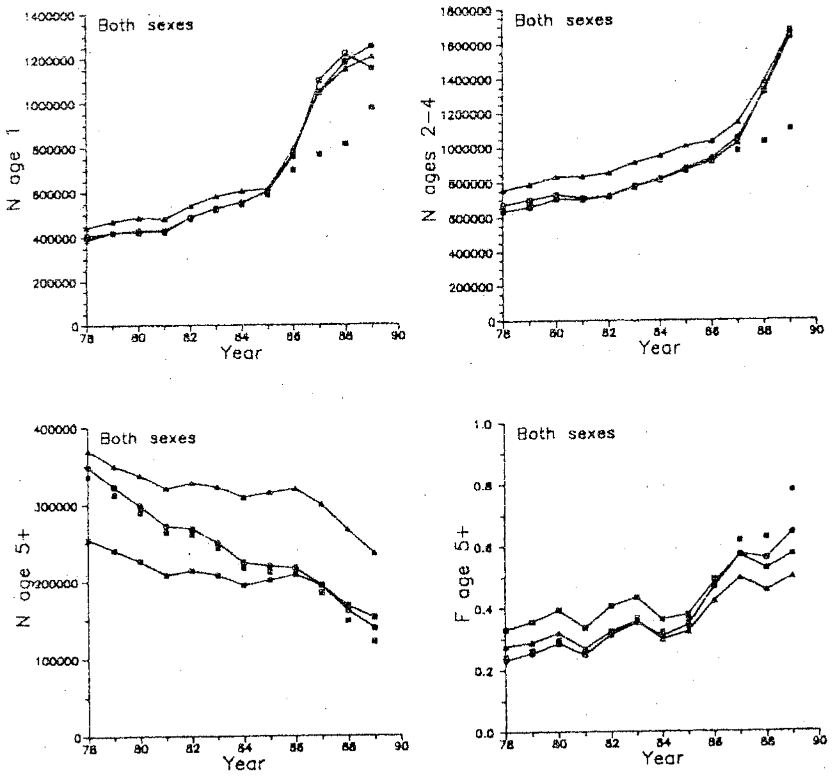

Figure 4: Estimates of population sizes and fishing mortalities for sexes combined. Solid squares are as in ICCAT (1991); other symbols are as in Figure 2.