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PRODUCTION MODEL ANALYSIS OF THE ATLANTIC YELLOWFIN TUNA (THUNNUS ALBACARES) FISHERY

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SUMMARY

The Atlantic yellowfin tuna fishery is presently at a mature state of development, with catches increasingly being maintained by large increases in fishing efficiency. Production model analyses indicate maximum sustainable yield (MSY) is at least 110,000 MT in the eastern Atlantic and 120,000 MT Atlantic-wide. The upper limit of sustainable catch is likely about 150,000 MT. A sustained decrease in catch with increased fishing effort is not yet apparent. The average rate of increase in catches was 3.3% since 1976.

RESUME

La pêcherie d'albacore de l'Atlantique a maintenant atteint sa maturité; ses captures se maintiennent de plus en plus grâce à de forts accroissements de l'efficacité de pêche. L'analyse du modèle de production signale que la production maximale équilibrée (PME) se situe au plus bas à 110.000 TM dans l'Atlantique est et à 120.000 TM pour l'ensemble de l'Atlantique. On ne distingue pas encore de baisse suivie des prises par suite de l'accroissement de l'effort. Le taux moyen d'augmentation des captures est de 3,3 % depuis 1976.

RESUMEN

La pesquería de rabil atlántico se encuentra en un avanzado estado de desarrollo, y cada vez más el nivel de captura se mantiene incrementando la eficacia pesquera. Los análisis del modelo de producción señalan que el rendimiento máximo sostenible (RMS) es al menos de 110.000 TM en el Atlántico Este y 120.000 TM en todo el Atlántico. El límite superior de la captura sostenible es probablemente de unas 150.000 TM. No aparece todavía un continuo descenso en la captura en respuesta a un incremento del esfuerzo pesquero. La tasa media de aumento en la captura ha sido de 3.3% desde 1976.

INTRODUCTION

Production model analyses of the Atlantic yellowfin tuna (YF) stocks have been carried out since 1972, and most recently by Coan (1980) and Fonteneau and Cayre (1981). Though lacking in analytical detail the production model provides direct assessment of the relationship between catch and effort or stock size. This relationship, as reflected in the shape of the production or yield curve, depends both upon the biology of the stock and upon the pattern of exploitation. The latter especially affects catch/effort (C/f) and effective fishing effort (f).

The Atlantic YF fishery is conducted throughout the tropical Atlantic with both surface and subsurface gear, but 90% of the catches come from the eastern Atlantic, primarily (average: 71%, 1976-80) caught by purse seiners in the Gulf of Guinea and off western Africa. FISM (France, Ivory-Coast, Senegal, Morocco) and Spanish purse seiners averaged 94% of the eastern Atlantic purse seine catch during the 1976-80 period, while the United States caught only 3.7%. A rapid influx of large purse seiners into the eastern Atlantic fishery began in 1974, and presently these fleets dominate the fishery. The changing nature of the FISM surface fishery has been described by Fonteneau (1979) and by Fonteneau and Slepoukha (1981).

The continuing increase of fishing effort due to the large purse seiners has made necessary the development of new C/f measures that account for the increased efficiency and offshore expansion of the fleet (Fonteneau and Marcille, 1979; Fonteneau, 1979). The new series, or vectors, of annual C/f measures are derived from the FISM purse seine fleet and are used in this report.

DATA AND METHODS

Catch-per-unit-effort (C/f)

New C/f vectors for the FISM surface fleet were introduced by Fonteneau and Marcille (1979) and Fonteneau (1979). These indexes of population size, by the area weighted rather than the effort weighted method as previously used, are theoretically a more correct measure of relative population size (see Beverton and Holt, 1957). Specifically the new C/f measures are derived from the FISM purse seine (PS) fleet in the traditional coastal fishery area, standardized to medium or large purse seiners, with the C/f from 1^{0} squares averaged over 15-day periods and excluding areas with surface temperatures <22^{0}C (Fonteneau, 1979 and 1981).

The revised C/f measures for the years 1969-80, are given by Fonteneau and Cayre (1981) for medium purse seiners (SM), large purse seiners (GS), and for combined purse seiners (MSGS) (Table 1, columns 1-3). Additionally they give revised C/f measures for combined baitboats (BB) and for SM and GS purse seiners, using the older, effort weighted method (Table 1, columns 4-6).

These data suggest that the YF stock supporting the present fishery became wholely exploited after 1968. The C/f index is therefore applicable after that date as a measure of the changes in population size. The area-weighted C/f shows the expected decrease in relative population size, while the effort weighted C/f has exhibited little downward trend up to the present time, even though effort had steadily increased (see Fonteneau and Cayre, 1981 and Coan, 1980).

Two different C/f vectors are used in this report. The first is the C/f combined for SM and GS purse seiners as given by Fonteneau and Cayre (1981). The second is an adjusted C/f measure incorporating both baitboat (BB) and purse seine (PS) data. The first will be called C/f-A and the second C/f-B.

In standardizing the effort (f) from one gear in terms of another, the ratio of the C/f's of the two is the power factor for conversion of effort (see Beverton and Holt, 1957). In terms of C/f, standardization to a measure based upon the standard unit of effort is effectively accomplished by multiplying the given C/f by the average ratio of the standard C/f to the given C/f. This is the method used by Coan (1980) and is used here to develop C/f-B, a measure based upon C/f's from BB's, SM's, and GS's. The procedure for obtaining C/f-B is as follows:

1. Standardize the BB C/f to SM effort units (given in PS-3 units), using the mean (=1.918) of the SM/BB C/f ratios, 1969-80 (excluding anomalous 1969, 1974 and 1980 data pairs whose ratios were $\geq$ 2 standard deviations from the average ratio treated as a regression through the origin). See Table 1, column 7. The geometric mean is used to obtain the most typical value from ratios that tend not to be normally distributed.

2. Adjust the SM standardized BB C/f in (1) to an area weighted measure, using the geometric mean (=.639) of the SM (area weighted)/SM (effort weighted) C/f ratios (column 1/column 5), 1969-80 (excluding the anomalous 1969, 1974 and 1980 data pairs). See Table 1, column 8.

3. Obtain BBSM, the mean of the area-weighted BB and SM C/f's (columns 8, 1), weighted by the respective coastal catches given in Fonteneau and Cayre (1981). This is in PS-3 units and is area weighted. See Table 1, column 9.

4. Standardize the BBSM index (column 9) to GS units (given in PS-5 units), using the geometric mean of GS/BBSM ratios as follows:

1969-74	GS/BBSM=2.703
1975-80	GS/BBSM=1.607

This two step ratio was calculated because of the distinct change in the ratios after 1974, due to the influx of large seiners. The anomalous 1971 and 1980 ratios were not used as they exceed the 95% confidence interval of the mean ratio of each time grouping, treated as regressions through the origin. See Table 1, column 10.

5. Obtain C/f-B (column 11) the mean of the BBSM C/f (column 10) and GS C/f (column 2), weighting by the respective catches as given in Fonteneau and Cayre (1981). This measure is in PS-5 effort units. The difference between C/f-A (column 3) and C/f-B (column 11) is that the latter includes the BB C/f data and also incorporates a 2-step adjustment involving the GS/BBSM ratios.

Catches

Catch data were taken from the ICCAT Report A (ICCAT, 1981). These data are tabulated according to eastern Atlantic surface (BB + PS) catches, eastern Atlantic surface + longline (LL) catches, and total Atlantic catches (Table 2). The projected 1981 catches from Report A were used to generate ratios to partition the preliminary 1981 catches (ICCAT, 1982) into gear and ocean area subtotals.

Effective Fishing Effort (f)

Effective fishing effort is obtained by dividing total catch by the appropriate C/f measure. The C/f must reflect the abundance of the stock generating the catch and the porportionality factor should be constant so that the measure is consistent. Both C/f-A and C/f-B are developed from the eastern Atlantic surface fishery, and so are considered here as applicable to the combined surface (BB + PS) catches there. This same applicability is assumed for the surface + LL catch, since the stock supplying the LL catch must to a large extent be the older age groups of the same surface fishery stock. Effective fishing effort for the eastern Atlantic surface and the eastern Atlantic surface + LL catch are given in columns 2-3 and 5-6 of Table 2. It is unlikely that the eastern Atlantic C/f accurately reflects changes in the western Atlantic stock. The western Atlantic YF catch is small (~10%) relative to the eastern Atlantic catch, and only recently has the fishery there been experiencing increased development. Therefore it is assumed here that the effective effort associated with any given western Atlantic catch is the same as the effort in the eastern Atlantic when the catch there was the same as the given western Atlantic catch. This was accomplished as follows:

1. The relationship between C/f-A or C/f-B to effective fishing effort in the eastern Atlantic is approximately a negative exponential. To obtain a stable regression relationship, given the uncertainty in the data, the functional, rather than the predictive, regression (Ricker 1973) was used. For the 1970-80 data these were:

$$\ln(C/f\text{-}A) = 1.377 - .012f \ , \ r^2 = 0.800$$
$$\ln(C/f\text{-}B) = 1.690 \quad .018f \ , \ r^2 = 0.956$$

This relationship from the eastern Atlantic surface + LL fishery defines the catch-effort relationship, which was solved iteratively to predict the f corresponding to any given western Atlantic catch.

2. Total Atlantic catches and effort were obtained by adding the eastern and western Atlantic catches and the eastern and western Atlantic effort (Table 2, columns 7-9).

Production Model Analysis

Production model, yield curves were fitted to the 1970-80 catch-effort data from the eastern Atlantic BB + PS fishery, the eastern Atlantic surface + LL fishery, and the total Atlantic fishery. In each case both c/f-A and c/f-B were applied. The fitting procedure was that of Fox (1975). For each case curves with shape parameters m=0, 1 and 2 were used. A weighted average effort over 3 years was computed to approximate equilibrium conditions (Gulland, 1969; Fox, 1975).

RESULTS

The production model analyses of the Atlantic YF fishery (Figures 1-3 for the C/f-A cases) indicate that maximum sustainable yield for surface and longline YF is at least 110,000 mt for the eastern Atlantic and 120,000 mt for the entire Atlantic (see Table 3). These are the approximate values estimated by the m=1 or 2 models using either C/f-A or C/f-B, and may be minimal since better curve fits are actually obtained with the m=0, asymptotic model. The latter would be preferred from the purely statistical point of view. The degree of fit index, here labeled r^2, varied between 83% and 94%, depending upon the model and C/f vector used.

The 1981 effort (estimated using the average 1975-80 ratio of effort to purse seine catch) was near to but below f-opt according to the m=1 model and using C/f-A. The same model using C/f-B, however, indicates overfishing with respect to MSY, with the observed catches being substantially farther above equilibrium.

DISCUSSION

Atlantic YF catches have been increasing but slowly over the last 5 years. This can be considered the major emperical evidence supporting conclusions that the fishery is operating near the MSY level. Catches dropped 1.4% in 1979 and 8.3% between 1979 and 1980, the first declines since 1971. Disregarding these declines, the average rate of increase in catches since 1976 was only 3.3%.

There is no evidence through 1981 that any sustained decrease in catch with increasing effort has begun. Unless a large expansion of the fishery (e.g. offshore) occurs, the MSY level should be near the present catch levels. The 1981 catch, 138,524 mt, increased 14.9% over 1980. This increase was due primarily to Spanish catches which increased 52% from 1980 to 1981.

The main difficulty in production model analyses is in determining a representative measure of effort. Using C/f-B instead of C/f-A (see Table 3), the fishery would appear to be operating beyond f-opt, with present catches substantially above MSY (cf Table 2). This is because C/f-B indicates a stronger decline in relative stock size. However, C/f-B is probably less reliable than C/f-A, since it is derived through a series of conversions of gear specific C/f's (see Table 1 and Methods). These conversions merely adjust all the specific C/f's to the same scale as the standard and do not necessarily increase the information or increase the sample size for the measurement of effort.

As in most fisheries, there is insufficient information in the catch and effort data to determine the correct shape of the yield curve. The relationship of catch as a function of effort is formed variously by the pattern of expansion relative to the areal distribution of the fishery, the choice of the c/f vector, the stage of development of the fishery, and by the biology of the stock. Therefore population-exploitation parameters inferred from production model analyses must be viewed with great caution. In the present situation the YF catches do not yet show a persistent decline, even though the production models, using C/f-B, consistently indicates f-opt has been surpassed (Table 3). The catch-effort data contain little information about the ultimate shape of the yield curve, and presently the curve with least curvature (m=0) fits best.

Nevertheless there is increasing indirect evidence that the production model with m=1 is more appropriate for most fish populations. Ricker (1975) has given a number of reasons why C/f should decline approximately exponentially with effort, corresponding to the m=1 or Gompertz model (Fox, 1970). Notice that negative exponential curves fit the 1970-80 YF data convincingly with r^2 values of 0.800 and 0.956 (see above). It should also be noted that the "fishing up" effect should be strongest in the early phases of a fishery when older age groups are relatively most abundant. Thus, initial high C/f's would contribute to a curvilinear relationship. This effect may explain some features of the C/f trends, especially in the longline data (see Honma, 1981). Finally ecological concepts regarding the r-K continuum of population strategies (e.g. Southwood, et al., 1974) suggests asymmetrical yield curves for most fish, with greatest production at lower population levels. Garrod and Knights (1979) examined the influence of life history characteristics on the productivity of different fish groups and concluded that fast growing pelagics tended to have the largest degree of asymmetry from the logistic production curve, i.e. toward curves with $m < 2$. Adams (1980) similarly found correspondence between life history patterns and the different forms of the yield models. Incrementally speaking, YF yield curves should more closely resemble the $m=1$ than the $m=2$ or $m=0$ curves (the latter does not admit the possibility of recruitment failure). The above arguments hold for situations where C/f is a consistent index of population size. Otherwise, as in the case of conspicuous, aggregated species, the data might lead to overestimates of population size and eventually to yield curves with $m >> 2$ (see May et al., 1979).

The $m=1$ production model suggests that the Atlantic wide YF fishery should produce an equilibrium MS^{Y} catch of at least 120,000 mt. A conservative upper bound might be 150,000 mt. These values are very similar to the estimates of Coan (1980) and Fonteneau and Cayre (1981). It can be shown, using a Monte Carlo procedure fitting the $m=1$ model to the eastern Atlantic data, that with uniformly distributed errors up to 5% in catch and effort measurements, the coefficient of variation for MSY is only 2.9% (Table 4), primarily due to errors in catch. However, MSY estimates have historically increased with expansion of the fishery (see Coan, 1980) and should be viewed in that context. Moreover MSY as a management objective must be tempered with consideration of the possibility that the population can become increasingly unstable as it is reduced, even before the level giving MSY is surpassed (Beddington and May, 1977).

Summarizing, it appears that the Atlantic YF fishery is presently at the mature stage of development, with catches increasingly being maintained by large increases in fishing efficiency, as indicated by the increasing importance of large purse seiners. Catches are near but probably have not surpassed MSY (at equilibrium). The C/f index for the eastern Atlantic appears to be between 1/2 and 1/3 of the initial, unfished level, depending upon the equation describing C/f-A or C/f-B respectively (described under Methods-effective fishing effort). Using an M/K ratio (natural mortality/von Bertalanffy parameter) of 1.90 and c (fraction of asymptotic length at recruitment) = 0.28 (see Lenarz et al. 1974), this corresponds to exploitation rates of 30-42% by the Beverton-Holt model (Beverton and Holt, 1964). Finally the $m=1$ model predicts, using C/f-A, an increase in equilibrium catch of only 0.4% for either a 10% or 20% increase in effort in the eastern Atlantic, and a 0% and -0.8% change in catch for the same percent effort increases over the total Atlantic.

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Table 1. Catch per unit effort (C/f).

Year	C/f (new)[1] SM	GS	SMGS	C/f (old)[2] BB	SM	GS	C/f (adjusted) St.BB-E[3]	St.BB-A[4]	BBSM[5]	St.BBSM[6]	MSGS[7]
1969	2.99	7.60	6.17	1.52	3.78	7.93	2.915	1.863	2.359	6.376	6.489
1970	1.59	4.10	2.92	1.06	2.39	4.84	2.033	1.299	1.469	3.971	4.004
1971	1.37	2.32	2.30	1.20	2.41	3.39	2.302	1.471	1.408	3.806	3.477
1972	1.74	3.87	3.36	1.43	2.87	5.13	2.743	1.753	1.744	4.714	4.497
1973	1.19	3.97	2.71	1.20	2.50	6.02	2.302	1.471	1.268	3.427	3.620
1974	1.43	3.51	2.81	1.39	1.40	5.53	2.666	1.704	1.523	4.117	3.838
1975	1.18	2.03	1.96	0.88	1.97	4.32	1.688	1.079	1.153	1.926	1.995
1976	1.44	2.61	2.21	1.28	2.07	4.87	2.455	1.569	1.487	2.483	2.578
1977	1.30	2.34	2.40	1.25	2.04	5.05	2.398	1.532	1.403	2.343	2.341
1978	1.09	1.91	1.95	1.01	1.71	4.74	1.937	1.238	1.154	1.927	1.913
1979	1.53	1.86	1.75	0.85	1.58	4.39	1.630	1.042	1.217	2.032	1.878
1980	2.32	1.72	1.90	0.99	3.98	3.71	1.899	1.213	1.702	2.842	1.844

[1]Area weighted C/f for traditional coastal fishery from Fonteneau and Cayre (1981). SMGS is C/f-A.

[2]Effort weighted C/f for traditional coastal fishery from Fonteneau and Cayre (1981).

[3]Standardized effort-weighted BB C/f. St. BB-E=1.918xBB, where 1.918 is the geometric mean of SM(old)/BB C/f's. See text.

[4]Standardized area-weighted BB C/f. St. BB-A=.639 x St. BB-E, where .639 is the geometric mean of SM(new)/SM(old) C/f's. In PS-3 units. See text.

[5]Mean of St. BB-A and SM(new) C/f's weighted by respective catches from Fonteneau and Cayre (1981).

[6]Standardized BBSM C/f. St. BBSM=2.703xBBSM or 1.670xBBSM, where 2.703 and 1.670 are the geometric means of GS(new)/BBSM C/f's. In PS-5 units. See text.

[7]Mean of St. BBSM and GS(new) C/f's, weighted by respective catches from Fonteneau and Cayre (1981). In PS-5 units. This is C/f-B. See text.

Table 2. YF catches[1] (10^3mt) and effective effort (f in 10^3 days fished).

Year	E. Atlantic Sfc. Catch[2] BB+PS	Effort[3] f-A	f-B	E. Atlantic Sfc+LL Catch[4] Sfc+LL	Effort f-A	f-B	Total Atlantic Sfc+LL Catch Sfc+LL	Effort f-A	f-B
1969	61.0	9.89	9.40	82.1	13.31	12.65	91.4	15.71	14.45
1970	43.3	14.83	10.75	60.6	20.75	15.15	72.1	23.75	17.35
1971	43.0	18.70	12.36	56.6	24.61	16.26	70.1	28.21	18.86
1972	60.6	18.04	13.47	78.9	23.48	17.53	93.5	27.28	20.33
1973	59.2	21.84	16.35	78.4	28.93	21.66	93.1	32.73	24.46
1974	72.8	25.91	18.96	90.1	32.06	23.46	103.9	35.66	26.06
1975	92.7	47.30	46.35	106.3	54.24	53.15	122.5	58.64	56.35
1976	99.0	44.80	38.37	111.8	50.59	43.33	125.0	53.99	45.93
1977	98.6	41.08	42.14	114.2	47.58	48.80	126.6	50.78	51.20
1978	106.3	54.51	55.65	117.6	60.31	61.57	131.8	64.11	64.37
1979	109.5	62.57	58.24	116.4	66.51	61.92	122.4	69.91	64.32
1980	97.4	51.26	52.94	110.6	58.21	60.11	120.4	60.81	61.91
1981	112.0	57.16[5]	55.58[5]	121.1	64.18[6]	62.40[6]	133.5	67.38[7]	64.80[7]

[1]From SCRS 1981 Report A; for 1981, projected catches from Report A were used to estimate ratios to partition catches in Table 3 of ICCAT Newsletter 12(1) according to gear and ocean areas.

[2]BB+PS=Baitboat + Purse Seine catches

[3]f-A obtained by dividing catch by C/f-A; f-B obtained by dividing catch by C/f-B.

[4]Sfc=Surface (BB+PS) catch; LL=Longline catch

[5]Estimated from 1975-80 geometric mean ratio:

f-A(E. Atlantic Sfc.)/E. Atlantic PS catch = .556
f-B(E. Atlantic Sfc.)/E. Atlantic PS catch = .541

[6]Estimated from 1975-80 geometric ratio:

f-A(E. Atlantic Sfc+LL)/E. Atlantic PS catch = .624
f-B(E. Atlantic Sfc+LL)/E. Atlantic PS catch = .607

[7]Estimated from C/f vs. f relationship; total f is sum of E. and W. Atlantic f's. See text.

Table 3. Summary of production model analyses of 1970-80 Atlantic YF catch and effort data.

Area	c/f[1]	m[2]	r[23]	MSY(10^3mt)	f-opt (10^3Days fished)	f-1980/f-opt	f-1981/f-opt
1. E. Atlantic Surface (BB+PS)	A	0	0.85	175	-	-	-
		1	0.84	105	73.9	0.69	0.77
		2	0.83	101	56.6	0.91	1.01
	B	0	0.92	136	-	-	-
		1	0.90	98	51.4	1.03	1.08
		2	0.87	101	44.8	1.18	1.24
2. E. Atlantic Total (Surface +LL)	A	0	0.85	173	-	-	-
		1	0.85	113	72.3	0.81	0.89
		2	0.84	111	58.8	0.99	1.09
	B	0	0.93	141	-	-	-
		1	0.91	109	52.6	1.14	1.19
		2	0.88	114	47.8	1.26	1.31
3. Total Atlantic (Surface+LL)	A	0	0.87	179	-	-	-
		1	0.86	123	71.7	0.85	0.94
		2	0.86	122	59.8	1.02	1.13
	B	0	0.91	150	-	-	-
		1	0.93	120	52.8	1.17	1.23
		2	0.90	125	49.1	1.26	1.32

[1] f-A or f-B from c/f-A or c/f-B

[2] Shape parameter

[3] Degree of fit index

Table 4. Sensitivity analysis of production model[1] on eastern Atlantic surface and longline data.

	Percent[2] frequency with variations in:		
1. MSY (10^3mt)	Catch and effort	Catch only	Effort only
107	0.0	0.0	
108	7.2	7.5	
109	10.1	9.7	
110	7.6	8.4	
111	9.7	8.3	
112	7.1	9.0	
113	11.5	9.5	
114	7.2	7.0	0.0
115	9.4	9.2	93.6
116	8.7	10.3	6.4
117	8.7	7.9	0.0
118	8.1	8.2	
119	4.7	5.0	
120	0.0	0.0	
MSY Range	108-119	108-119	113-114
x	113.30	113.32	113.06
s^2	10.820	10.994	0.060
s/x	.029	.029	.002
2. f-opt (10^3 days fished)	Catch and effort	Catch only	Effort only
69		11.7	10.9
70		13.8	14.0
71	0.0	11.9	13.2
72	83.1	13.0	12.9
73	16.9	14.1	13.8
74	0.0	14.0	12.8
75		16.5	17.1
76		5.0	5.3
f-opt Range	72-73	69-76	69-76
x	72.17	72.37	72.38
s^2	.141	4.578	4.570
s/x	.005	.030	.030

[1] Monte Carlo process, fitting m=1 production model with ± 5% uniform distribution of errors.

[2] Of 1000 iterations of PRODFIT (Fox, 1975)

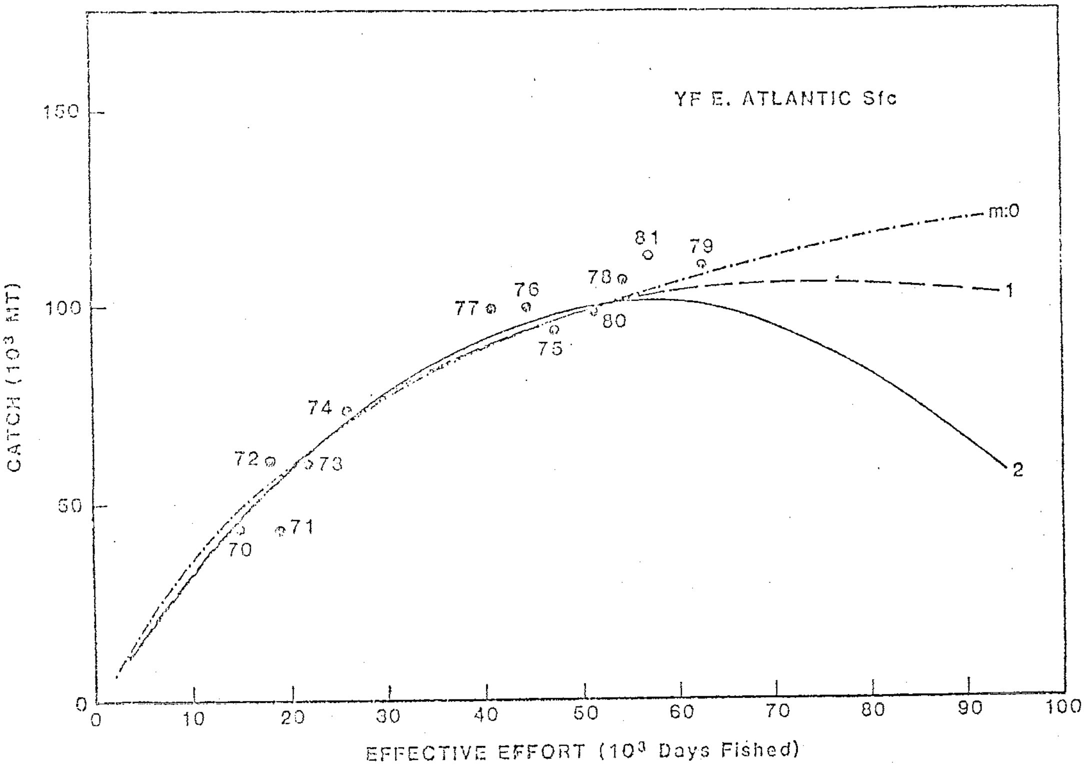

Figure 1. Yield-effort curve for the E. Atlantic YF surface (Sfc) fishery, using C/f-A. Purse seine and baitboat catches are included. The 1981 effort level is estimated. A 3-year weighted average of fishing effort is used in fitting the curve.

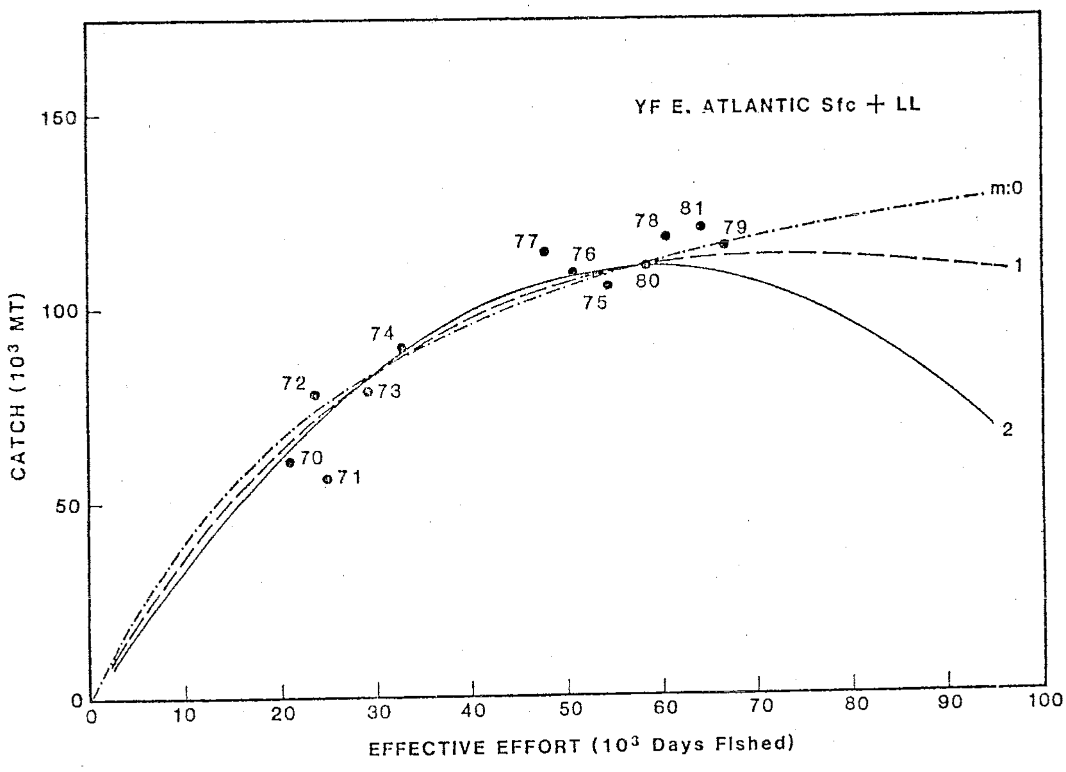

Figure 2. Yield-effort curve for the E. Atlantic YF surface (Sfc) + longline (LL) fishery, using C/f-A. The 1981 effort level is estimated. A 3-year weighted average of fishing effort is used in fitting the curve.

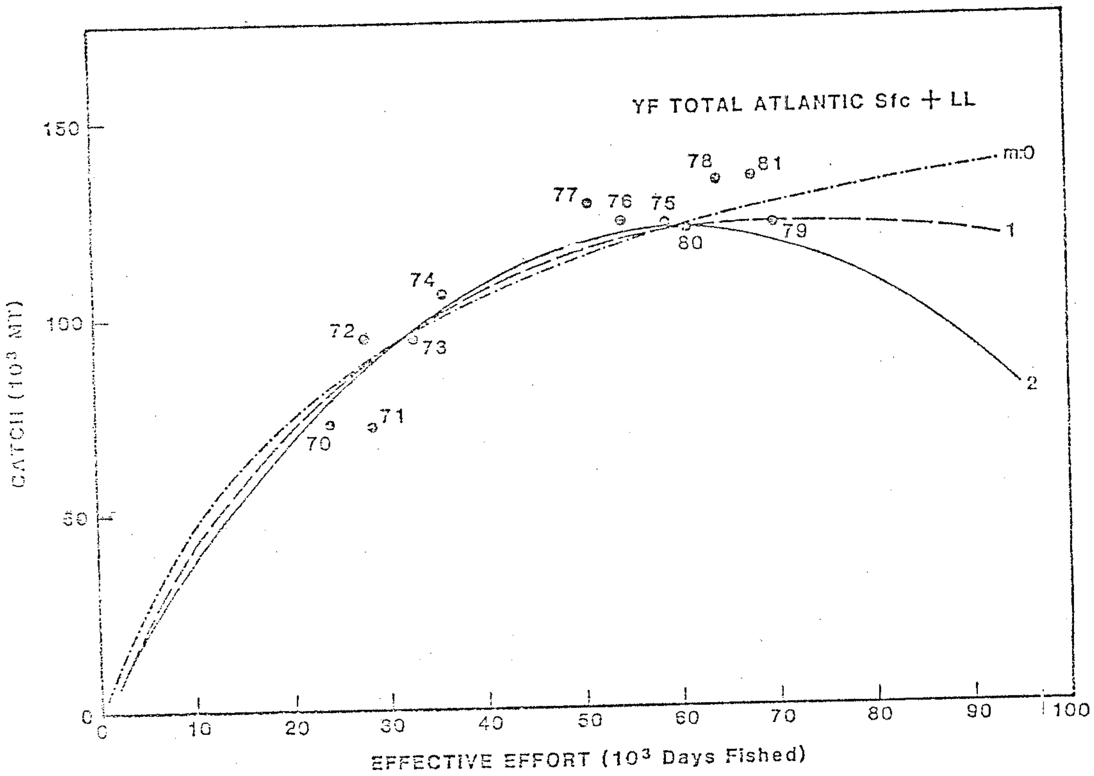

Figure 3. Yield-effort curve for the total Atlantic YF surface (Sfc) + longline (LL) fishery, using C/f-A. The 1981 effort level is estimated. A 3-year weighted average of fishing effort is used in fitting the curve.