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A PRODUCTION MODEL ANALYSIS OF THE STATUS OF ATLANTIC YELLOWFIN TUNA

by

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SUMMARY

The generalized stock production model was used to evaluate the status of Atlantic yellowfin tuna. Since the relationship between the surface and longline fisheries has not been determined, we first examined the surface fishery separately and then the two combined fisheries.

Our best current estimates of the sustainable average yield for the 1972 levels of fishing effort are 53,000 MT for the eastern Atlantic surface fishery alone or 79,000 MT for the total Atlantic yellowfin tuna fishery -- the estimated maximum sustainable average yields are 71,000 MT and 92,000 MT respectively.

While previously the best fitting production model indicated that overfishing could cause severe reductions in catch, the best fitting model of the present analysis, using revised data, predicts no decline in sustainable average catches at any increased level of fishing. Neither of these predictions beyond the range of data are believed by the authors to be biologically reasonable for Atlantic yellowfin tuna.

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RESUME

La situation de l'albacore dans l'Atlantique a été évaluée au moyen du modèle généralisé de production. Etant donné que la relation entre la pêcherie de surface et la palangre n'a pas encore été établie, nous avons tout d'abord examiné la pêcherie de surface seule, puis les deux pêcheries combinées.

Notre meilleure estimation actuelle du rendement moyen soutenu aux niveaux de 1972 de l'effort de pêche s'élève à 53.000 tonnes pour la pêcherie de surface de l'Atlantique Est seulement, ou à 79.000 tonnes pour la pêche de surface à l'albacore dans l'ensemble de l'Atlantique. Le rendement moyen maximal soutenu estimé s'élève dans chaque cas à 71.000 et 92.000 tonnes.

Alors que le modèle de production le plus précis indiquait auparavant qu'une exploitation excessive pourrait entraîner une baisse importante des prises, le modèle le plus précis de la présente analyse, basé sur des données révisées, ne prévoit pas de déclin des prises moyennes soutenues à aucun des niveaux accrus de la pêche. Les auteurs du présent rapport estiment qu'aucune de ces prévisions au-delà de l'éventail des données disponibles puisse raisonnablement s'appliquer à l'albacore de l'Atlantique du point de vue biologique.

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RESUMEN

Se utilizó el modelo de producción del stock generalizado para evaluar la situación del rabil Atlántico. Teniendo en cuenta que la relación entre las pesquerías de superficie y con palangre no ha sido determinada, hemos analizado primero, por separado, la pesquería de superficie y después, las pesquerías combinadas.

Nuestras estimaciones óptimas actuales del promedio de rendimiento sostenible para los niveles de pesca de 1972 son 53.000 toneladas solamente para la pesquería de superficie del Atlántico oriental y 79.000 toneladas para toda la pesquería de rabil Atlántico. Las estimaciones de promedios de rendimiento máximo sostenible son 71.000 y 92.000 toneladas respectivamente.

Anteriormente, el mejor modelo de producción indicaba que la sobrepesca podía causar unas reducciones agudas en la captura, y por el contrario, en el presente análisis que utiliza datos revisados, el mejor modelo predice que no habrá descenso en el promedio de capturas sostenibles con ningún aumento del nivel de pesca. Los autores opinan que ninguna de las predicciones que van más allá de los datos disponibles son razonables, desde el punto de vista biológico, para el rabil Atlántico.

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INTRODUCTION

Concern has been expressed over the status of the Atlantic yellowfin tuna since the surface fishery expanded in the late 1960's. The total Atlantic catch peaked in 1969, subsequently declining in 1970 and in 1971 (ICCAT, 1973). This concern has led to previous analyses of the status of the Atlantic yellowfin tuna (e.g., FAO, 1968; ICCAT, 1972; Fox and Lenarz, 1972), and proposals for establishing an overall quota for managing the resource. The most recent analysis (Fox and Lenarz, 1972) found that both the surface fishery and the total Atlantic fishery apparently had achieved a plateau in the catch of yellowfin tuna and concluded, as have previous analyses, that little or no increase in yellowfin catch, on the average, will occur under the present constitution of the fishery. However, there have been substantive changes in the data base and there has been an apparent record catch for 1972. This paper is an extension of our previous analysis in order to examine the impact of the data changes and to update the estimates of the production model parameters.

ANALYSIS

The production model approach to examining the status of fisheries represents an application of the Lotka-Volterra equations, with some modifications, to catch and fishing effort data. Since this type of analysis is crude compared with a truly biological analysis it is important to emphasize the implicit assumptions: (1) the population is closed or fortuitously behaves as if closed and (2) the concept of achieving equilibrium applies to the population. Additional assumptions about the fishery and the data are also needed: (1) the constitution of the fishery has remained constant (selectivity, and distribution, temporal distribution, and catchability) or changes have been adjusted for in the data series and (2) a sufficient time series of data exists covering several population levels.

The Model

We utilized the generalized stock production model (Pella and Tomlinson, 1969),

$$\frac{dP}{dt} = HP^{m} - KP - qfP \tag{1}$$

where P = population size, q = catchability coefficient, f = fishing effort standardized to be proportional to the instantaneous fishing mortality coefficient, and H, K, and m are parameters. At equilibrium we have

$$U^* = (a + bf)^{\frac{1}{m-1}} \qquad (2)$$

and

$$Y^* = f(a + bf)^{\frac{1}{m-1}} \qquad (3)$$

where U^* = equilibrium catch rate, Y^* = equilibrium yield and a, b, and m are parameters; i.e., a and b are recombinations of H, K, and q. Differentiating Y^* with respect to f in equation (3), the relationships of interest to management are obtained:

$$f_{opt} = a(\frac{1}{m} - 1)/b$$

$$U^*_{opt} = (a/m)^{\frac{1}{m-1}}$$

$$Y^*_{max} = f_{opt} \quad U^*_{opt}$$

where f_{opt} is the optimum fishing effort in the sense that Y^* is maximized, U^*_{opt} is the catch rate at the point where Y^* is maximized, and Y^*_{max} is the estimate of maximum sustainable average yield.

Equations (2) and (3) reduce to three simple models for $m \equiv 0$, $m \to 1$, and $m \equiv 2$. Equation (2) is a hyperbola for $m \equiv 0$, an exponential model for $m \to 1$, and a straight line for $m \equiv 2$. Equation (3) is a model asymptotic to the maximum sustainable average yield, Y^*_{max}, for $m \equiv 0$, a model dome-shaped curve which is asymptotic to zero for $m \to 1$, and a parabola for $m \equiv 2$. Since these three models generally bracket the likely responses of equilibrium yield, Y^*, to fishing effort, since the data are relatively insensitive to changing the estimate of m, and since there is likely a good deal of inaccuracy in the data, we confined our analysis to the three simple models.

As in our previous paper (Fox and Lenarz, 1972), we used computer program PRØDFIT (Fox, 1972) to fit the three models to the fishery data. One difference is that the program was modified to use a weighted average of fishing effort over the total number of years that a year class contributes significantly to the catch, A_n, rather than a simple average over the mean number of years, (see Appendix I).

The Data

The source of Atlantic yellowfin catch data, 1964-72, was ICCAT (1973, ST/TOTAL/73/2) with some modifications. By country these modifications are:

1. Brazil -
   (a) 1964-71 multiplied by 3/7 due to species mix assumed the same as for 1971.
   (b) 1972 estimated as the average for 1967-71.
2. Canada -
   1972 estimated as 0.0.
3. Taiwan -
   (a) 1964-71 multiplied by 1.15 for round weight.
   (b) 1972 estimated as continuation of the trend 1969-71.
4. Cuba -
   (a) 1964 multiplied by 0.8 due to the species mix assumed the same as for 1965.
   (b) 1972 estimated as the average of 1967-71.

5. Korea - 1964-72 multiplied by 1.15 for round weight.

6. Norway - 1972 estimated at 0.5 (Fonteneau, pers. comm.)

7. United States - Update of the preliminary statistics; 1971 = 4.4, 1972 = 12.0.

8. Venezuela - (a) 1964-67 multiplied by 0.62 for species mix assumed the same as the average 1968-71.
   (b) 1972 estimated the same as the average for 1967-71.

The catch was subdivided into an estimate of the eastern Atlantic surface fishery alone by the addition of the South African catch for 1964 to the "total surface" line in ICCAT (1973, ST/TOTAL/73/2) and similarly subtracting the catch of French vessels from the western Atlantic in 1972 (Fonteneau,[1] pers. comm.) and the estimated Brazilian catch in 1972 from the estimated total surface catch for 1972.

For the surface fishery, two series of catch per unit effort data were available to us. The first, Series I, was an extension of the catch rates we used previously and obtained from ICCAT (1972, Table 5) for 1964-71, and from Pianet (1973) and Fonteneau (pers. comm.) for 1972. The second set, Series II, was obtained from A. Fonteneau (pers. comm.). Series I is calculated from several gear types from several major areas as follows:

1. The catch rates of each gear type in each area were normalized by dividing its entire series by its 1969-71 average catch rate.

2. The normalized catch rates were averaged over gear types within each area.

3. The area averages were then averaged within years to obtain density indices for the eastern Atlantic surface fishery.

Series II data were not available by area, but were separated into large and small baitboats, and small purse seiners while Series I data were not. The Series II catch rates were calculated as follows:

1. The small and large baitboat catch rates were adjusted by multiplying them by the ratio of the small purse seiner 1964-72 mean catch rate to the mean of each of the baitboat catch rate sets.

2. The three sets were combined as an average weighted by the size of their respective year by year catches.

Table 1 gives the estimated eastern Atlantic surface yellowfin catch and both series of catch rates with their corresponding effective fishing effort data, 1964-72. Both series were used in subsequent analyses.

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Table 1.--Catch, catch rate, and effective effort data for the eastern Atlantic yellowfin tuna surface fishery, 1964-1972

Year	Catch[1] (10^3 metric tons) Y	Catch Rate I[2] U^{I}	Effective Effort I f^{I}	Catch Rate II[3] U^{II}	Effective Effort II f^{II}
1964	25.8	0.191	135.1	3.06	8.43
1965	26.8	0.147	182.3	2.51	10.68
1966	37.7	0.180	209.4	3.04	12.40
1967	36.4	0.136	267.6	3.41	10.67
1968	54.6	0.161	339.1	3.56	15.34
1969	61.6	0.125	492.8	2.68	22.99
1970	44.7	0.084	532.1	1.86	24.03
1971	43.7	0.085	514.1	1.78	24.55
1972	64.7	0.109	593.6	2.26	28.63

[1] ICCAT (1973) with modifications as noted in text.

[2] ICCAT (1972, Table 5), 1964-71; 1972 from Pianet (1973) and Fonteneau (pers. comm.)

[3] Fonteneau (pers. comm.).

The estimated total Atlantic longline yellowfin catch, catch rate, and effective fishing effort, 1964-72, are given in Table 2. The catch rate in terms of weight was estimated by multiplying the catch rate in numbers from ICCAT (1972, Table 5) by the average weight of yellowfin estimated from the reported Japanese catch in weight from ICCAT (1973, ST/TOTAL/73/2) and the reported Japanese catch in numbers (Fisheries Agency of Japan, 1967a, 1967b, 1968, 1969, 1970, 1971, 1972, 1973).

The estimated total Atlantic yellowfin combined surface and longline catch, catch rate, and effective fishing effort, 1964-72, are given in Table 3. Series I catch rates were obtained by normalizing the longline catch rates with the 1969-71 average and then averaging them with the Series I surface catch rates weighted by the size of their catch. The Series II catch rates were obtained by normalizing both the longline and the Series II surface catch rates by their 1964-71 average and then averaging both sets weighted by the size of their catch. The rationale behind averaging the surface and longline catch rates is that the overlap in their exploited age groups is considerable (Figure 1), the resultant tends to dampen out year class fluctuations, and the indices are highly correlated (Figures 2 and 3). The correlation with the longline catch rates is greater for surface Series II (r = 0.951) than for surface Series I (r = 0.889). As stated before, both series were utilized in the following analyses.

Table 2.--Catch, catch rate, and effective effort data for the total Atlantic yellowfin tuna longline fishery, 1964-72

Year	Catch[1] (10^3 metric tons) Y	Catch[2] rate (numbers per 100 hooks) U	Average[3] Yellowfin weight (kg) $\overline{W}$	Catch rate (kg per 100 hooks) U	Effective effort (10^6 hooks) f
1964	37.4	0.90	39.93	35.94	1.041
1965	38.8	0.76	39.48	30.00	1.293
1966	25.3	0.69	55.95	38.61	0.655
1967	19.7	1.01	34.97	35.32	0.558
1968	27.2	0.82	50.73	41.60	0.653
1969	30.5	0.72	40.58	29.22	1.044
1970	31.1	0.51	35.11	17.91	1.736
1971	30.6	0.57	37.67	21.47	1.425
1972	26.8	--	--	--	--

[1] ICCAT (1973) with modifications as noted in text.

[2] ICCAT (1972, Table 4).

[3] Total weight of Japanese longline yellowfin catch from ICCAT (1973) divided by reported numbers of yellowfin caught (Fisheries Agency of Japan, 1967a, 1967b, 1968, 1969, 1970, 1971, 1972, 1973.

Table 3.--Catch, catch rate, and effective effort data for the combined total surface and longline Atlantic yellowfin tuna fishery, 1964-72

Year	Catch[1] (10^3 metric tons) Y	Catch rate I[2] U^{I}	Effective effort I f^{I}	Catch rate II[3] U^{II}	Effective effort II f^{II}
1964	63.8	0.171	373.1	0.1137	561.1
1965	65.9	0.138	477.5	0.0942	699.6
1966	63.2	0.176	359.1	0.1161	544.4
1967	56.4	0.142	397.2	0.1205	468.0
1968	82.0	0.168	488.1	0.1310	626.0
1969	92.4	0.126	733.3	0.0964	958.5
1970	76.1	0.082	928.0	0.0636	1196.5
1971	74.6	0.089	838.2	0.0665	1121.8
1972	94.5	0.109[4]	867.0	0.0826[4]	1144.1

[1] ICCAT (1973) with modifications as noted in text.

[2] Average of surface and standardized longline catch rates weighted by catch. Surface catch rate from series I.

[3] Average of standardized surface and longline catch rates weighted by catch. Surface catch rate from series II.

[4] Surface catch rate alone.

The Results

The three production models were fitted separately to the data of the eastern Atlantic surface fishery (Table 1) and to the data of the Atlantic fishery as a whole (Table 3) using a range of values for the number of year classes contributing significantly to the catch, A_n, i.e., 1-5 years. Unfortunately, the data for the longline fishery were not available separated between the western and eastern Atlantic for the entire series of years. The most cogent analysis would involve the eastern Atlantic combined longline and surface fishery data. Separated catch data were available for the Japanese longline fishery, 1965-70 (Honma, 1972); but the assumptions necessary to arrive at estimates including the Korean and Taiwanese fleets and the recent years (1971-72) would lead to crude data and, with the lack of separated effort data, would provide an essentially meaningless analysis.

Eastern Atlantic surface fishery.--Nearly 87% of the surface catch consists of 3 year classes, ages 1-3 (Table 4). Therefore, the production model fitted with $A_n = 3$ was selected to represent the best parameter estimates. The sensitivity of this assumption was also examined.

Table 5 gives the results for the three production models for each of the two series of catch rates. Examination of the residual sum of squares[2/] indicates that the Series II catch rates yielded slightly better fits for each of the three models. Within both catch rate series the asymptotic model ($m \equiv 0$) provided the best fit to the data. The asymptotic model resulted in an 11% reduction in the sum of squares over assuming the logistic, or Schaefer, model ($m \equiv 2$) for Series II. The data, along with the three equilibrium models are plotted in Figure 4 for Series II.

At the 1972 level of fishing effort the asymptotic model predicts a sustainable average yield, Y^*_{1972} of 53,000 metric tons (MT), 21% less than the 1972 catch - the maximum sustainable average yield of 71,000 MT, of course, occurs at infinite fishing effort (Table 5). Y^*_{max} for the logistic and exponential models is estimated to be in the vicinity of 52,000 metric tons (MT) at 19 and 4%, respectively, lower fishing effort than was generated in 1972 - their predicted sustainable average yield for the 1972 level of effort is 50-52,000 MT, very near their respective Y^*_{max} estimates. Figure 5 indicates that for $A_n \geq 3$, the estimates of Y^*_{max} tend to stabilize, more so for $m \equiv 2$ and $m \rightarrow 1$. The Y^*_{1972} for the asymptotic mode ($m \equiv 0$) - not plotted in Figure 5 - are nearly identical to the Y^*_{max} for the other two models at each of the assumed number of year classes, A_n (Figure 5).

Total Atlantic fishery.--The longline fishery also consists mainly of 3 year classes, 97%, but 1 year greater (ages 2-4) than the surface fishery (Table 4). Therefore, $A_n = 4$ was selected to represent the best parameter estimates.

[2/] The error terms are weighted by the square of their expected catch rates, so the sums are reasonably comparable.

Table 4.--Average age composition by weight of yellowfin tuna caught by gear-type in the tropical Atlantic Ocean, 1967-71[1]

Age	Surface gear			Longline gear		
	Weight (10^3 metric tons)	Rank	Cumulative % by rank	Weight (10^3 metric tons)	Rank	Cumulative % by rank
1	12.49	2	63.0	0.26	5	100.0
2	15.45	1	34.8	7.19	2	75.5
3	10.50	3	86.7	13.24	1	48.9
4	4.80	4	97.5	5.75	3	96.8
5	0.90	5	99.5	0.60	4	99.0
6	0.20	6	100.0	0.01	6	100.0

[1] Calculated from Lenarz et al. (1972, Table 2)

Table 5.--Production model parameter estimates for the eastern Atlantic Ocean yellowfin tuna surface fishery, 1964-72. Assuming three age groups contribute significantly to the catch ($A_n = 3$)

m	Y^*_{max} (10^3 metric tons)	f_{opt}	U_{opt}	q ($\times 10^{-3}$)	F_{opt}	F_{1972}/F_{opt}	Y^*_{1972}	Y_{1972}/Y^*_{1972}	Sum of squares
Catch Rate Series I									
2	52.1	508	0.103	0.55	0.28	1.17	50.6	1.28	0.1373
1	52.1	601	0.087	0.79	0.47	0.99	52.1	1.24	0.1280
0[1]	75.6	∞	0	0.76	∞	0	53.9	1.20	0.1263
Catch Rate Series II									
2	52.0	24.0	2.16	19.1	0.46	1.19	50.1	1.29	0.1242
1	51.6	27.6	1.87	25.7	0.71	1.04	51.6	1.25	0.1140
0[1]	70.8	∞	0	28.0	∞	0	53.3	1.21	0.1108

[1] Minimum sum of squares

The results of the three production model fits to the two series of catch rates are given in Table 6. As with the eastern Atlantic surface fishery, the best model (i.e., least sum of squares) is the asymptotic model ($m \equiv 0$) - the reduction in sum of squares for the Series II catch rates over assuming the logistic model ($m \equiv 2$) is a substantial 25%. As before, the best fit to two of the three models is obtained with the Series II catch rates. Figure 6 illustrates the Series II data series and the estimated equilibrium relationships.

At the 1972 level of fishing effort, the asymptotic model ($m \equiv 0$) predicts a sustainable average yield, Y^*_{1972}, of 79,000 MT, 20% less than the 1972 catch - the estimated maximum sustainable average yield of 92,000 MT, of course, occurs at infinite fishing effort (Table 6). Y^*_{max} for the logistic and exponential models is estimated to be in the vicinity of 80,000 MT at 15% and 8%, respectively, lower fishing effort than generated in 1972 - their Y^*_{1972} are about 79,000 MT. Figure 7 indicates that, as with the eastern Atlantic surface data, Y* for $m \equiv 2$ and $m \rightarrow 1$ is largely independent of A_n - this is similarly true for Y^*_{1972} of the asymptotic model.

DISCUSSION

The best current estimates of the sustainable average yield for the 1972 levels of fishing effort are 53,000 MT for the eastern Atlantic surface fishery alone and 79,000 MT for the total Atlantic yellowfin tuna fishery - the estimated maximum sustainable average yields are 71,000 MT and 92,000 MT, respectively. These current estimates are greater than those estimated from the data last year (Fox and Lenarz, 1972). More importantly, however, the model of best fit has changed radically from one which predicts severely reduced sustainable average catches with "overfishing" (i.e., $m > 3$) to one which predicts no decline in sustainable average catches at any increased level of fishing (i.e., $m \equiv 0$). Neither of these two extremes are believed by the authors to be biologically reasonable for Atlantic yellowfin tuna (the former likely to be feasible if fishing immature individuals with density independent growth and mortality and directly density dependent reproductive success and the latter likely to be feasible if fishing mature individuals with inversely density dependent growth and directly density dependent mortality and largely density independent reproductive success as measured by recruitment).

Fitting the data of the eastern Atlantic surface fishery alone to the production models implicitly assumes that either (1) the longline and surface fisheries are wholly independent, or (2) the effective fishing effort of the longline fishery has remained constant in quantity and in selectivity over the period of analysis (1964-72). The first assumption seems unlikely to be valid from the examination of Figures 1-3. The degree of validity of the second assumption is not known. Table 2 indicates that the effective longline fishing effort for the whole Atlantic substantially decreased in 1964-67, then increased to a peak in 1970, and decreased again in 1971. However, it is not known at present whether this recent increase in effective effort is due, for the most part, to increased fishing in the western Atlantic or to simultaneously increased fishing activity throughout the Atlantic.

Table 6.--Production model parameter estimates for the total Atlantic Ocean yellowfin tuna fishery, 1964-1972. Assuming four age groups contribute significantly to the catch ($A_n = 4$).

m	Y^*_{max} (10^3 metric tons)	f_{opt}	U_{opt}	q ($\times 10^{-3}$)	F_{opt}	F_{1972}/F_{opt}	Y^*_{1972} (10^3 metric tons)	Y_{1972}/Y^*_{1972}	Sum of squares
Catch Rate Series I									
2	80.3	802	0.100	1.01	0.81	1.07	79.8	1.18	0.1277
1	79.8	912	0.088	0.88	0.80	0.95	79.6	1.18	0.1170
0[1/]	104.9	∞	0	1.01	∞	0	79.9	1.18	0.1091
Catch Rate Series II									
2	80.8	990	0.082	1.18	1.16	1.15	79.0	1.19	0.1342
1	78.8	1055	0.075	1.49	1.57	1.08	78.5	1.20	0.1163
0[1/]	92.2	∞	0	1.20	∞	0	78.6	1.20	0.1006

[1/] Minimum sum of squares.

Fitting the data of the total Atlantic fishery for yellowfin tuna combined implicitly assumes either that (1) there is one population throughout the Atlantic or (2) effort is spread across several populations and that the relative amount of effort among populations has remained reasonably constant. The first assumption seems unreasonable from historical experience of the Japanese longline fishery (e.g. Wise and Le Guen, 1969), and from the general belief of scientists that there are at least eastern and western stocks of yellowfin tuna in the Atlantic. The second assumption may not be fulfilled as development of surface fishing has occurred nearly exclusively in the eastern Atlantic. The longline geographic emphasis may have shifted, although this is speculation at this point.

As indicated in an earlier statement in this paper, it is unfortunate that the longline catch and effort is not presently available separated into eastern and western components as outlined by Honma (1972). Every effort should be made such that the data will be available in this manner for a more cogent analysis.

CONCLUSIONS

It is apparent that the Atlantic yellowfin tuna fishery is approaching or has attained a plateau where substantially increased sustainable average yield of yellowfin tuna will not be obtained by increasing fishing effort without some concomitant change in the constitution of the fishery (i.e., selectivity by age, spatial or temporal distribution of fishing effort). It is also apparent that the extreme concern previously expressed for Atlantic yellowfin tuna due to declining catches and catch rates no longer has valid bases, i.e. (1) the 1971 catch has been revised upward to nearly the 1970 level due primarily to a revision of the Japanese longline catch (Tables 1 and 3), (2) the 1972 catch was a record for the history of the fishery (Tables 1 and 3), and (3) the catch rate series indicate an increase in apparent abundance in 1970-72 (Tables 1 and 3).

From what is presently known of the 1973 season - (1) the 1973 American fleet, at one-half of its 1972 size, has shifted to fishing largely for skipjack in areas which historically have produced little yellowfin, hence resulting in a decrease in effort on yellowfin, and (2) it is reported that the 1973 French-Ivory Coast-Senegalese fleet has been doing nearly as well as in 1972 for yellowfin tuna (La Pêche Maritime, 1973; Fonteneau, pers. comm.) - it is concluded that the status of the Atlantic yellowfin tuna remains good This conclusion, however, should not defer expedient seeking, evaluation, and embodiment of an effective management system under the auspices of ICCAT such that when it becomes necessary to implement regulatory measures, ICCAT will be able to act in a timely and precise fashion.

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APPENDIX I

The averaged fishing effort for fitting the production models was weighted by the number of year classes that the fishing effort directly affected in a given year. For example with

$$A_n = 3$$

$$\bar{f}_i = \frac{3f_i + 2f_{i-1} + f_{i-2}}{6}$$

and with

$$A_n = 4$$

$$\bar{f}_i = \frac{4f_i + 3f_{i-1} + 2f_{i-2} + f_{i-3}}{10}$$

FIGURES

Figure 1. Average age composition of the Atlantic yellowfin tuna catch by surface and longline gear, 1967-71 (Lenarz et al., 1972, Table 2).

Figure 2. Correlation between the surface catch rate Series I and the longline catch rate, 1964-71. 1972 not included (open circle).

Figure 3. Correlation between the surface catch rate Series II and the longline catch rate, 1964-71. 1972 not included (open circle).

Figure 4. Eastern Atlantic yellowfin surface fishery curves of sustainable average yield for three production models and the empirical data, 1964-72.

Figure 5. Relationship between the estimate of maximum sustainable average yield, Y^*_{max}, and the assumed number of year classes, A_n, of three production models for the eastern Atlantic yellowfin surface fishery. The arrow indicates the A_n selected as providing the best parameter estimates.

Figure 6. Total Atlantic yellowfin tuna fishery curves of sustainable average yield for three production models and the empirical data, 1964-72.

Figure 7. Relationship between the estimate of maximum sustainable average yield, Y^*_{max}, and the assumed number of year classes, A_n, of three production models for the total Atlantic yellowfin tuna fishery. The arrow indicates the A_n selected as providing the best parameter estimates.

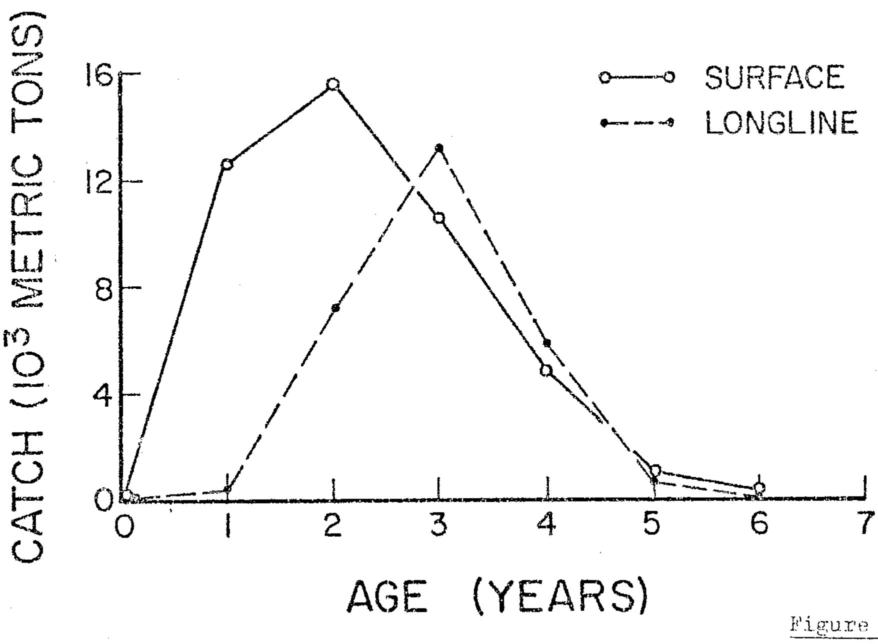

Figure 1

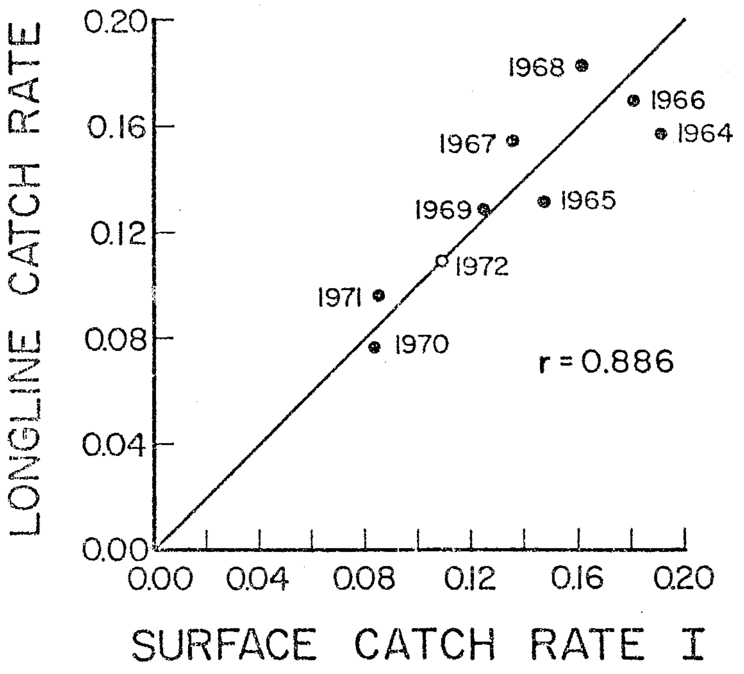

Figure 2

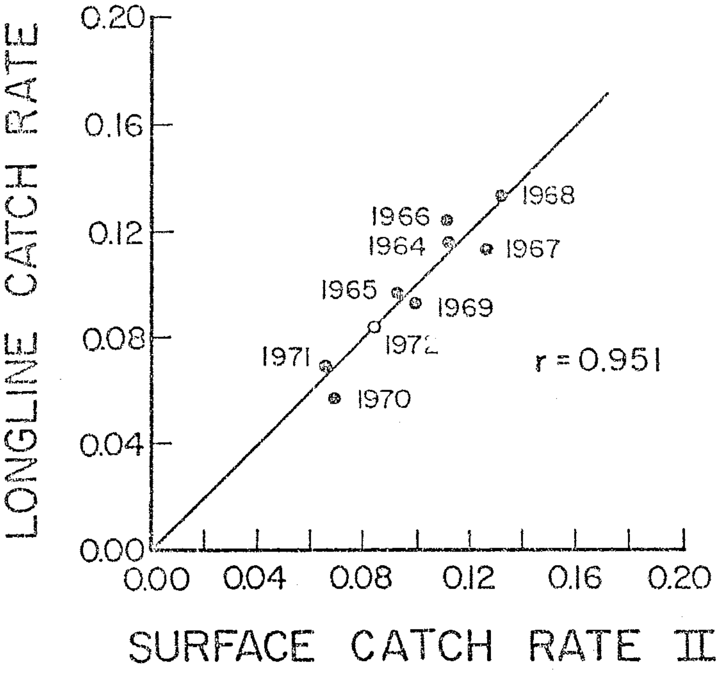

Figure 3

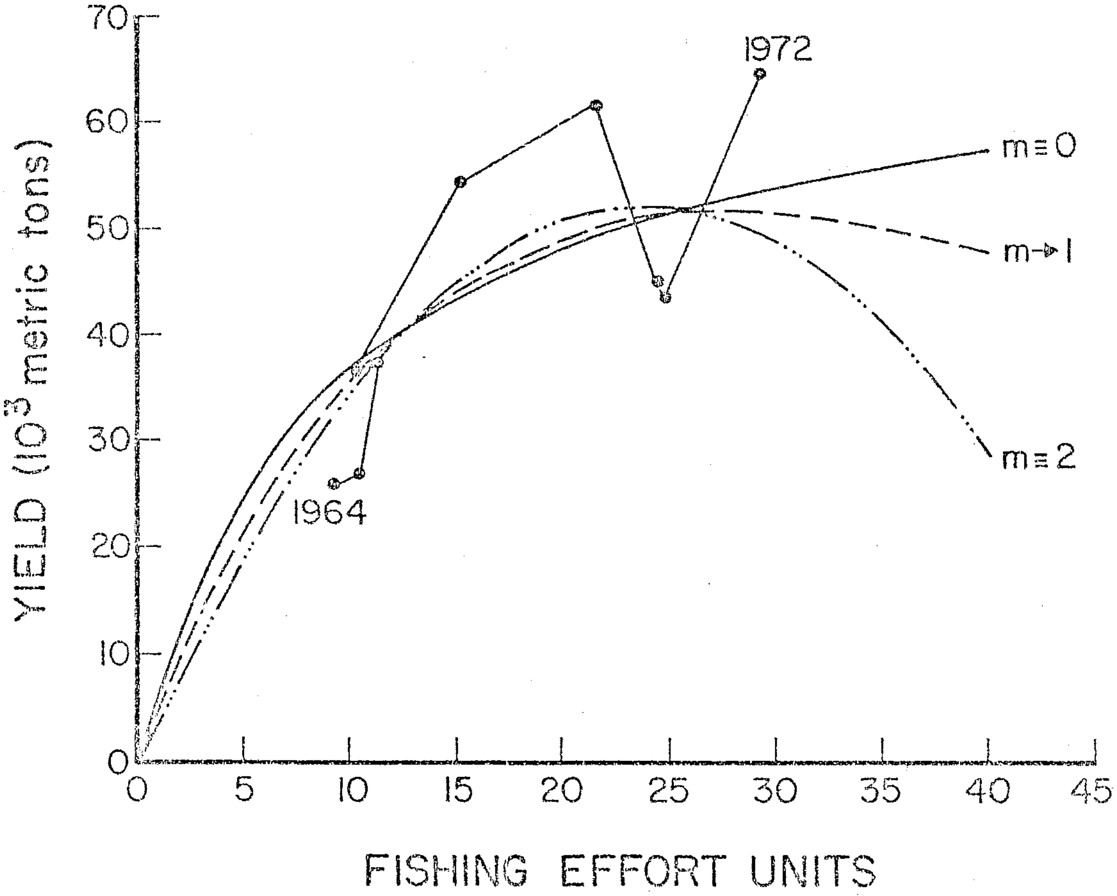

Figure 4

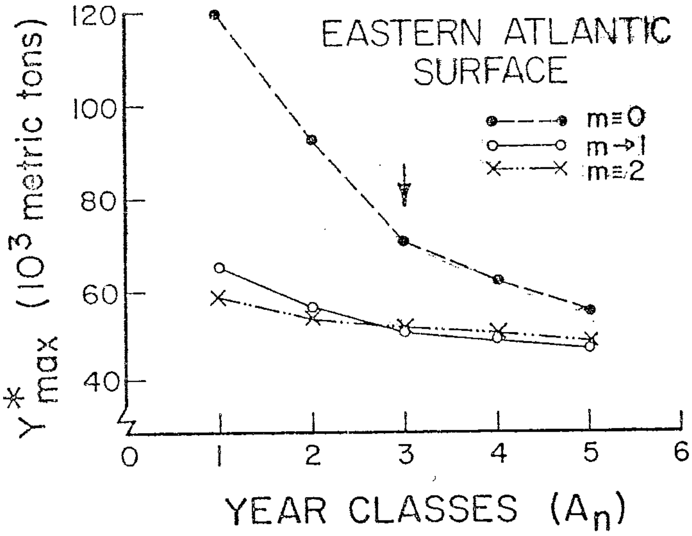

Figure 5

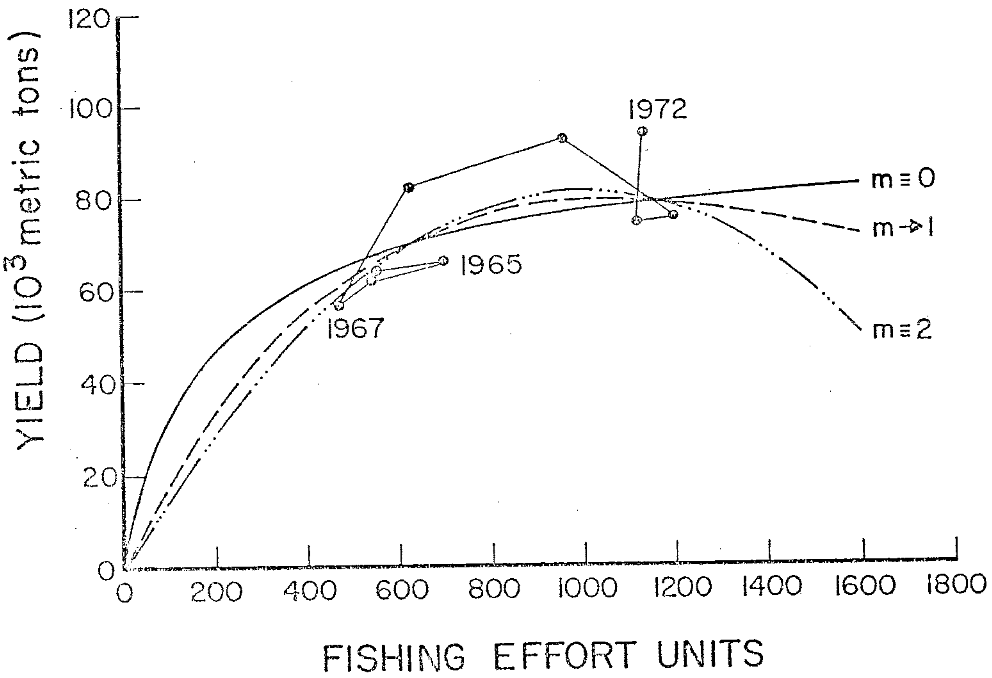

Figure 6

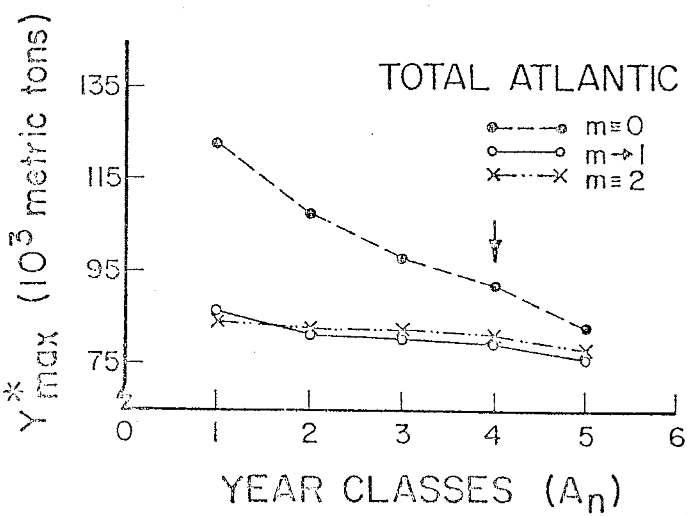

Figure 7