Col.Vol.Sci.Pap. ICCAT, 28 : 147-155 (1988)

STOCK ASSESSMENT OF SOUTH ATLANTIC ALBACORE BY USING PRODUCTION MODEL ANALYSIS, 1967-1986

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SUMMARY

This paper deals with the stock assessment of the south Atlantic albacore resource by using surplus production models to analyze catch and effort statistics dating from 1967 to 1986. The analyses of effective fishing effort spent on the resource has been carried out in terms of effective hooks (Case 1) and effective fishing intensity (Case 2) for comparison.

The results show that: (1) a generalized production model with parameter m equaling 2.00 appears to be the best fit of the data set; (2) the maximum sustained yield (MSY) of the resource was estimated to be in the range of 23,830 MT to 24,760 MT per year for Case 1 and Case 2 respectively; (3) there is no significant difference between the estimated MSYs by using the two cases of effective effort.

The current catch level (28,050 MT in 1985) is just about 10 percent over the upper limit of the estimated MSY whereas the current effort level was about 20 percent higher than the estimated maximum level producing the MSY. It is suggested that the stock has been reaching its maximum exploitation phase since the early 1980s and hence careful monitoring of the fishery should be continued.

RESUME

Ce document traite de l'évaluation des ressources du stock de germon de l'Atlantique sud en utilisant les modèles de production excédentaire pour analyser les statistiques de prise et effort de la période 1967-1986. Les analyses de l'effort de pêche effective des ressources ont été menées à bien en termes d'hameçons effectifs (Cas 1) et d'intensité de pêche effective (Cas 2) pour établir une comparaison.

Les résultats montrent que: (1) un modèle de production généralisé avec un paramètre m = 2.00 semble être le meilleur ajustement du jeu de données, (2) la production maximum soutenue (PME) des ressources a été estimée se situer dans la gamme de 23.760-24.580 TM et de 23.830 à 24.760 TM par an pour le Cas 1 et 2 respectivement; (3) il n'existe pas de différence importante entre la PME estimée en utilisant les deux cas de l'effort effectif.

Le niveau actuel des prises (28.050 TM en 1985) se situe juste au-dessus de 10 % de la limite supérieure de la PME estimée alors que le niveau actuel de l'effort était d'environ 20 % de plus que le niveau maximum estimé produisant la PME. Il est suggéré que le stock a atteint sa phase d'exploitation maximum au début des années 80 et il est donc conseillé de suivre de près la pêcherie.

RESUMEN

Este documento trata sobre la evaluación del stock de atún blanco en el Atlántico Sur, utilizando modelos de producción excedente para analizar las estadísticas de captura y esfuerzo desde 1967 a 1986. Los análisis de esfuerzo de pesca efectivo aplicados al recurso han sido llevados a cabo en términos de anzuelos efectivos (Caso 1) e intensidad efectiva de pesca (Caso 2), para su comparación.

Los resultados muestran que: (1), un modelo de producción generalizado, con el parámetro m igual a 2.00 parece ser el mejor ajuste del conjunto de datos; (2) se calculó que el rendimiento máximo sostenible (RMS) del recurso se encontraba en la escala de 23.760 t a 24.580 t por año y de 23.830 t a 24.760 t por año para los Casos 1 y 2, respectivamente; (3), no hay diferencias significativas entre los RMS estimados utilizando los dos casos de esfuerzo efectivo.

El nivel de captura actual (28.050 t en 1985) se encuentra un 10% por encima del límite superior del RMS calculado, mientras que el nivel de esfuerzo actual era de un 20% superior que el nivel máximo estimado de producción del RMS. Se sugiere que el stock ha estado alcanzando su fase de explotación máxima desde principios de 1980, y se deberá, por tanto, continuar un cuidadoso seguimiento.

INTRODUCTION

Albacore (*Thunnus alalunga*) is one of the most abundant and economically important tuna species in the Atlantic Ocean. The resource has firstly been exploited in commercial scale by the Japanese longliners in the late 1950s but the fleet gradually switch their target species from albacore to bigeye and bluefin tunas since early 1970s. The Taiwanese longliners joint the activities since mid 1960s and became the major fleet targetting on the resource. In 1985, e.g., the albacore harvested by the Taiwan fleet comprised 85% of the total atlantic albacore caught in the Atlantic. In recent years the development of surface fisheries, i.e., troll lines, bait boat, and purseiners operated in the Atlantic fished considerable amount of smaller sized fish of the tunas resources in the surface layer.

The Atlantic albacore population is believed to be two distinct and separate stocks by the 5°N latitude (Yang et al., 1969; Yang, 1970; Bartoo, 1979; Yang and Sun, 1983). The southern stock has been majorly fished by the Taiwanese fleet since early 1970s. Scientists of the Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) have expressed concern about the ability of Atlantic tuna stocks to sustain the high catch level since mid 1970s. The south albacore stock is one of the stocks they are concerned which led to previous analyses of the status of South Atlantic albacore (Shiohama, 1977, 1978, 1979; Bartoo and Coan, 1983; Yang and Sun, 1983; Liu, 1985).

The main purpose of this study is to assess the current status of the albacore resource in the southern Atlantic Ocean by fitting the surplus production models upon the updated catch and standardized fishing effort data of from 1967 to 1986.

MATERIAL AND METHOD

Production models form one of the two groups of models used in studying fish population and assessing the state of fish stock (Gulland, 1983). They originated from Graham (1935), who utilized the logistic model to estimate the yield which might be expected from North Sea fish stock. Schaefer (1954, 1957) developed a modified version of the logistic model and used it to estimated the maximum sustainable yield (MSY) for the California sardine, the Pacific halibut, and the yellowfin tuna of the eastern tropical Pacific Ocean. Pella and Tomlinson (1969) developed a more flexible formulation that allows the simple parabola of the Schaefer model to be skewed to the left or right, permitting the best empirical fit to the observed data. Fox (1975) described a procedure for fitting the Pella-Tomlinson model that requires equilibrium approximations. Finally, Schnute (1977) derived linear and nonlinear methods for estimating the coefficients of the Schaefer model.

The general production model for a single-species system is given by (Schaefer, 1954):

$$dP/dt = P(t)g(P(t)) - P(t)h(f(t)) \qquad (1)$$

where P(t) is the population size at time t, g(P(t)) is the regulatory function of the rate of population increase, h(f(t)) is the function of fishing mortality excerted by f(t), units of fishing effort. Pella and Tomlinson (1969) introduced the most flexible simple function for P(t)g(P(t)) as

$$P(t)g(P(t)) = HP^{m}(t) - KP(t) \qquad (2)$$

where H, K, m are constant parameters and H, K must be positive when m < 1, or H, K must be negative when m > 1. The general assumption about the function of fishing mortality is:

$$h(f(t)) = F(t) = qf(t) \qquad (3)$$

where F(t) is the fishing mortality rate, q is the catchability coeffficient, f(t) is the fishing effort standardized to be proportional to the F(t). Substituting (2) and (3) into (1), the generealized stock production model was obtained (Pella and Tomlinson, 1969) as follow:

$$dP/dt = HP^{m}(t) - KP(t) - qf(t)P(t) \qquad (4)$$

At equilibrium situation; we then have:

$$Y = qf\left(\frac{qf + k}{H}\right)^{1/(m-1)} = f(a+bf)^{1/(m-1)} \qquad (5)$$

$$U = Y/f = q\left(\frac{qf + k}{H}\right)^{1/(m-1)} = (a+bf)^{1/(m-1)} \qquad (6)$$

where Y is the equilibrium yield and U is the equilibrium catch per unit effort, a and b are parameters; i.e., a and b are recombinations of H, K, and q. The relationships of interest in fishery management are obtained by differentiating equation (5) with respect to f:

$$fopt = \frac{K(1-m)}{mq} = a\left(\frac{1}{m} - 1\right) / b \qquad (7)$$

$$Uopt = \left(\frac{qK}{Hm}\right)^{1/(m-1)} = (a/m)^{1/(m-1)} \qquad (8)$$

$$Ymax = MSY = fopt.Uopt = H\left(\frac{K}{mH}\right)^{m/(m-1)} - K\left(\frac{K}{mH}\right)^{1/(m-1)}$$

$$= (m)^{1/(1-m)} a^{m/(m-1)} \left(\frac{1}{m} - 1\right)/b \qquad (9)$$

where: fopt is the optimum fishing efffort required to produce Ymax, the maximum sustainable yield; Uopt is the catch per unit effort at point where Y is maximized.

From the above equations, we know that m cannot equal 1, for other values of m in equations (5), (6), we get a family of curves, for which m=0 (asymptotic model), m approaches but does not equal 1 (Gompertz model, or Fox's exponential model) (Fox 1970) and m=2 (logistic model) (Schefer, 1954 1957) are special cases.

Fox (1975) developed a computer program PRODFIT to fit generalized production models through control parameter, m. PRODFIT fits the model by average fishing effort as suggested by Gulland (1961,1969).

The average fishing effort ($\bar{f}i$) is computed by following the formula with SUBROUTINE AVEFF OF PRODFIT (Fox,1975) as:

$$\bar{f}i = (kfi + (k-1).fi-1 + ... + fi-k+1) / (k + (k-1) + ... + 1)$$

where: k is the number of year class which contributes most significantly to the catch.

In this study, PRODFIT was used to fit the three models (m=0.0, 1.001 and 2.0) to the fishery data. The number of significant year classes contributing to the catch of albacore fishery in the South Atlantic Ocean was obtained by checking the age composition. It was set at 3 (k=3) then later at 4 (K=4), following Bartoo and Coan (1983).

Two types of data were needed for PRODFIT:

1) Total annual catch: Annual catch data of albacore in the South Atlantic Ocean from 1967 to 1985 were compiled from ICCAT Statistical Bulletins (ICCAT, 1982; 1981; 1985), there data are shown in Fig. 1 and Table 2.

2) Standardization of effort: The longline effort measured in hooks was chosen as the standard measure of fishing effort for South Atlantic albacore fishery because nearly all catch from south stock is exploited by longline boats (Fig.1). The detailed procedure for the standardization of longline fishing effort using Honma's method (1973) is described by Yang and Sun (1983). Two cases of effective effort in this report were used as inputs to PRODFIT. Effective effort in Case 1 was expressed by effective hooks and in Case 2 by fishing intensity (effective hooks per 5 square). The results of the standardization of longline fishing effort are shown in Table 1. This effective effort was then raised to the total catch. The results of which are shown in Table 2.

RESULTS

Catch and Standardized Effort

From the fluctuation of annual CPU1 (mt/1000000 hooks) and CPU2 (mt/10000 hooks/5'sq.) (Fig. 1), it shown the stock of South Atlantic albacore has been arrived equilibrium although the annual total catch fluctuates very much. Annual total catch of albacore in the south Atlantic Ocean fluctuated between 13,310 mt and 33,260 mt during the years 1967 to 1973. It become fairly stable between 17,540 mt and 23,590 mt during the period 1974 to 1981. In 1982 was 28,970 mt, but the following two years descending to 13,310 mt in 1984, and acending to 28,050 mt in 1985. (Table 2, Fig. 2).

Effective effort rose rapidly from 1968 and reached its high value of about 148 million hooks (1.54 million hooks per 5 square) in 1973, and then fluctuated between 75 to 110 million hooks (0.82 to 1.22 million hooks per 5 square) during the years of 1974 to 1980, increased steadily to 156 million hooks (1.69 million hooks per 5 square) in 1982. But in recent years, 1983 and 1984 descending to 70 million hooks (0.76 million hooks per 5 sqare) after that acending to 150 million hooks (1.68 million hooks per 5 square) in 1985.

Production Model Analysis

Catch and standardized effort data for Case 1 and Case 2 in the South Atlantic albacore fishery (Table 2) were used as inputs to the PRODFIT computer program to estimate production model parmeters.

Case 1

For Case 1, effective effort was expressed in effective hooks. The results of the estimated maximum sustainable yield (MSY) and optimum fishing effeort (fopt) are compared in Table 3 with the observed catch and effort of 1985. Table 3 also lists the optimal value of catch per unit effort (Uopt) and degree of fit (r2). Estimated yield curves for K=3 and K=4 are shown in Fig. 3 and 4.

For K=3, the best fitted model (r2=0.190) has a Schaeffer type equilibrium yield curve (m=2.0) with the estimated MSY is 24,500 mt at an optimum effective fishing effort of 121 million hooks. The poorest fitted model (r2=.127) has a broad, flat-topped equilibrium yield curve (m=0.0) with the estimated MSY of 36,800 mt at an infinit amount of fishing effort. The skew dome-shaped equilibrium yield curve (m=1.001, r2=.165) gives an estimated MSY of 24,600 mt for fopt at 153 million effective hooks.

For K=4, when m=2.0 (r2=0.170), the estimated MSY is 23,800 mt and fopt is 126 million effective effort. At m=0.0 (r2=0.11) the estimated MSY is 33,650 mt and the fopt is of infinite. When m=1.001 (r2=0.14), the estimated MSY 23,900 mt and the fopt is 154 million effective hooks.

Case 2

For Case 2, effective effort was expressed in fishing intensity. The results shown in Table 4 and Fig. 5 and 6 are similar to those in Case 1. For K=3, the best fitted model (r2 =0.185) is m=2.0 with a predicted MSY of 24,500 mt with fishing intensity of 1.32 million hooks per 5'sp. The poorest fitted model (r2=0.12) is m=0.0 with an estimated MSY of 38,100 mt with fopt at infinite. At m=1.001 (r2=0.168), the estimated MSY is 24,800 mt with fopt at 1.69 million hooks per 5 square.

For K=4, when m=0.0 (r2=0.1), the estimated MSY is 35,100 mt while fopt is infinite. At m=2.0 (r2=0.163), the estimated MSY is 23,830 mt and the fopt was 1.38 million hooks per 5 square. When m=1.001 (r2=0.131), the estimated MSY was 24,100 mt and fopt was 1.71 million hooks per 5 square.

DISCUSSION

Production model analysis is crude compared with a truly biological analysis. Pella and Tomlinson (1969), Fox and Lenern (1974), Fox (1974) and Rinaldo and Coan (1979) considered that some assumptions are necessary for applying this model approach to particular stock: (a) the population is either an isolated population or a unit stock; (b) an equilibrium condition can be achieved; (c) the constitutions (selectivity, catchability and temporal distribution pattern) of the fishery have remained constant; (d) there are no time lags in the population response to its equilibrium mechanism. More detailed discussion of the assumptions can be found in Pella and Tomlinson (1969) and Fox (1974).

Nevertheless, as stated by Fox (1970) " Since use of surplus yield models require only catch and effort data, these models are particularly advantageous when age determination and tagging are difficult, when such biological data don't exist, or when knowledge of the biological system is insufficient to describe recruitment, growth, or natural mortality if cannot be assumed constant through all ranges of population size." Csirke and Caddy (1983) also noted that production models are among the simplest and most widely used approaches in the assessment of exploited fish populations and because of the ease of application of these models in their simple form, the collection of catch and effort statistics, and their subsequent utilization models has become the standard approach to fisheries assessment in many parts of the world.

Uhler (1979) predicted that production models will continue for some time to serve as a basis for management of many of the world's fisheries. The SCRS of ICCAT also considered production model analysis to be one of the standard methods for evaluating tuna stocks in the Atlantic Ocean. Therefore, these previous studies on the status of South Atlantic albacore all employed production models (Shiohama, 1977, 1978, 1979; Bartoo and Coan, 1983; Yang and Sun, 1984; Liu, 1985).

The value of MSY estimated by this present study are lower than those of Yang and Sun (1984), and the fopt also lower 0.84 times. The difference in results seem to be due to the recent two years (1983 and 1984) had very lower catch and effort for albacore in the South Atlantic Ocean. And the effective effort data derived in Yang and Sun (1984) was based on combined Taiwanese and Japanese longline fisheries but in this study the recent three years (1983, 1984 and 1985) data only based on Taiwanese longline fishery due to the catch of albacore by Japanese longline fishery is very low in recent three years. Based on the deterministic production model analyses for Cases 1 and 2, the current catch (28,050 mt in 1985) is about 10% over the predicted equilibrium MSY and the current effort is about 20% over that needed to produce the equilibrium MSY. The status of the South Atlantic albacore stock, judged by present study, appears that the stock has been fully exploited beyond MSY level since 1981. We should continue to use the production model as one of the means of monitoring the status of the stock.

ACKNOWLEDGEMENTS

We would like to express our thanks to Miss Chiou-Yueh Chang, In-Chin Cheng and Mr. Cha-Kai Chang at the Tuna Research Center, Institute of Oceanography, National Taiwan Univesity, for their assistance with this work.

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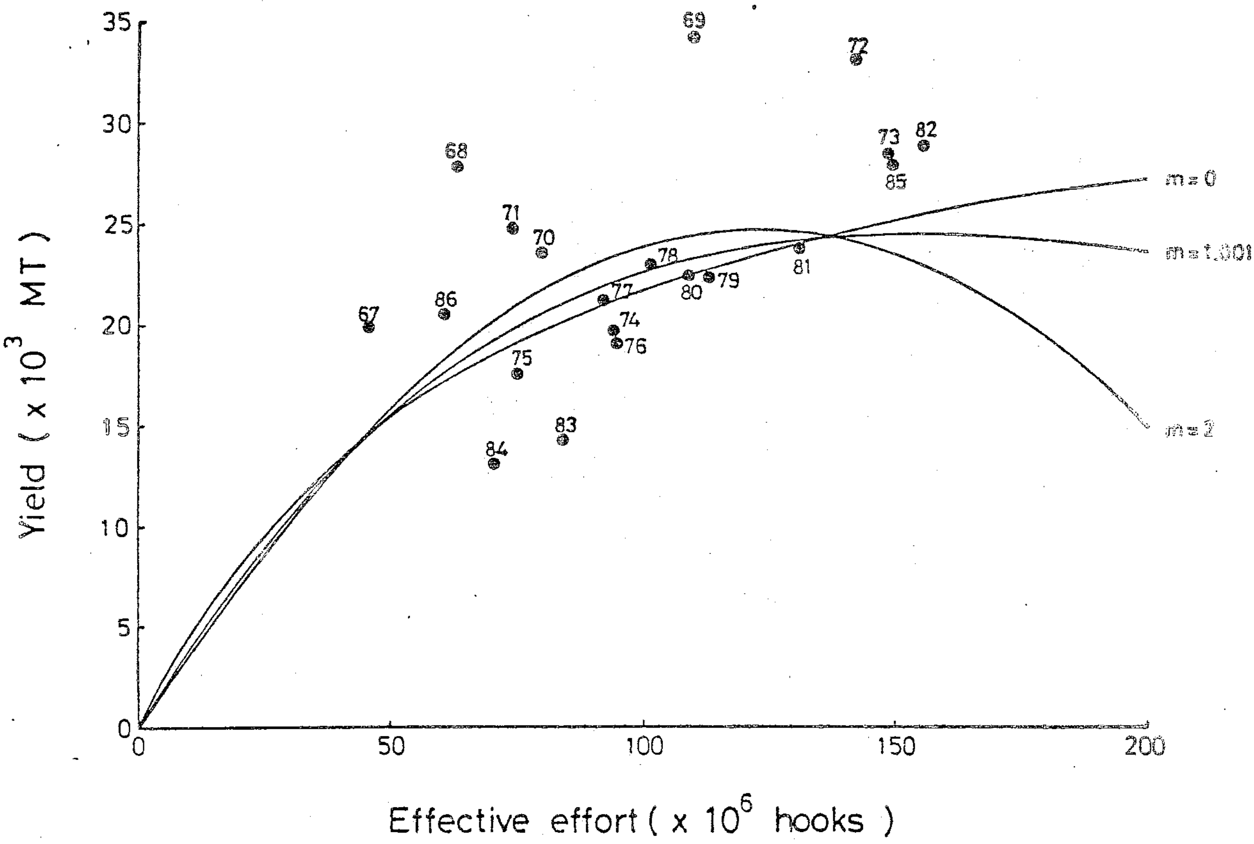

Fig. 3. Equilibrium yield curves and observed data for South Atlantic albacore fishery and assuming three significant year-classes in the catch 1967-1985 (Case 1)

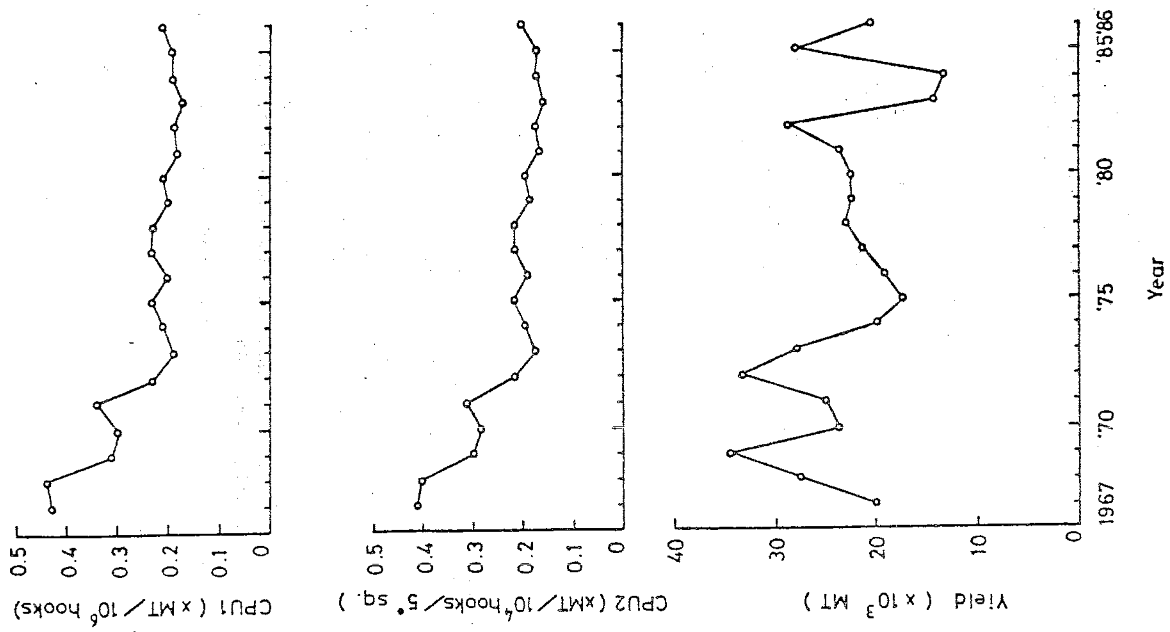

Fig. 1. Fluctuation of annual CPU1, CPU2 and total catch of South Atlantic albacore in 1967 - 1985.

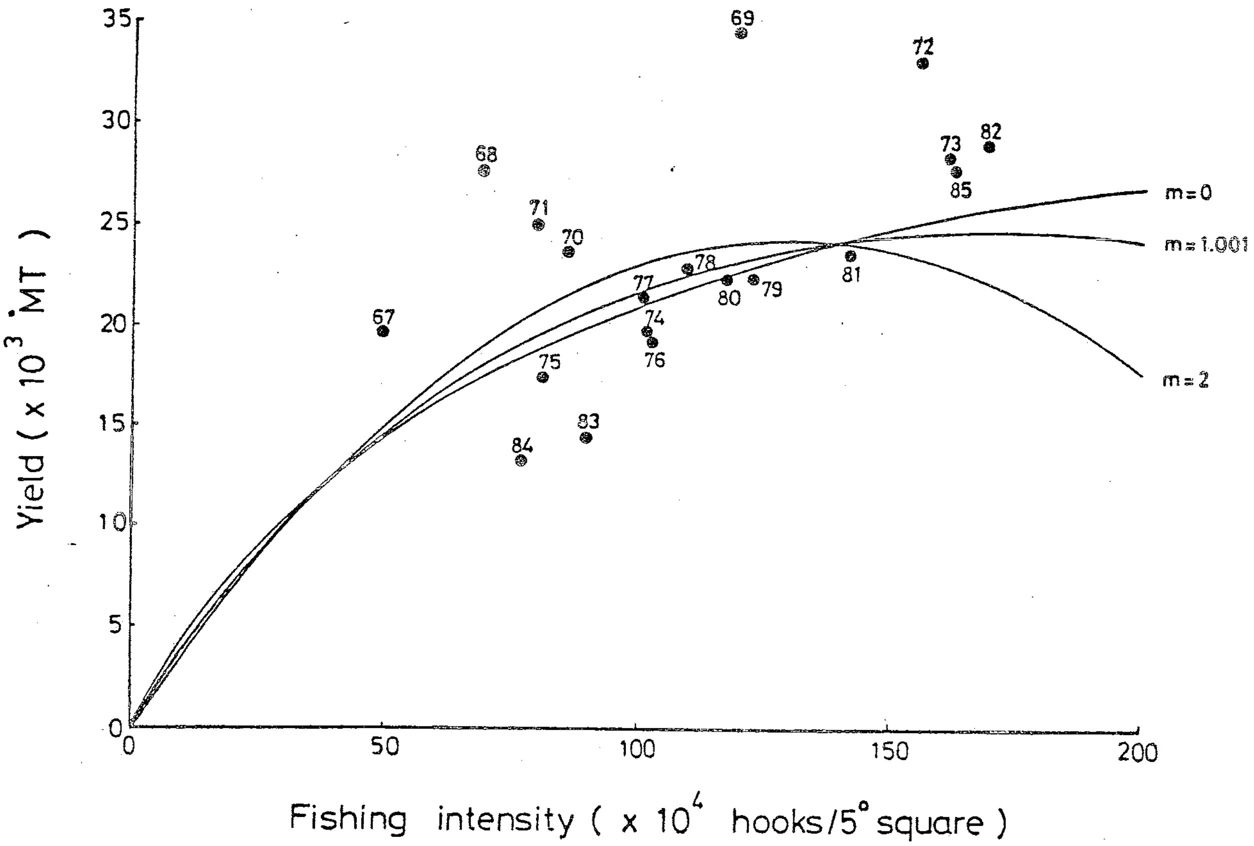

Fig. 5. Equilibrium yield curves and observed data for South Atlantic albacore fishery and assuming three significant year-classes in the catch, 1967-1985. (Case 2)

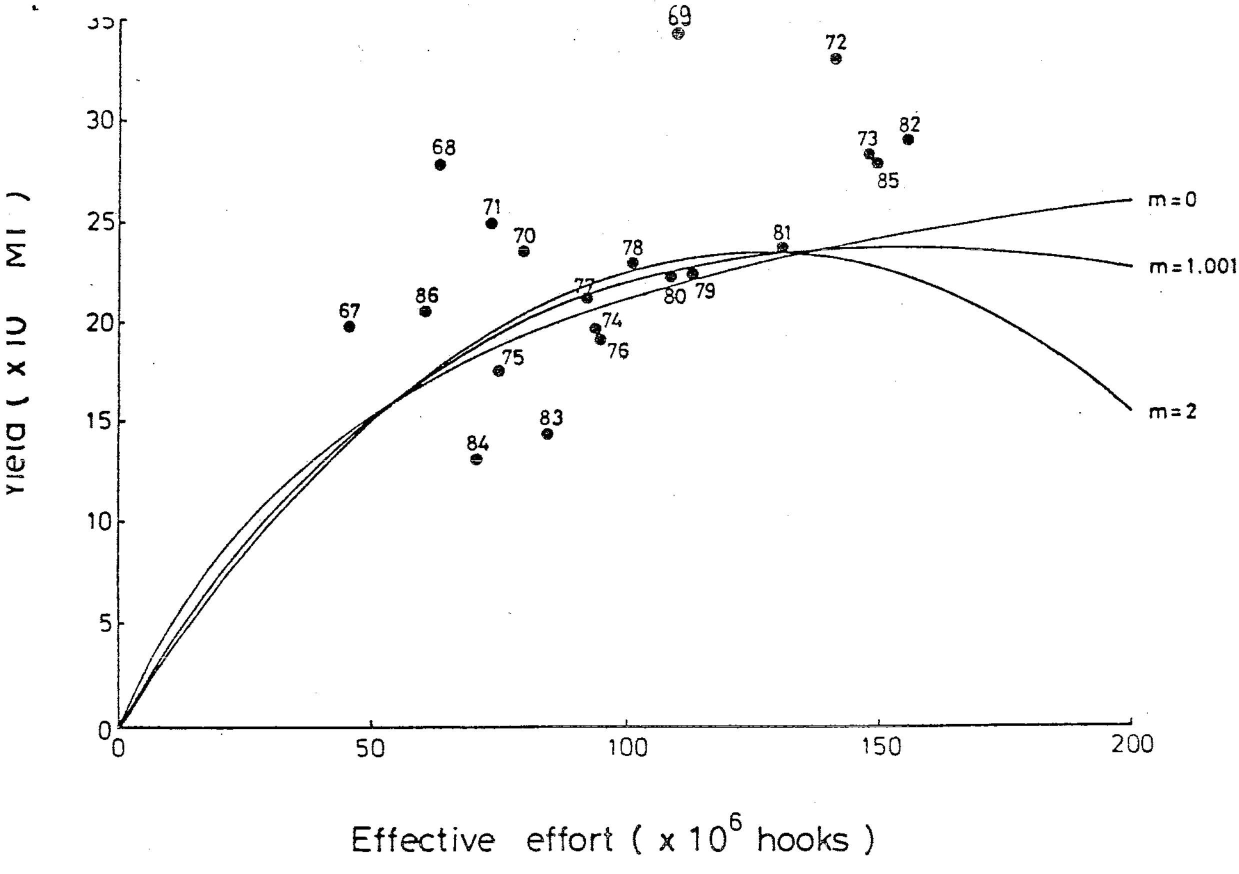

Fig. 4. Equilibrium yield curves and observed data for South Atlantic albacore fishery and assuming four significant year-classes in the catch, 1967-1985. (Case 1)

Table 1. Catch and effort statistics of albacore caught by the Taiwanese, the Japanese, and the Korean longliners in the south Atlantic Ocean, 1967-1986.

Year	Taiwan Longline Fishery			Japan Longline Fishery			Korea Longline Fishery			Total		
	Catch in Number (x1000)	Mean Wt./fish (Kg)	Nominal Effort (x100000 Hooks)	Catch in Number (x1000)	Mean Wt./fish (Kg)	Nominal Effort (x100000 Hooks)	Catch in Number (x1000)	Mean Wt./fish (Kg)	Nominal Effort (x100000 Hooks)	Catch in Number (x1000)	Catch in Weight (mt) x1000	Nominal Effort (x100000 Hooks)
1967	40.6	25.8	9.54	436.7	17.7	173.56	80.3	15.0	15.40	557.7	10.00	198.51
1968	722.2	16.0	198.06	739.4	16.1	187.67	15.4	15.0	5.19	1477.0	23.69	390.92
1969	849.8	14.8	266.19	244.0	26.0	191.00	20.0	15.0	8.89	1113.8	19.22	466.08
1970	672.4	18.2	210.13	453.9	13.0	250.09	-	-	-	1126.4	18.14	460.26
1971	1273.6	13.8	366.08	218.5	14.8	181.28	-	-	-	1492.0	20.80	547.49
1972	1209.6	20.6	411.18	147.8	14.1	190.99	-	-	-	1357.4	27.00	602.16
1973	1099.0	20.2	413.94	38.4	7.3	204.45	-	-	-	1147.4	22.48	618.39
1974	973.5	17.2	350.01	25.9	4.2	101.22	90.3	15.0	204.85	1089.7	18.21	650.07
1975	1031.6	13.0	309.55	26.8	11.3	139.55	18.2	15.0	47.05	1076.6	13.99	496.41
1976	919.5	15.7	316.19	6.3	12.2	57.67	104.3	15.0	128.38	1030.2	16.08	503.00
1977	1063.6	15.0	308.73	7.6	13.1	150.72	107.6	15.0	101.25	1178.8	17.67	561.72
1978	1432.1	14.4	402.08	10.6	12.3	279.43	44.0	15.0	80.11	1486.7	21.41	762.62
1979	1076.0	18.9	323.91	7.8	13.1	359.39	16.3	15.0	54.43	1100.1	20.68	738.23
1980	1102.1	17.1	332.24	26.4	12.8	309.90	19.4	15.0	67.21	1148.0	19.47	709.34
1981	1119.1	16.5	397.94	40.6	14.0	300.18	19.0	15.0	95.54	1178.6	19.32	793.80
1982	1320.0	17.4	461.68	42.6	13.2	384.61	20.1	15.0	102.93	1382.8	23.83	949.32
1983	642.9	15.2	227.29	10.4	13.0	229.58	25.7	15.0	124.77	679.0	10.29	581.84
1984	535.8	14.8	168.98	15.8	13.0	407.47	22.0	15.0	113.25	573.6	8.47	689.70
1985	1365.5	13.8	481.75							1365.5	18.84	481.75
1986												

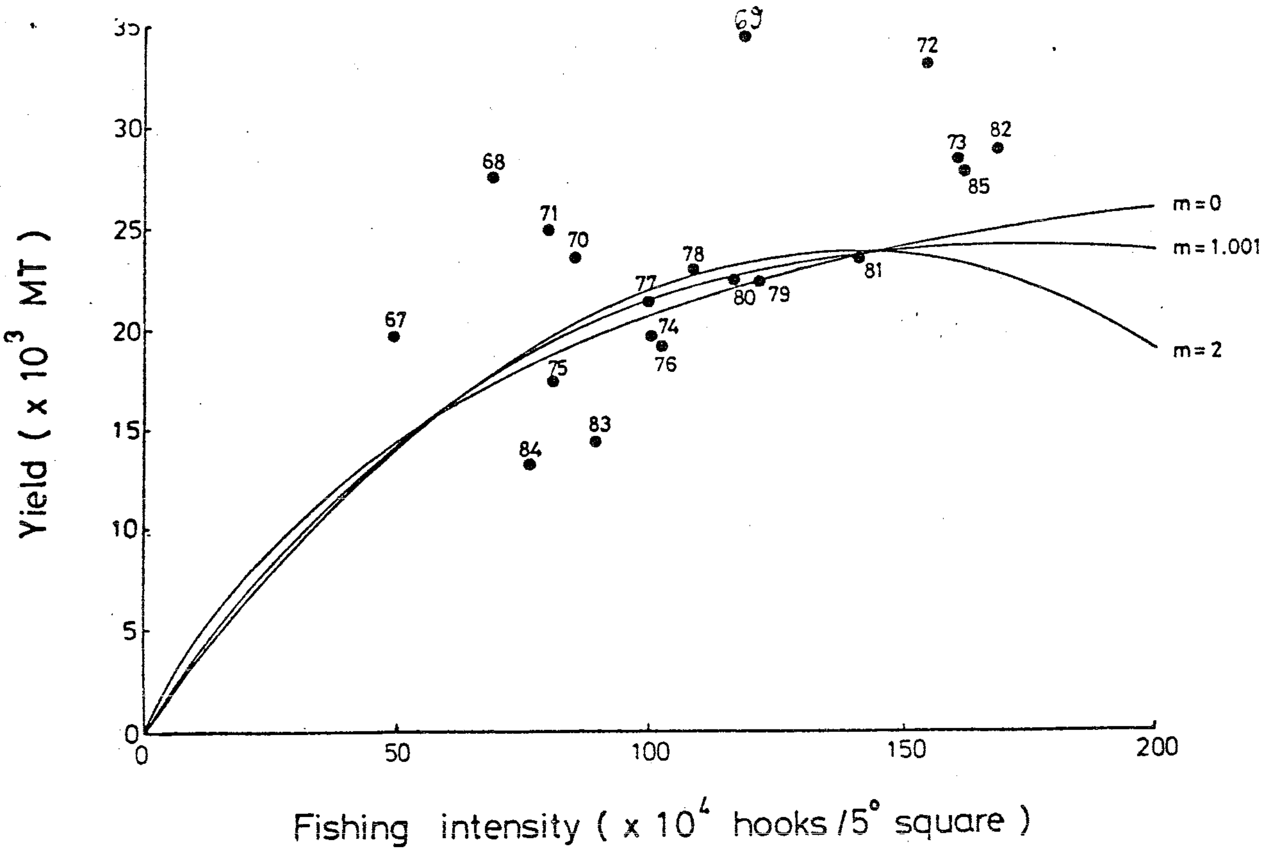

Fig. 6. Equilibrium yield curves and observed data for South Atlantic albacore fishery and assuming four significant year-classes in the catch, 1967-1985. (Case 2)

Table 2. Catch, effective effort, and fishing intensity data for south Atlantic albacore fisheries, 1967-1986.

Year	Longline Fishery: Catch in Number (x1000)	Longline Fishery: Catch in Weight (mt) x1000	Longline Fishery: Effective Effort $(\times 10^5$ Hooks)	Longline Fishery: Fishing Intensity $(\times 10^4$ Hooks /5' sq.	All Fisheries: Catch in Weight (mt) x1000	All Fisheries: Effective Effort $(\times 10^5$ Hooks)	All Fisheries: Fishing Intensity $(\times 10^4$ Hooks /5' sq.
1967	557.7	10.00	189.00	20.15	19.80	456.49	48.66
1968	1477.0	23.69	490.98	54.13	27.84	629.60	69.41
1969	1113.8	19.22	522.95	56.26	34.56	1103.88	118.77
1970	1126.4	18.14	554.76	59.84	23.65	792.53	85.49
1971	1492.0	20.80	646.39	70.18	25.02	737.46	80.07
1972	1357.4	27.00	853.48	92.93	33.20	1420.07	154.62
1973	1147.4	22.48	880.45	95.53	28.23	1468.61	161.30
1974	1089.7	18.21	762.07	82.49	19.70	937.01	101.43
1975	1076.6	13.99	678.18	73.96	17.53	751.37	81.94
1976	1030.2	16.08	743.23	80.59	19.25	944.61	102.43
1977	1178.8	17.67	746.65	80.87	21.37	920.90	99.74
1978	1486.7	21.41	953.36	103.60	23.05	1005.32	109.24
1979	1100.1	20.68	812.08	87.84	22.50	1129.96	122.23
1980	1148.0	19.47	815.10	87.92	22.54	1088.63	117.43
1981	1178.6	19.32	965.00	103.68	23.59	1314.01	141.18
1982	1382.8	23.83	1096.51	118.41	28.98	1563.41	168.84
1983	679.0	10.29	584.84	62.00	14.40	843.54	89.42
1984	573.6	8.47	446.36	48.38	13.31	704.46	76.67
1985	1365.5	18.84	1070.25	116.00	28.05	1495.59	162.10
1986	1532.0	20.61	1004.00	100.00	20.61	1004.00	100.00

Table 3. Estimated production model parameters for South Atlantic albacore, 1967-1986 (Case 1).

No. of significant year class (K)	m	Uopt (mt/10^3 effective hooks)	fopt (10^6 effective hooks)	MSY (10^3 mt)	Degree of fit index (r2)	1985 Actual catch (10^3 mt)	1985 Effort (10^6 effective hooks)
3	0.0	0	&	36.79	.127	28.05	149.56
3	1.001	.161	152.97	24.58	.165	28.05	149.56
3	2	.202	120.76	24.40	.190	28.05	149.56
4	0.0	0	&	33.65	.106	28.05	149.56
4	1.001	.155	153.96	23.86	.139	28.05	149.56
4	2	.188	126.35	23.76	.170	28.05	149.56

Table 4. Estimated production model parameters for South Atlantic albacore, 1967-1986 (Case 2).

No. of significant year class (k)	m	Uopt (mt/10^3 hooks/5° sq.)	fopt (10^4 hooks/5° sq.)	MSY (10^3 mt)	Degree of fit index (r2)	Actual catch (10^3 mt	Effort (10^4 hooks/ 5° sq.)
3	0.0	0	&	38.13	.120	28.05	162.10
3	1.0001	0.146	169.39	24.76	.158	28.05	162.10
3	2	0.186	131.65	24.44	.185	28.05	162.10
4	0.0	0	&	35.14	.100	28.05	162.10
4	1.0001	0.140	171.74	24.10	.131	28.05	162.10
4	2	0.172	138.35	23.83	.163	28.05	162.10