

A PRODUCTION MODEL ANALYSIS OF YELLOWFIN TUNA (THUNNUS  
ALBACARES) STOCKS IN THE ATLANTIC OCEAN, 1964-77

by

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SUMMARY

Scientists of the Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) expressed concern at the 1977 meeting over the possible changes in the status of yellowfin tuna stocks in the Atlantic Ocean due to the expansion of the fishery into a new offshore area in the eastern Atlantic Ocean. Large purse seiners (Class 5 to 7, carrying capacity greater than 450 MT) are the primary vessels involved in fishing this new offshore area.

Production model analyses were performed to determine the status of yellowfin tuna stocks in the Atlantic Ocean as affected by the expansion of the fishery. Revisions in catches and catch per day at sea (CPDA) are incorporated. Large purse seine CPDA and large purse seine catches from the offshore area are included in the analysis (case II) by standardizing them to the average CPDA of Class 3 French-Ivory Coast-Senegalese-Moroccan (FISM) purse seiners. We also performed analyses that exclude large purse seine CPDA and large purse seine catches made in the offshore area (case I).

The broad flat-topped equilibrium catch curve ( $m = 0.0$ ) is the best fitting model for data from the eastern Atlantic surface fishery, cases I and II, and the total Atlantic fishery. Maximum sustainable average yield (MSAY) for the eastern Atlantic surface fishery is 143,100 MT based on standardized effort with large seine CPDA (case II) and 116,000 MT based on standardized effort without large seiner CPDA (case I). These estimates are 28 and 32% higher than the estimates of MSAY reported in 1977 (111,800 and 88,000 MT). The increase in MSAY is partially due to the addition of large seiner CPDA, but primarily due to increased catches from the offshore area in 1975 to 1977 combined with updated data. MSAY for the total Atlantic fishery is higher by 18% (161,800 MT) over the estimate (137,700 MT) reported in 1977.

Conclusions reached are as follows:

The status of Atlantic yellowfin tuna, judged by production model analysis, appears to be more optimistic than in previous analyses. The increase in estimated MSAY between case I and case II surface fishery analyses plus the decrease in fit between cases I and II, suggest slow mixing of yellowfin tuna in the eastern Atlantic and an increase in the equilibrium yield due to the offshore expansion of the surface fishery. The best fitting models ( $m=0.0$ ) indicate an increase in equilibrium yield of between 5 and 10% is obtainable with a 25% increase in fishing effort. However, the fits for  $m=2.0$  are only marginally worse than for  $m=0.0$  and these models indicate decreases in equilibrium yield of nearly 10% for the eastern Atlantic surface fishery and nearly 20% for the total Atlantic fishery with a 25% increase in fishing effort. Therefore, this suggests that it is very uncertain as to whether any sustainable increases in catch can be made and the fishery should continue to receive careful scrutiny.

## INTRODUCTION

This analysis updates the previous production model analysis (Fox and Coan, 1978) on the status of Atlantic yellowfin tuna; revised estimates of catches and CPDA have been incorporated.

Recent expansion of the yellowfin tuna fishery to a new offshore area (Figure 1) of the eastern tropical Atlantic Ocean has caused concern over possible changes in the status of yellowfin tuna stocks in the Atlantic Ocean (ICCAT, 1978a). Nearly 20% of the Atlantic yellowfin tuna catch in 1977 came from the offshore area where larger yellowfin tuna are caught by purse seiners. In our analysis, as in the past, two basic stock structures are assumed; 1) an eastern Atlantic stock exploited only by surface gears (baitboat and purse seiners) and 2) a total Atlantic stock exploited by surface and longline gears. Also investigated is the possibility that the eastern Atlantic stock may consist of two stocks which may mix at some unknown rate, one in the inshore area and one in the offshore area fished by large purse seiners (Class 5 to 7, i.e. greater than 450 MT carrying capacity). Our analysis differs from that of Rinaldo and Coan, MS<sup>1</sup> in that large purse seine CPDA and estimates of 1977 catches and CPDA are used.

## CATCH AND CATCH ADJUSTMENTS

Annual catches of yellowfin tuna for 1966 to 1976 were compiled from the ICCAT Statistical Bulletin (ICCAT, 1978b); estimates for 1964 and 1965 were taken from Fox and Coan (1978). Yellowfin tuna catches were tabulated separately for the eastern Atlantic surface fishery (Table 3), and for the total Atlantic longline and surface fishery (Table 5).

Large purse seine yellowfin tuna catches from the offshore area were subtracted from yellowfin tuna catches for the entire eastern Atlantic surface fishery. This was done with catch data by one degree area for French-Ivory Coast-Senegalese-Moroccan (FISM) and American large purse seiners (Table 3).

## STANDARDIZATION OF EFFORT

Fishing effort for the eastern Atlantic surface fishery was standardized to produce two different cases: I) Catch per day at sea (CPDA) for large purse seiners and catches from the offshore area for large purse seiners were omitted, and II) CPDA and catches from the offshore area for large purse seiners were included. The standardization procedure followed similar steps outlined by Fox and Coan (1978).

Step 1) CPDA for FISM baitboats (Classes 2 and 3) and purse seiners (Classes 3 and 4) were standardized to Class 3 purse seine CPDA by multiplying each gear's CPDA by the ratio of the average 1969 to 1977 CPDA of Class 3 purse seiners to the 1969 to 1977 average CPDA for each gear and class (Table 1).

Step 2) For case II (large purse seine CPDA included) FISM Class 5 purse seiners were treated as in Step 1. FISM Class 6 and Class 7 purse seiners were standardized to FISM Class 3 purse seine CPDA by multiplying yearly CPDA for Class 6 and Class 7 purse seiners by the ratio of the 1974 to 1977 average Class 3 purse seine CPDA to the 1974 to 1977 average CPDA for Class 6 and Class 7 purse seiners (Table 1).

<sup>1</sup>Rinaldo, R. G. and A. L. Coan. MS. Effects of stock structure hypotheses for Atlantic yellowfin tuna (Thunnus albacares) on production model analysis. SCRS/78/73.

Step 3) The standardized catch per day at sea for FISM baitboats, small purse seiners and large purse seiners from steps 1) or 2) were combined by averaging them for baitboat Class 2 and 3, purse seine Class 3 and 4 and purse seine Class 5 through Class 7, respectively (Table 2).

Step 4) The catch per standard day at sea (CPSDA) for the eastern Atlantic surface fishery cases I and II were calculated as the weighted average of the standardized CPDA for baitboats, small purse seiners and large purse seiners using the yearly FISM catches for each gear as the weighting factors (Table 3).

Step 5) Standard days at sea (SDA) for the eastern Atlantic surface fishery, cases I and II, were calculated by dividing the yearly CPSDA in each case into the appropriate, adjusted yearly catches (Table 3).

SDA for the total Atlantic fishery was calculated using case II (large seine data included) and followed these steps.

Step 1) Yellowfin tuna catches of the surface fishery from the western Atlantic were added to yellowfin tuna catches of the surface fishery from the eastern Atlantic and SDA were calculated by dividing by the case II CPSDA (Table 5).

Step 2) Japanese longline hook rate II based on fishing intensity rather than nominal hooks was converted to hook rate III (hook rate based on weight) by multiplying hook rate II for each year by the average weight of yellowfin tuna caught by Japanese longline gear in that year (Table 4).

Step 3) Hook rate III was standardized to the eastern Atlantic surface fishery CPSDA by multiplying each year's hook rate III by the ratio of the average surface CPSDA for 1964-1976 to the average hook rate III for the same years (Table 5).

Step 4) Longline CPSDA for 1977 (Table 5) was calculated from the linear regression equation of longline CPSDA to surface CPSDA.

Step 5) Longline CPSDA was used to calculate longline SDA by dividing the total longline catch in each year by its respective CPSDA (Table 5).

Step 6) Catch and effort for the longline and surface fishery were added to calculate catch and effort for the total Atlantic fishery (Table 5).

## PRODUCTION MODEL ANALYSIS

Catch and standardized effort for case I and II in the eastern Atlantic surface fishery (Table 3) and for the total Atlantic fishery (Table 5) were used as inputs to computer program PROFIT (Fox, 1975). Three special-case forms of the generalized production model (Pella and Tomlinson, 1969) were used:  $m = 0.0$ ,  $m = 1.0$ , and  $m = 2.0$ , where the

parameter,  $m$ , determines the shape of the yield curve. The number of significant age groups in the fishery ( $A_n$ ) was set equal to 3 for the eastern Atlantic surface fishery cases and to 4 for the total Atlantic fishery on the basis of age composition data from the fishery (Coan, 1978).

Case I: Eastern Atlantic surface fishery excluding large purse seiner CPDA and large purse seine catches from the offshore area

The best fitting model ( $r^2 = 0.750$ ) is the broad flat-topped equilibrium yield curve ( $m = 0.0$ ). Maximum sustainable average yield (MSAY) is 116,000 MT at infinite amount of fishing effort. The equilibrium yield at the 1977 level of fishing effort is 75,900 MT which is 8,800 MT under the actual 1977 yellowfin tuna catch (84,700 MT, Table 6). During the period 1974 to 1977, when large seiners fished the offshore area, standardized fishing effort showed a 31% increase and catches showed a 12% increase within the inshore area (Figure 2). In this analysis, it is assumed that yellowfin tuna in the offshore area do not mix or mix very slowly with yellowfin tuna in the inshore area.

Case II: Eastern Atlantic surface fishery including large purse seiner CPDA and large purse seine catches from the offshore area

The best fitting model ( $r^2 = 0.670$ ) is the broad flat-topped equilibrium yield curve ( $m = 0.0$ ). The estimated MSAY at infinite fishing effort increases from case I when large seine CPDA and large seine catches from the offshore area are included in the analysis. The increase is 23% to 143,100 MT (Table 6). The equilibrium yield at the 1977 level of effort is 87,200 MT or 15,700 MT under the actual 1977 catch. Standardized effort has increased 38% from 1974 to 1977 while catches have increased by 35% (Figure 3). In this analysis, it is assumed that the fisheries in the inshore and offshore area exploit a single yellowfin tuna stock.

Total Atlantic surface and longline fishery

The best fitting model ( $r^2 = 0.722$ ) is the broad flat-topped equilibrium yield curve ( $m = 0.0$ ). MSAY is 161,800 MT at an infinite amount of fishing effort (Table 6). Estimated equilibrium yield at the 1977 effort level is 109,900 MT and is 18,300 MT below the actual 1977 catch (Figure 4).

SUMMARY AND CONCLUSIONS

The broad, flat-topped equilibrium yield curve ( $m = 0.0$ ) is the best fitting model for all cases investigated in our analysis. This is consistent with our previous analysis (Fox and Coan, 1978). Estimates of MSAY for the eastern Atlantic surface fishery cases have increased by 32 and 28% in cases I and II respectively over the results of the 1977 analysis. The increases in the estimates of MSAY are partially due to

the addition of large seiner CPDA in the current analysis, but are more significantly attributable to increased catches in 1976 and 1977. Estimated MSAY for the total Atlantic fishery has increased by 18% over the 1977 analysis, despite decreasing catches by the longline fleet (Table 5).

Conclusions reached are as follows:

The status of Atlantic yellowfin tuna, judged by production model analysis, appears to be more optimistic than in previous analyses. The increase in estimated MSAY between case I and case II surface fishery analyses plus the decrease in fit between cases I and II, suggest slow mixing of yellowfin tuna in the eastern Atlantic and an increase in the equilibrium yield due to the offshore expansion of the surface fishery. The best fitting models ( $m = 0.0$ ) indicate an increase in equilibrium yield between 5 and 10% is obtainable with a 25% increase in fishing effort. However, the fits for  $m = 2.0$  are only marginally worse than for  $m = 0.0$  and these models indicate decreases in equilibrium yield of nearly 10% for the eastern Atlantic surface fishery and nearly 20% for the total Atlantic fishery with a 25% increase in fishing effort. Therefore, this suggests that it is very uncertain as to whether any sustainable increases in catch can be made and the fishery should continue to receive careful scrutiny.

LITERATURE CITED

- Coan, A. L. 1978. Length and age composition of yellowfin tuna (*Thunnus albacares*) from the Atlantic Ocean, 1966-76. ICCAT Coll. Vol. Sci. Pap., VII (SCRS 1977): 4-20.
- Fisheries Agency of Japan. 1967-78. Annual report of effort and catch statistics by area on Japanese tuna longline fishery, 1964-1976. Research and Development Department, Fisheries Agency of Japan, Japan.
- Fox, W. W., Jr. 1975. Fitting the generalized stock production model by least-squares and equilibrium approximation. Fish. Bull., U.S. 73(1): 23-36.
- Fox, W. W., Jr. and A. L. Coan. 1978. A production model analysis of Atlantic yellowfin tuna (*Thunnus albacares*) 1964-76. ICCAT Coll. Vol. Sci. Pap., VII (SCRS 1977): 73-81.
- ICCAT. 1978a. Report for biennial period, 1976-77. Part II (1977). Inter. Comm. Conserv. Atlantic Tunas, Madrid, Spain. 200 p.
- \_\_\_\_\_. 1978b. Statistical Bulletin. Vol. 8-1977 (ed. 1). Inter. Comm. Conserv. Atlantic Tunas, Madrid, Spain. 88 p.
- Pella, J. J. and P. K. Tomlinson. 1969. A generalized stock production model. Inter-Am. Trop. Tuna Comm., Bull. 13: 419-496.

Table 2. Catch per standard day at sea (CPSDA) and catches (metric tons  $\times 10^3$ ) for French Ivory Coast, Senegalese and Moroccan baitboats, small purse seiners (Class 3 and 4) and large purse seiners (Class 5 to 7).

| Year | Baitboat |       | Small purse seine |                    |                    | Large purse seine |       |
|------|----------|-------|-------------------|--------------------|--------------------|-------------------|-------|
|      | CPSDA    | Catch | CPSDA             | Catch <sup>1</sup> | Catch <sup>2</sup> | CPSDA             | Catch |
| 1964 | 3.22     | 13.2  | 2.74              | 4.3                | 4.3                |                   |       |
| 1965 | 2.90     | 14.7  | 2.46              | 5.4                | 5.4                |                   |       |
| 1966 | 3.23     | 15.9  | 3.43              | 7.5                | 7.5                |                   |       |
| 1967 | 3.75     | 14.9  | 3.63              | 8.9                | 8.9                |                   |       |
| 1968 | 5.01     | 19.9  | 3.47              | 12.6               | 12.6               |                   |       |
| 1969 | 2.64     | 14.2  | 3.25              | 14.7               | 11.8               | 2.18              | 2.9   |
| 1970 | 1.99     | 8.1   | 2.30              | 17.9               | 11.3               | 2.45              | 6.7   |
| 1971 | 2.00     | 7.8   | 2.13              | 18.0               | 12.3               | 1.81              | 5.7   |
| 1972 | 2.52     | 8.4   | 2.67              | 24.3               | 15.9               | 2.21              | 8.7   |
| 1973 | 2.10     | 5.6   | 2.03              | 24.8               | 16.1               | 2.15              | 8.9   |
| 1974 | 2.30     | 6.4   | 2.40              | 32.3               | 15.2               | 1.99              | 17.6  |
| 1975 | 2.17     | 2.8   | 2.08              | 34.0               | 9.5                | 2.53              | 33.4  |
| 1976 | 2.98     | 4.2   | 2.16              | 36.2               | 6.6                | 2.20              | 41.1  |
| 1977 | 2.34     | 3.5   | 2.01              | 29.6               | 5.0                | 2.16              | 42.5  |

<sup>1</sup>Large purse seine catches from the inshore area are included.

<sup>2</sup>Small purse seine catches only.

Table 3. Average catch per standard day at sea (CPSDA), catch (metric tons  $\times 10^3$ ) and effort (standard days at sea  $\times 10^3$ ) for the eastern Atlantic surface fishery for yellowfin tuna, 1964-1977.

| Year | Case I <sup>1</sup> |                           |                             | Case II <sup>2</sup> |                           |                             |
|------|---------------------|---------------------------|-----------------------------|----------------------|---------------------------|-----------------------------|
|      | Average CPSDA       | Catch (MT $\times 10^3$ ) | Effort (SDA $\times 10^3$ ) | Average CPSDA        | Catch (MT $\times 10^3$ ) | Effort (SDA $\times 10^3$ ) |
| 1964 | 3.10                | 28.1                      | 9.06                        | 3.10                 | 28.1                      | 9.06                        |
| 1965 | 2.78                | 29.1                      | 10.47                       | 2.78                 | 29.1                      | 10.47                       |
| 1966 | 3.29                | 34.7                      | 10.54                       | 3.29                 | 34.7                      | 10.55                       |
| 1967 | 3.71                | 34.8                      | 9.38                        | 3.71                 | 34.8                      | 9.38                        |
| 1968 | 4.41                | 52.6                      | 11.94                       | 4.41                 | 52.7                      | 11.95                       |
| 1969 | 2.95                | 60.1                      | 20.38                       | 2.84                 | 60.9                      | 21.44                       |
| 1970 | 2.20                | 44.4                      | 20.19                       | 2.24                 | 44.5                      | 19.87                       |
| 1971 | 2.09                | 42.6                      | 20.37                       | 2.02                 | 42.6                      | 21.09                       |
| 1972 | 2.63                | 62.1                      | 23.61                       | 2.51                 | 62.9                      | 25.06                       |
| 1973 | 2.04                | 59.4                      | 29.12                       | 2.08                 | 59.7                      | 28.70                       |
| 1974 | 2.38                | 75.6                      | 31.77                       | 2.20                 | 76.2                      | 34.64                       |
| 1975 | 2.09                | 77.1                      | 36.88                       | 2.41                 | 88.6                      | 36.76                       |
| 1976 | 2.24                | 83.3                      | 37.20                       | 2.26                 | 95.0                      | 42.05                       |
| 1977 | 2.04                | 84.7                      | 41.52                       | 2.16                 | 102.9                     | 47.63                       |

<sup>1</sup>Data excludes large purse seine CPDA and large purse seine catches from the offshore area.

<sup>2</sup>Data includes large purse seine CPDA and large purse seine catches from the offshore area.

Table 1. Catch per day at sea (CPDA) and catch per standard day at sea (CPSDA) for yellowfin tuna caught by French, Ivory Coast, Senegalese and Moroccan tuna vessels in the eastern Atlantic, 1964-1977, corrected for effort on skipjack tuna.<sup>1,2</sup>

| Year            | Baitboat <sup>3</sup> |       |         |       |         |       |         | Purse seine <sup>3</sup> |         |       |         |       |         |       |
|-----------------|-----------------------|-------|---------|-------|---------|-------|---------|--------------------------|---------|-------|---------|-------|---------|-------|
|                 | Class 1               |       | Class 2 |       | Class 3 |       | Class 4 |                          | Class 5 |       | Class 6 |       | Class 7 |       |
|                 | CPDA                  | CPSDA | CPDA    | CPSDA | CPDA    | CPSDA | CPDA    | CPSDA                    | CPDA    | CPSDA | CPDA    | CPSDA | CPDA    | CPSDA |
| 1964            | 1.66                  | 2.93  | 2.91    | 3.51  | 2.74    | 2.74  | 2.74    | 2.46                     | 2.74    | 2.28  | 2.16    | 2.18  | 2.02    | 2.02  |
| 1965            | 1.80                  | 3.18  | 2.16    | 2.61  | 2.46    | 2.46  | 2.46    | 2.13                     | 2.46    | 2.08  | 1.81    | 1.81  | 2.25    | 2.25  |
| 1966            | 1.78                  | 3.14  | 2.74    | 3.31  | 3.43    | 3.43  | 3.43    | 2.47                     | 3.43    | 2.47  | 2.15    | 2.15  | 2.24    | 2.24  |
| 1967            | 2.28                  | 4.02  | 2.88    | 3.48  | 3.63    | 3.63  | 3.63    | 2.53                     | 3.47    | 2.34  | 2.19    | 2.19  | 7.81    | 7.81  |
| 1968            | 2.59                  | 4.57  | 4.51    | 5.44  | 3.47    | 3.47  | 3.47    | 2.89                     | 3.47    | 2.77  | 2.15    | 2.15  | 7.77    | 7.77  |
| 1969            | 1.50                  | 2.65  | 2.18    | 2.63  | 3.39    | 3.34  | 3.34    | 2.28                     | 3.39    | 2.45  | 2.19    | 2.19  | 6.27    | 6.27  |
| 1970            | 1.16                  | 2.05  | 1.60    | 1.93  | 2.30    | 2.30  | 2.30    | 1.95                     | 2.30    | 2.45  | 2.15    | 2.15  | 1.81    | 1.81  |
| 1971            | 1.20                  | 2.12  | 1.55    | 1.87  | 2.10    | 2.10  | 2.10    | 1.81                     | 2.10    | 2.45  | 2.15    | 2.15  | 1.81    | 1.81  |
| 1972            | 1.33                  | 2.35  | 2.22    | 2.68  | 2.86    | 2.86  | 2.86    | 2.47                     | 2.86    | 2.47  | 2.15    | 2.15  | 1.81    | 1.81  |
| 1973            | 1.19                  | 2.10  | 2.10    | 2.09  | 2.10    | 2.10  | 2.10    | 1.95                     | 2.10    | 2.19  | 2.15    | 2.15  | 1.81    | 1.81  |
| 1974            | 1.35                  | 2.38  | 1.84    | 2.22  | 2.26    | 2.26  | 2.26    | 2.53                     | 2.34    | 2.34  | 2.19    | 2.19  | 1.81    | 1.81  |
| 1975            | 1.19                  | 2.10  | 1.84    | 2.22  | 1.81    | 1.81  | 1.81    | 2.09                     | 2.34    | 2.34  | 2.19    | 2.19  | 1.81    | 1.81  |
| 1976            | 1.67                  | 2.95  | 2.494   | 3.01  | 2.22    | 2.22  | 2.22    | 2.09                     | 2.94    | 2.94  | 2.42    | 2.42  | 1.81    | 1.81  |
| 1977            | 1.33                  | 2.35  | 1.934   | 2.33  | 2.02    | 2.02  | 2.02    | 1.99                     | 2.94    | 2.94  | 2.42    | 2.42  | 1.81    | 1.81  |
| $\bar{x}$ 69-77 | 1.32                  |       | 1.93    |       | 2.33    |       | 3.45    |                          | 5.78    |       | 9.71    |       | 7.21    |       |
| $\bar{x}$ 74-77 |                       |       |         |       | 2.08    |       |         |                          |         |       |         |       |         |       |

<sup>1</sup>In metric tons per day at sea.

<sup>2</sup>CPDA for 1964-1968 from A. Fonteneau (pers. comm. ORSTOM, Abidjan, Ivory Coast). CPDA for 1969-1977 from G. Hamm, Y. Le Hir, J. Harcellille, Statistiques de Pêche de la Flottille FISH (France, Côte d'Ivoire, Senegal, Maroc) Annuels 1976 et 1977.

<sup>3</sup>Class 2 = 100-200 metric tons carrying capacity; Class 3 = 200-300 metric tons carrying capacity; Class 4 = 300-450 metric tons carrying capacity; Class 5 = 450-600 metric tons carrying capacity; Class 6 = 600+ metric tons carrying capacity.

<sup>4</sup>Estimated from the linear regression equation of class 1 baitboat CPDA, to class 2 baitboat CPDA<sub>2</sub>. CPDA<sub>2</sub> = 0.25 + 1.64 CPDA<sub>1</sub>;  $r^2 = 0.83$ .

Table 4. Yellowfin tuna catch per unit effort (hook, rate), for Japanese longline vessels in the Atlantic Ocean, 1964-1976.

| Year              | Hook rate I <sup>1</sup><br>(fish/100 hooks) | Hook rate II <sup>2</sup> | Catch                                  |   | Hook rate III |
|-------------------|--|---------------------------|--|---|---------------|
|                   |  |                           | (fish x 10 <sup>3</sup> ) <sup>1</sup> | (metric tons x 10 <sup>3</sup> ) <sup>3</sup> |               |
| 1964              | 1.03   | 0.96                      | 879.2                                  | 35.1  | 38.32         |
| 1965              | 0.95   | 0.83                      | 927.3                                  | 36.6  | 32.76         |
| 1966              | 0.73   | 0.72                      | 394.5                                  | 33.4  | 40.88         |
| 1967              | 1.18   | 0.94                      | 366.0                                  | 12.8  | 32.87         |
| 1968              | 0.91   | 0.84                      | 274.2                                  | 13.9  | 42.58         |
| 1969              | 0.82   | 0.76                      | 241.8                                  | 10.0  | 31.43         |
| 1970              | 0.46   | 0.65                      | 189.6                                  | 6.8   | 23.31         |
| 1971              | 0.52   | 0.56                      | 292.1                                  | 11.0  | 21.09         |
| 1972              | 0.36   | 0.51                      | 159.0                                  | 7.5   | 24.06         |
| 1973              | 0.30   | 0.48                      | 108.6                                  | 4.2   | 18.56         |
| 1974              | 0.25   | 0.63                      | 94.7                                   | 4.3   | 28.61         |
| 1975              | 0.20   | 0.40                      | 116.3                                  | 6.0   | 20.64         |
| 1976 <sup>4</sup> | 0.32   | 0.56                      | 104.0                                  | 3.4   | 18.31         |
| Average 1964-76   |  |                           |  |   | 28.72         |

<sup>1</sup>Fisheries Agency of Japan (1967-1978).<sup>2</sup>Kume (pers. comm., Far Seas Fisheries Research Laboratory, Shimizu, Japan).<sup>3</sup>ICCAT (1978b).<sup>4</sup>Suzuki (pers. comm., Far Seas Fisheries Research Laboratory, Shimizu, Japan).Table 5. Catch (metric tons x 10<sup>3</sup>), catch per standard day at sea (CPSDA), and effort (standard days at sea x 10<sup>3</sup>) for the Atlantic surface and longline fishery for yellowfin tuna, 1964-1977.

| Year | Atlantic surface fishery |                         |                          | Atlantic longline fishery |                         |                          | Total Atlantic fishery |                         |                          |
|------|--------------------------|-------------------------|--------------------------|---------------------------|-------------------------|--------------------------|------------------------|-------------------------|--------------------------|
|      | CPSDA                    | Catch                   | Effort                   | CPSDA                     | Catch                   | Effort                   | CPSDA                  | Catch                   | Effort                   |
|      |                          | (MT x 10 <sup>3</sup> ) | (SDA x 10 <sup>3</sup> ) |                           | (MT x 10 <sup>3</sup> ) | (SDA x 10 <sup>3</sup> ) |                        | (MT x 10 <sup>3</sup> ) | (SDA x 10 <sup>3</sup> ) |
| 1964 | 3.10                     | 28.1                    | 9.06                     | 3.68                      | 40.3                    | 10.95                    | 3.42                   | 68.4                    | 20.01                    |
| 1965 | 2.78                     | 29.1                    | 10.47                    | 3.15                      | 40.7                    | 12.92                    | 2.98                   | 69.8                    | 23.39                    |
| 1966 | 3.29                     | 34.7                    | 10.55                    | 3.93                      | 27.2                    | 6.92                     | 3.54                   | 61.9                    | 17.47                    |
| 1967 | 3.71                     | 35.0                    | 9.43                     | 3.16                      | 21.7                    | 6.87                     | 3.48                   | 56.7                    | 16.30                    |
| 1968 | 4.41                     | 52.8                    | 11.97                    | 4.09                      | 28.2                    | 6.89                     | 4.29                   | 81.0                    | 18.86                    |
| 1969 | 2.84                     | 60.9                    | 21.44                    | 3.02                      | 30.8                    | 10.20                    | 2.90                   | 91.7                    | 31.64                    |
| 1970 | 2.24                     | 44.5                    | 19.87                    | 2.24                      | 31.3                    | 13.97                    | 2.24                   | 75.8                    | 33.84                    |
| 1971 | 2.02                     | 42.6                    | 21.09                    | 2.03                      | 29.0                    | 14.29                    | 2.02                   | 71.6                    | 35.38                    |
| 1972 | 2.51                     | 65.8                    | 26.22                    | 2.31                      | 29.6                    | 12.81                    | 2.44                   | 95.4                    | 39.03                    |
| 1973 | 2.08                     | 61.7                    | 29.66                    | 1.78                      | 32.0                    | 17.98                    | 1.97                   | 93.7                    | 47.64                    |
| 1974 | 2.20                     | 77.8                    | 35.36                    | 2.75                      | 30.3                    | 11.02                    | 2.33                   | 108.1                   | 46.38                    |
| 1975 | 2.41                     | 90.6                    | 37.59                    | 1.98                      | 29.5                    | 14.90                    | 2.29                   | 120.1                   | 52.49                    |
| 1976 | 2.26                     | 95.7                    | 42.33                    | 1.76                      | 24.6                    | 13.95                    | 2.14                   | 120.2                   | 56.28                    |
| 1977 | 2.16                     | 103.7                   | 48.00                    | 2.21 <sup>1</sup>         | 24.5                    | 11.10                    | 2.17                   | 128.2                   | 59.11                    |

<sup>1</sup>Estimated from the regression equation of longline CPSDA (CPSDA<sub>1</sub>) to surface CPSDA (CPSDA<sub>2</sub>).  
CPSDA<sub>1</sub> = 0.07 + 0.97 (CPSDA<sub>2</sub>); r<sup>2</sup> = 0.72.

Table 6. Estimated production model parameters for the eastern Atlantic surface fishery and total Atlantic surface and longline fishery, 1964-1977.

|                                    | m | Degree of fit (r <sup>2</sup> ) | U <sub>max</sub> (CPSDA) | f <sub>opt</sub> (x 10 <sup>3</sup> SDA) | y <sub>max</sub> (x 10 <sup>3</sup> MT) | q (x 10 <sup>-2</sup> ) | 1977 actual catch (x 10 <sup>3</sup> MT) | 1977 equilibrium catch (x 10 <sup>3</sup> MT) |
|------------------------------------|---|---------------------------------|--------------------------|--|---|-------------------------|--|---|
| Eastern Surface: A <sub>n</sub> =3 |   |                                 |                          |  |   |                         |  |   |
| W/o large seine data (case I)      | 0 | 0.750                           | 5.29                     | ∞  | 116.0                                   | 1.92                    | 84.7                                     | 75.9  |
|                                    | 1 | 0.705                           | 4.34                     | 47.05                                    | 75.1                                    | 2.07                    | 84.7                                     | 74.6  |
|                                    | 2 | 0.660                           | 3.92                     | 37.67                                    | 73.9                                    | 2.28                    | 84.7                                     | 73.2  |
| With large seine data (case II)    | 0 | 0.670                           | 4.69                     | ∞  | 143.1                                   | 1.84                    | 102.9                                    | 87.2  |
|                                    | 1 | 0.619                           | 4.04                     | 59.15                                    | 88.0                                    | 1.77                    | 102.9                                    | 86.0  |
|                                    | 2 | 0.572                           | 3.73                     | 45.57                                    | 85.0                                    | 1.51                    | 102.9                                    | 84.8  |
| Total Atlantic: A <sub>n</sub> =4  |   |                                 |                          |  |   |                         |  |   |
| With large seine data              | 0 | 0.722                           | 5.79                     | ∞  | 161.8                                   | 0.94                    | 128.2                                    | 109.9   |
|                                    | 1 | 0.673                           | 4.45                     | 66.77                                    | 109.3                                   | 0.95                    | 128.2                                    | 108.7   |
|                                    | 2 | 0.627                           | 3.95                     | 54.64                                    | 107.8                                   | 0.87                    | 128.2                                    | 106.8   |

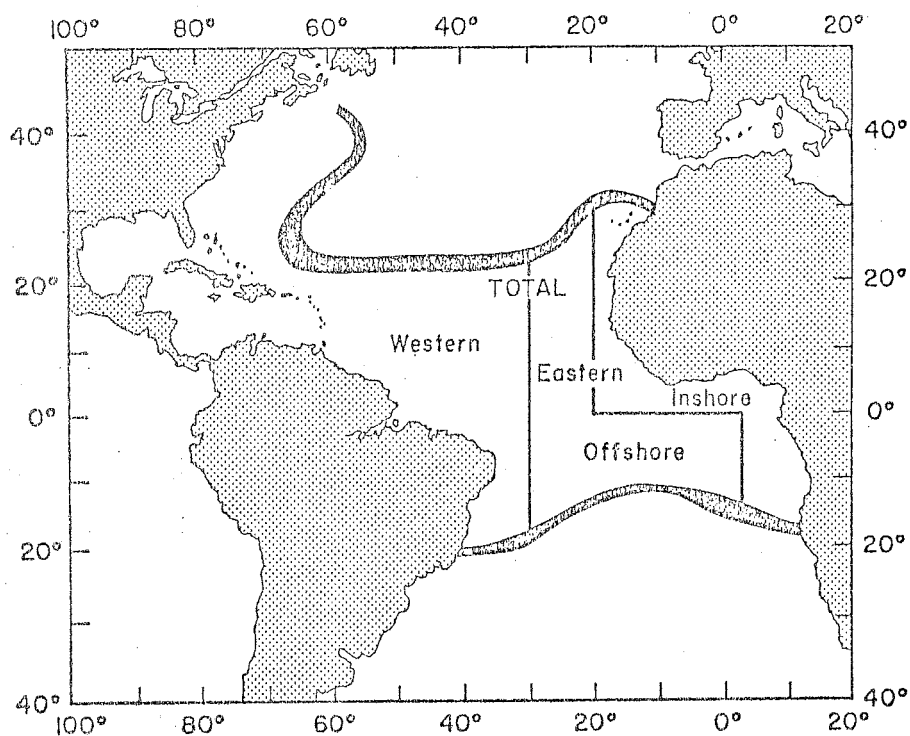


Figure 1. Regions of catches of yellowfin tuna exploited by longline and surface gears in the Atlantic Ocean. Offshore and inshore areas are shown for the eastern Atlantic.

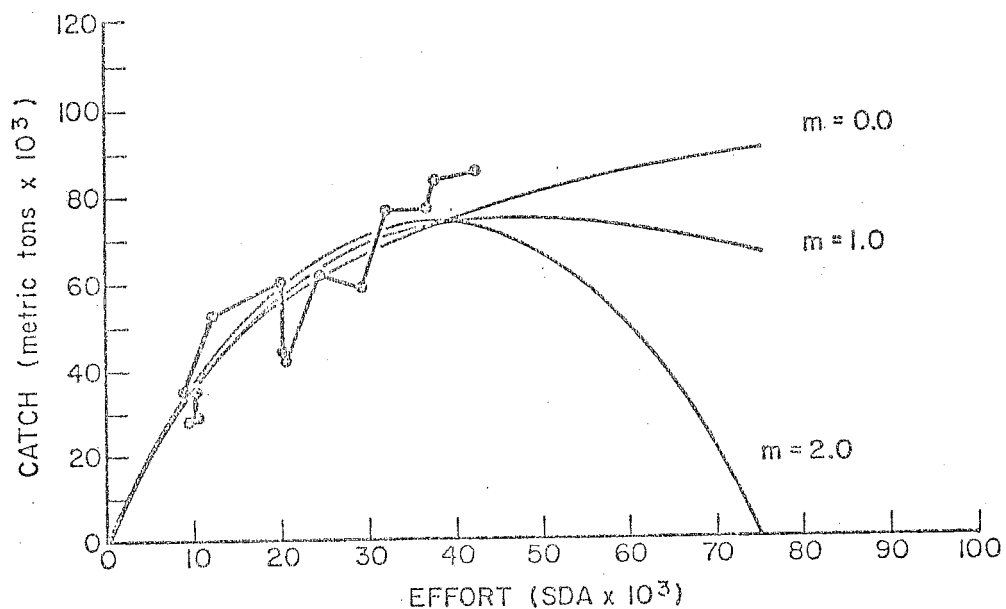


Figure 2. Equilibrium yield curves for 3 production models ( $m = 0.0$ ,  $1.0$ ,  $2.0$ ) fitted to catch (metric tons) and effort (standard days at sea) data of the eastern Atlantic surface fishery for yellowfin tuna, 1964-1977. Data from large purse seiners fishing the offshore area have been excluded.

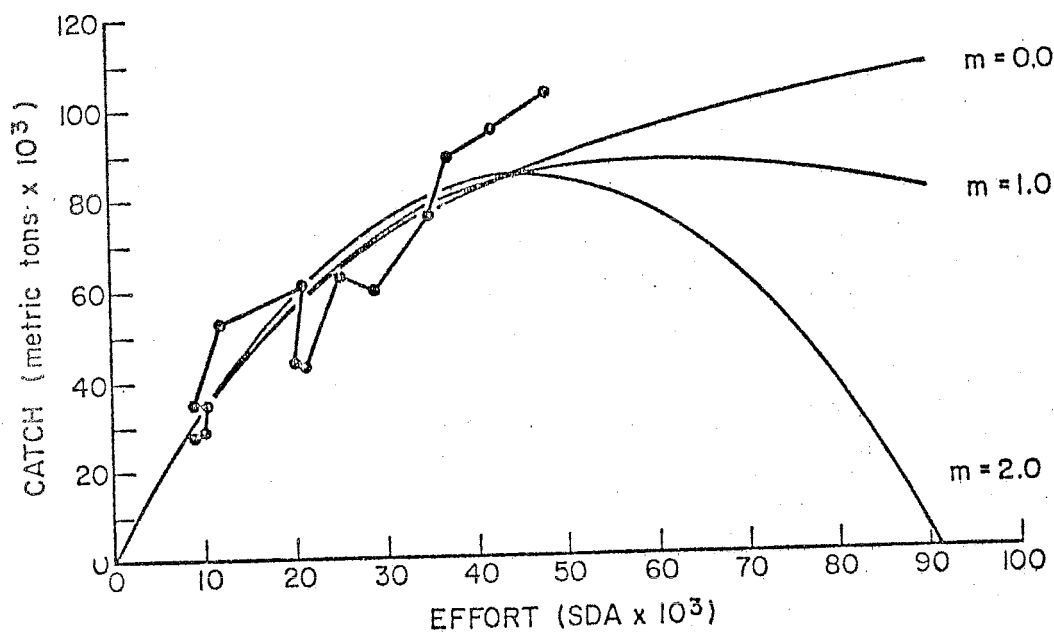


Figure 3. Equilibrium yield curves for 3 production models ( $m = 0.0, 1.0, 2.0$ ) fitted to catch (metric tons) and effort (standard days at sea) data of the eastern Atlantic surface fishery for yellowfin tuna, 1964-1977. Data from large purse seiners fishing the offshore area are included.

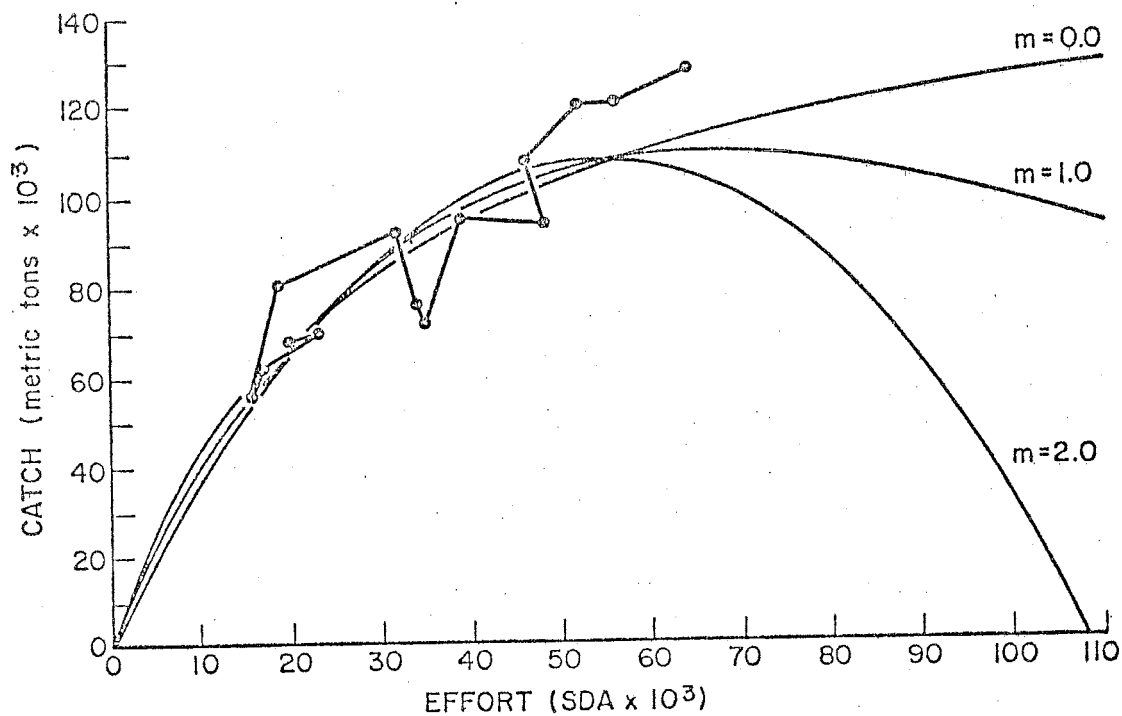


Figure 4. Equilibrium yield curves for 3 production models ( $m = 0.0, 1.0, 2.0$ ) fitted to catch (metric tons) and effort (standard days at sea) data of the total Atlantic fishery for yellowfin tuna, 1964-1977.