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YIELD-PER-RECRUIT ANALYSIS OF NORTH ATLANTIC ALBACORE (THUNNUS ALALUNGA)

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SUMMARY

In this paper, a new North Atlantic albacore demographic table is presented, based on a surface catch-by-age revision and new longline catch-by-age data.

With this demographic table, a cohort analysis was applied for the 1959-1971 cohorts, and recruitment for the population and fishing mortality for each fishery were obtained. Based on these data, a yield-per-recruit analysis was done.

RESUME

Ce document présente un nouveau tableau démographique pour le germon de l'Atlantique nord, basé sur la révision des prises de surface par âge et de nouvelles prises palangrières par âge.

A partir de ce nouveau tableau démographique, une analyse de cohortes a été appliquée aux cohortes de 1959-1971, et le recrutement de la population et la mortalité par pêche de chacune des pêcheries ont été obtenus. Une analyse de rendement par recrue a été effectuée en se basant sur ces données.

RESUMEN

En este documento se presenta una nueva tabla demográfica del rabil del Atlántico Norte, basada en captura de superficie mediante revisión de la edad y una nueva captura con palangre por edad.

Con esta tabla demográfica, se aplicó un análisis de cohortes para las cohortes de 1959-1971, obteniéndose el reclutamiento de la población y mortalidad por pesca para cada pesquería. Basándose en estos datos, se efectuó un análisis de rendimiento por recluta.

1. Introduction.

The North Atlantic albacore population is captured by means of two fishing methods - longline and surface fisheries. The surface fishery, however, is not all of the same type, but includes various methods, the most important being baitboat and trolling. (González-Garcés and Mejuto, SCRS/84/61).

In recent years the situation analysis of this population was done using production models (González-Garcés, 1981; González-Garcés and Mejuto, 1984) or multicohort analysis (Antoine and González-Garces, 1982, 1983; Bard and González-Garcés, 1980). However, cohort analysis have not been realized for serveral years. The most recent ones were those done by Bard (1978), Bartoo (1979), Le Gall (1977) and Le Gall et al (1975).

The basis problems which made the researchers avoid the use of cohort analysis was the difficulty in making a demographic table of the capture of longline fishery due to the problems in obtaining a precise age and size specific key for individuals of more than five years of age. The most often used method used until now to obtain the age-specific capture of longline fishery was the use of quarterly size-age keys (Bartoo op. cit., Morita, 1977) based on the growth equations of Bard (1974) and Beardsley (1981).

Based on the results of these cohort analyses, estimates of yield per recruit were made (Bartoo, op. cit.) Bard and González-Garcés (op. cit.) also estimated the yield per recruit of the population by means of simulation of the equilibrated population using multi-cohort analyses.

As consequence of the above it was seen that it would be useful to review the situation of the population of the North Atlantic albacore by means of cohort analyses. It would also be useful to estimate the yield per recruit of the general popultaion as well as that of the surface and longline fishery using a new demographic table of captures that would not only attempt to improve the system of assigning an age to each size, but would also take into account the updating of the total catch in the population made by different countries. Size samples for longline fishery would be included not only for Japan but also for Korea and Taiwan.

A new method was used for this to estimate the catch by age for longline fishery based on the "strength of the age group" (see chapter on methodology) that was applied to a review of the estimates of catch by size obtained from the data of catches and size samples for small areas and total catches of the population supplied by the International Commission for the Conservation of Atlantic Tuna. (ICCAT)

2. Data assessed

The data used to assess the yield-per-recruit of North Atlantic albacore were from three categories: the total yearly catch by country and gear type from 1961 through 1981, the total yearly age-specific surface catch from 1962 through 1981, and the total yearly length-specific longline catch from 1965 through 1981. The three categories are discussed individually.

The total yearly catches by country and gear type were from ICCAT (1981, 1982_a, 1982_b, and 1983). These data provided total catch levels to which age and length-specific data in the remaining two categories were raised.

The yearly age-specific surface catches were based on Spanish and French baitboat and troll data from Antoine and González-Garcés (1983), Bard and González-Garcés (1979, 1980), and González-Garcés and Mejuto (1984). Canary Islands length-frequency data were provided by A. Santos, I.E.O., Tenerife. For purposes of substitution these data were divided into four groups:

A. Spanish and French yearly age-specific baitboat catches from the Bay of Biscay.

B. Spanish yearly age-specific baitboat catches from the Canary Islands.

C. Spanish yearly age-specific catches from the fall baitboat fishery near the Azores and Madeira.

D. Spanish and French yearly trolling age-specific catches from the Bay of Biscay.

Where country or gear strata lacked data substitutions were made using age-structured data from the most appropriate of the above groups. These substitutions, by country, were as follows:

Spain - For Canary Islands catches during the years 1962 through 1972 we used group B, year 1976.

Portugal - For the period 1962 through 1972 group B catches from the same years were used. For the Azores fishery, 1974through 1981, group A data from the same period were used. Group B data, years 1974 through 1981 were used for the Madeira fishery for the same period.

U.S.A. - Group D data were used for the period 1972 through 1981.

U.S.S.R. - For years 1979 and 1981 group D data for the same years were used.

The third category, yearly length-specific longline catches, was based on the length-frequency data available from Japan, Korea and Taiwan. Based on the type of information available the countries were divided into three groups to make the estimates - Group 1 includes Japan only; Group 2: includes Korea and Taiwan, Group 3: includes the rest of the countries that fish with longline - Cuba, Panama, the United States and Venezuela.

The estimates for each group were made in the following way:

Group 1. - The Japanese length frequency samples in 1.0 intervals were weighted by the number of fish captured in the 5 degree square from which the samples were taken. The number of fish in each square was taken from catch-strength statistics for the Japanese fleet. Due to the lack of information on size frequency in 1970, this was substituted by that of 1971.

Group 2. - Due to the relatively unimportant number of size samples existing in Korea and Japan, the size frequency of the same area and quarter of one country was considered representative of the catches of any of the countries. In this case the area used was the ICCAT area. The size samples that appeared in 2 cm. intervals, were transformed into samples of 1 cm. intervals, by means of simple division by two in each interval. The size frequencies in 1.0 cm. intervals were weighted by the number of fish captured in the ICCAT areas from which the samples were taken. The number of fish in each area was estimated from the capture and effort statistics of Korea and Taiwan. The lack of data in certain years made necessary the following substitutions.

Year without data	Substitution
1965, 1966	1967
70, 71, 71, 71 and 74	1975

Group 3. - Due to lack of availability of data, the year by year size distribution of Group 2 was applied to the joint captures of all these countries.

The basic data used in this third category were provided by the Secretary of ICCAT. Data for groups 1 and 2 were processed by P. Pallares (IEO, Madrid, Spain). Data for group 3 were processed by C. Shaw (SWFC, La Jolla, California, U.S.A.)

3. Methodology

This analysis was conducted in five principal steps:

1. Calculate a year class strength index based on surface gear age frequency to be used as one weighting factor in the technique for aging longline caught albacore (next step).
2. Establish longline age frequencies from length frequency data by means of a weighted-probability matrix aging technique.
3. Combine longline age frequencies with existing age frequencies for surface caught albacore to form catch table from which cohorts are formed.
4. Conduct cohort analysis and in so doing find the average age-specific fishing mortality vector.
5. Perform a yield-per-recruit analysis for surface and longline caught albacore, both individually and combined.

Year class-Strength Index. A year class strength index was used as one of two weighting factors used to weight the probability matrix as described below. The index consists of one value for each year class used in the analysis and was found by the following procedure:

1. Calculate the age-specific catch rates for each predominant age class in the surface fishery (ages two through five) for all catch years or portions therof used in the cohort analysis.
2. Determining the highest value among all catch years or portions for each of the predominant ages.
3. For each age class, find the proportion of the highest value for each individual catch year in the analysis.
4. Finally, average the values for the predominant age classes within each cohort.

Age Longline Catches. The ages of albacore caught in the North Atlantic longline fishery were estimated by using a weighted probability matrix method which previous and ongoing research has shown to be a methodology less prone to bias than other techniques for estimating ages in catches of fish. This procedure takes into account the fact that there is measureable variability around a given growth curve and this information can be used to avoid the error of, for example, calling a large six year old fish a nine year old fish. The steps taken to age the catches with procedure are as follows:

1. Define the growth parameters to be used. The von Bertallanfy growth function was used in this study:

$$l_t = L_\infty\left[1 - \exp - k\,(t - t_o)\right]$$

where:

l_t = the length at some given time t,

L_∞ = the theoretical largest average size,

k = The von Bertallanfy growth parameter, and

t_o = the fitted x-intercept.

The specific parameters for North Atlantic albacore (from Bard, 1974) are:

L_∞ = 134.4

k = 0.183

t_o = -0.35

2. Determine the variability in the size of fish of each age around the deterministic curve. Because no information regarding this variability was available to us for North Atlantic albacore we used the variability at age for albacore in the North Pacific where growth characteristics appear to be quite similar. In North Pacific albacore the variability in sizes increases consistently with size, thus providing a constant coefficient of variation (the standard deviation divided by the mean) of 0.82. We employed this coefficient to generate a Gaussian curve around the von Bertallanfy curve at the midpoint of each age interval up to and including age six. Ages seven and older were assumed to have the same variability as age six, for want of information, real or theoretical, to indicate whether, as the fish approach their assymptote, the variability in growth increases, decreases, or stays the same. The end result of this step is an unweighted matrix with the number of rows equal to the number of size intervals (cm.) and the number of columns equal to the number of age intervals. The value in each cell is the probability of a fish of a given size being a particular age.

In the unweighted matrix described above, the area under the curve for each age is the same (each is equal to one by definition of the Gaussian curve). Weighting these curves differently is necessary to account for the fact that some ages are more likely to be caught than others, but assigning weights is a difficult, paradoxical problem because truly precise weighting factors would depend on apriori knowledge of the age structure, which, in turn, would make this exercise unnecessary. However, a sensitivity analysis in progress at the SWFC has shown that a reasonable and straightforward approximation is possible by first aging the catch by using the age-break method and using the proportions of each age as weighting factors for the probability matrix aging technique. In this study the yearly length frequencies were individually aged with the age-break method although in situations where length frequency data are consistent, the length frequency could be combined and then aged to provide overall weighting factors. A second set of weighting factors was also used to weight the ages differently and this was the year class strength index described previously. This set, given equal weight with the first set, essentially re-weighted each age class, depending on the strength of the cohort to which it belongs. Note that each set of weighting factors or combination of sets must equal one when summed across ages to ensure that the number of fish in all age groups is equal to the sum of fish in the original length frequency.

3. Combine data sets. The age-specific surface and longline data were combined to form a single catch table from which 13 cohorts (cohort years 1959 through 1971) were formed.

4. Cohort analysis. A cohort analysis was sued to estimate the average fishing mortality (F) vector for the 13 cohorts described in the previous step. This analysis was conducted using an algorithm described by Gulland (1965) implemented on a micro-computer. The fishing mortality at the oldest age was estimated for each cohort by subtracting the assumed natural mortality (M) of 0.2 annually (from Murphy and Sakagawa, 1977) from the total mortality (Z), as represented by the slope of the catch curve at the oldest ages. The individual F vectors were then averaged to produce the average F vector. This F vector was decomposed into a surface F vector and a longline F vector by apportioning the value of F at each age on the basis of the average surface and longline catches at that age.

5. The yield-per-recruit. The yield-per-recruit for the surface, longline and total fishery was estimated using the computer program MGEAR (Lenarz et al 1974) based on the algorithm of Ricker (1975) implemented on a micro-computer. These computations were made

with a time step of one year, the assumed natural mortality as stated previously and the weights at each time step from the length-weight relationsip parameters of Beardsley (1971).

4. Results and Conclusions

Table 1 presents the capture by gears of the albacore population of the North Atlantic in the period 1961 through 1981. Captures that are neither longline nor baitboat are included in the trolling gear data.

Table 2 presents the yearly demographic distribution obtained for the population of North Atlantic albacore. In 1961 through 1964 only surface fishery catches are included, while in the rest of the years, 1965 through 1981, surface fishery is included as well as longline.

There are notable differences between this table and those used by other authors in order to apply cohort analyses.

Bard (op. cit.), Le Gall (op. cit.) and Le Gall et al (op. cit.) use the same method to make their demographic tables. The most important differences in the method used in the present document are: the use by the above-mentioned authors of size frequencies proceding only from the Japanese fleet, while in this study the size frequencies of Japan, Taiwan, and Korea were used; the use of a fixed size (or length)-age key for all the years - this key doesn't reflect the possible variations of recruitment, while the present study bases its calculations of captures for age groups precisely on the "strength" of the age groups and on the differences in the total captures as much in surface fishery as in longline (basically on the latter) due to improvements in the countries' statistics, and readjustments of the division of the captures between Northern Atlantic and Southern Atlantic stock of any country. On the other hand, the three above-mentioned articles, as well as the present one, used the growth equation of Bard (1974) for their calculations.

Bartoo's demographic table (op. cit.) differes from the present one in its use of size frequencies for longline fishery of Japan and Taiwan, but not for that of Korea; the use of a fixed length-age key for all the years - this key doesn't take into account possible variations of recruitment; the use of Beardsley (1971) growth equationand differences in the total yearly captures due to the same causes explained previously.

Table 3 presents the total mortality (Z) obtained for each of the cohorts of 1959 through 1971, as well as the natural mortality (M) used and the fishing mortality (Fi = Zi - M) obtained and used as instant mortality rates for fish of the last age class (Ft) as introductory information for the cohort analyses.

Figure 1 presents the median percentage of capture by age groups in surface and longline fisheriesfrom the period 1965 through 1981. It shows clearly how surface fishery captures fundamentally, and almost exclusively, age groups 2, 3, and 4, and in an important way age 5, while longline captures fundamentally ages 6, 7, 8, 9, and 10.

The average F vector broken down into a surface F vector and a longline F vector is shown in Figure 2. It can be seen here how surface gear produces fishing mortality basically in ages 3 and 4, while longline fishery produces its maximum fishing mortality in ages 6, 7 and 8. It is interesting to point out that neither surface gear nor longline produce a great effect on age group 5. This is due perhaps to gear recruitment problems since this age group is not still recruited totally by surface gear, but not yet totally recruited by longline.

This is due to the fact that the albacore begins to mature sexually at this age. As maturation does not occur at the same time to a hundred per cent of the individuals, those that do not mature sexually continue to be accessible to surface gear since their behavior does not change, but those that do mature sexually become accessible to longline fishery due to their behavior change in the migrations they make and in the depth in which they live. However, it appears that because of these behavior changes there may be a part of the individuals that are not accesible to longline or to surface gears. This behavior change might explain the slight capture of this age group by both fishing gears.

The abundance of individuals of age group 2, obtained from cohort analysis used as recruitment index, is shown in Figure 3. It demonstrates clearly the similarity in tendencies and fluctuations compared to other estimates of recruitment obtained through cohort analyses (Bard, 1978), multicohort analyses (Antoine and Gonz´lez-Garcés, 1983) and through capture tendencies per unit of effort (CPUE) of age group 3 (González-Garcés and Mejuto, 1984).

The results of the yield-per-recruit are presented in the form of "yield lines" (isopletes) of the total population (Figure 4), of surface fishery (Figure 5) and of longline fishery (Figure 6).

The global results of the North Atlantic population, with their average yield-per-recruit of the period 1959 through 1971 of about 3.8 kilograms, are lower than those obtained by Bartoo (1979), 4.03 kilos, for the period 1963 through 1971, but higher than those obtained by Bard and González-Garcés (1980) of 3.29 kilos for the period 1962 through 1972. These differences are certainly due to the different demographic tables used in each case.

The analyses of the yield lines of the total population seem to indicate that effort variations would not cause a strong variation of the yield-per-recruit. Instead it appears that gains would be obtained by increasing the age (or size) of the first capture, in this paper considered to be at about 2 years of age, in that period.

In the case of surface fishery it also appears that strength EFFORT variations do not implicate important variations in the yield-per-recruit and that increases of age (or size) or the first capture do not cause important increases in the yield per recruit until 4 years of age, and that higher ages at first capture would cause losses.

In longline fishery, considering a first capture age for this gear of about 5 years, for the period studied, it appears that effort changes do not implicate important changes in the yield per recruit. And at the same time, it does not appear that age (or size) increases of first capture produced important increases in the yield per recruit.

CONCLUSIONS

In view of the results obtained in this paper it may be concluded that :

Fishing mortality in this population is not exercised in a uniform way throughout the life of the albacore, showing two maximums in fishing mortality, one centered around the ages of 3 and 4, and the other around the ages of 6,7,8 and 9, and especially around the ages of 7 and 8. The first maximum is due to the pressure of surface fishery and the second to long line. The recruitment evolution confirms the results other authors has obtained previously. During the period studied, cohorts from 1959-1971, the most noteworthy fact is the variability of the recruitment without clearly defined tendencies.

The results of yield per recruit seem to indicate that the cohorts from 1959 to 1971 were captured with a fishing effort that produced yields per recruit close to maximum. However the age (or size) of the first capture was somewhat low, and increases in this first capture age could result in an increase in yield per recruit.

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YEAR	Trolling (TROL)	Bait boat (BB)	Longline (LL)	TOTAL (TM)
1957	30 028	11 959	135	42 122
1958	33 945	17 558	945	52 448
1959	30 796	18 517	599	49 912
1960	33 072	18 139	1 281	52 492
1961	20 907	21 120	480	42 507
1962	30 943	21 469	5 843	58 255
1963	24 625	20 739	14 711	60 075
1964	28 058	20 428	15 868	64 354
1965	25 544	20 112	14 731	60 387
1966	22 791	16 757	7 686	47 234
1967	30 669	18 349	9 549	58 567
1968	23 993	13 936	7 746	45 675
1969	17 923	14 569	14 794	47 286
1970	15 706	14 388	16 061	46 155
1971	24 029	15 677	17 850	57 556
1972	26 527	8 196	14 727	49 450
1973	18 712	10 133	18 128	46 973
1974	20 971	16 678	14 637	52 286
1975	9 474	19 197	12 710	41 381
1976	13 918	20 402	23 006	57 326
1977	16 483	15 559	20 869	52 911
1978	22 569	11 744	14 157	48 470
1979	22 125	15 947	11 615	49 687
1980	12 586	16 177	9 470	38 233
1981	10 900	13 415	9 816	34 131
1982	12 957	15 873	13 190	42 020

Table 1.- Captures of North Atlantic albacore by fishery, and total, 1957 through 1982.

Year/Age	2	3	4	5	6	7	8	9	10+
1961	924 200	4 461 200	1 804 199	291 200	0	0	0	0	0
1962	648 400	5 195 901	2 617 700	294 200	0	0	0	0	0
1963	1 032 899	4 080 200	3 209 899	185 100	0	0	0	0	0
1964	824 600	5 690 500	2 523 799	208 100	0	0	0	0	0
1965	3 210 199	3 864 002	2 224 676	66 548	165 222	225 545	135 179	44 163	14 532
1966	701 116	5 432 516	1 258 743	199 478	178 130	98 910	34 114	8 759	1 032
1967	1 599 300	6 318 399	1 915 191	287 298	67 320	164 056	92 092	25 598	3 091
1968	1 114 700	4 576 198	1 636 499	231 790	247 729	59 309	19 873	2 077	500
1969	464 800	4 267 200	1 117 700	516 095	284 391	157 320	23 227	3 093	600
1970	2 546 270	2 462 493	1 246 465	471 680	302 252	118 700	52 508	12 036	5 445
1971	879 598	5 562 652	943 655	632 167	261 742	235 833	44 586	17 571	4 579
1972	856 325	2 851 516	1 448 072	633 069	216 710	179 684	86 876	16 738	7 358
1973	202 501	2 299 539	1 671 447	642 600	306 158	210 810	88 284	36 868	6 488
1974	128 352	1 902 313	2 469 274	648 603	210 563	194 560	75 841	32 366	20 312
1975	379 201	920 449	1 402 927	468 958	360 223	218 202	113 867	63 451	47 366
1976	659 366	2 336 055	732 952	1 066 232	582 902	396 884	99 445	36 591	7 041
1977	421 403	2 546 239	1 415 243	943 327	595 870	192 123	93 304	17 233	6 515
1978	2 374 950	2 878 240	1 269 060	507 411	413 618	178 024	44 474	16 697	21 053
1979	855 419	3 420 766	1 889 949	293 991	163 281	103 417	76 359	30 712	24 592
1980	1 064 182	2 738 384	1 353 395	214 389	104 114	44 624	48 326	37 029	33 239
1981	842 062	1 060 270	1 507 476	627 532	131 751	84 649	45 932	63 291	49 902

Table 2.- Demographic table of yearly captures of North Atlantic albacore. For the period 1961 through 1964 only surface fishery is included. For 1965 through 1981 the total captures of both surface fisheries and longline are included.

Cohort	Z	M	F_t
1959	0.547	0.2	0.347
1960	0.465	0.2	0.265
1961	0.818	0.2	0.618
1962	0.510	0.2	0.310
1963	0.717	0.2	0.517
1964	0.591	0.2	0.391
1965	0.562	0.2	0.362
1966	0.510	0.2	0.310
1967	0.404	0.2	0.204
1968	0.643	0.2	0.443
1969	0.603	0.2	0.403
1970	0.838	0.2	0.638
1971	0.553	0.2	0.353

Table 3.- Instantaneous mortality rates of the cohorts in the period 1959 through 1971 of the North Atlantic albacore population. Z = total mortality. M = natural mortality. F = fishing mortality.

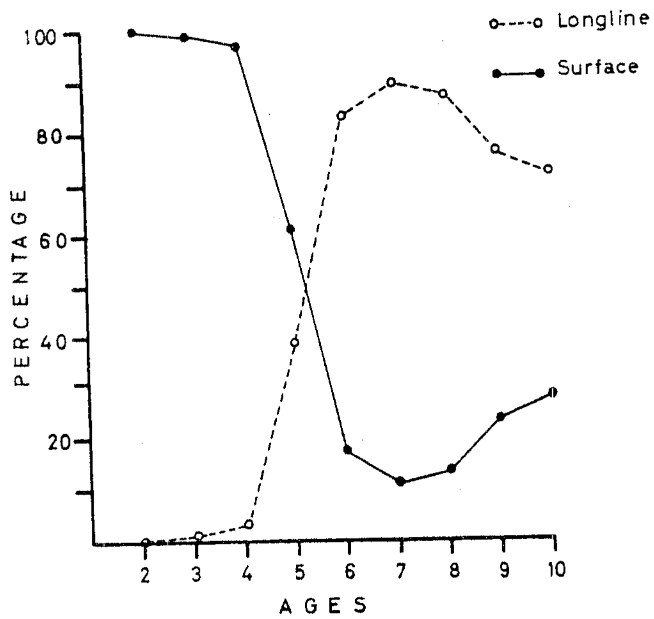

Figure 1.- Average percentage for the years 1965 through 1981, of the capture by surface fishery and by longline of the North Atlant: albacore.

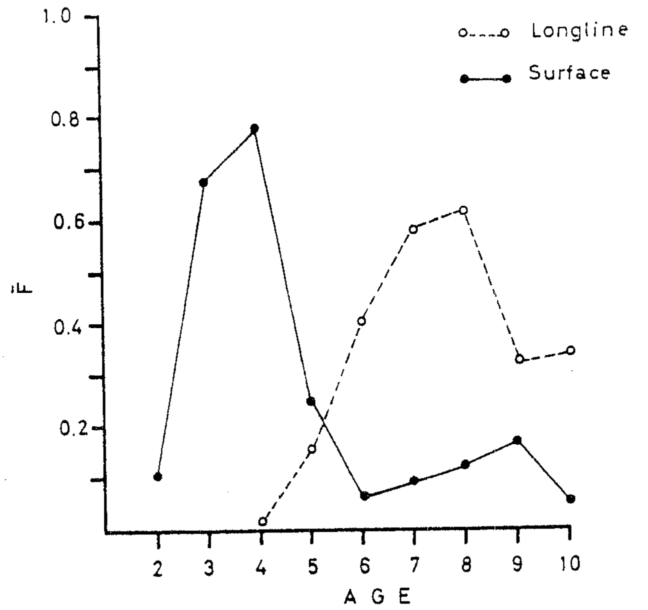

Figure 2.- Average vector of fishing mortality (F) decomposed into an average surface vector (F_s) and an average longline vector (F_{ll}) The F vectors were averaged for the cohorts from 1959 through 1971.

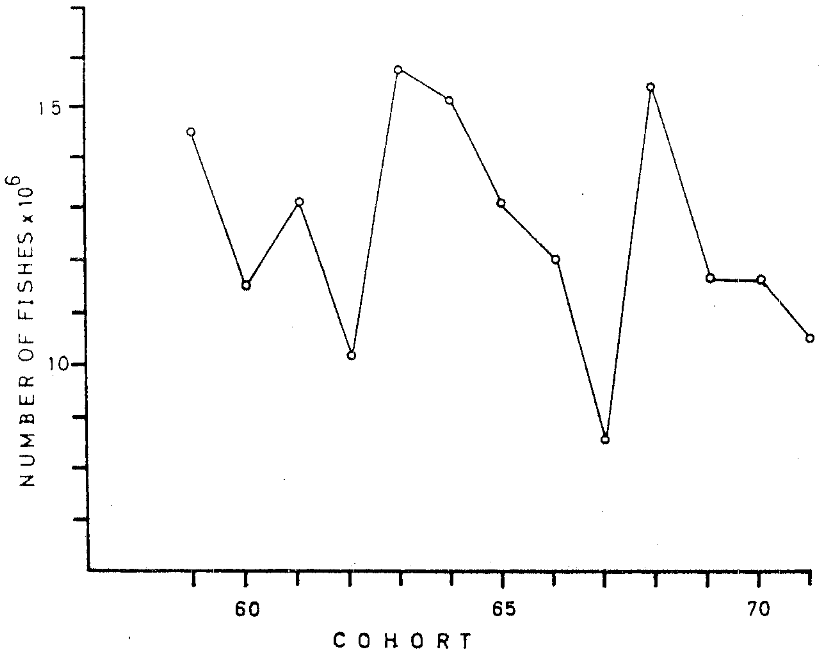

Figure 3.- Recruitment in abundance of fishes of age 2, of the population of North Atlantic albacore.

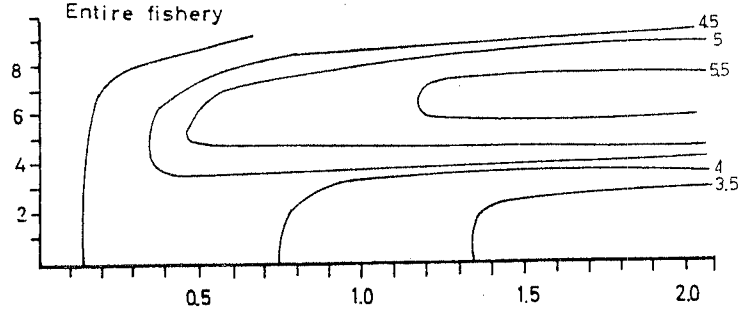

Figure 4.-Isopleths (yield lines) of yield per recruit of the total fishery of North Atlantic albacore.

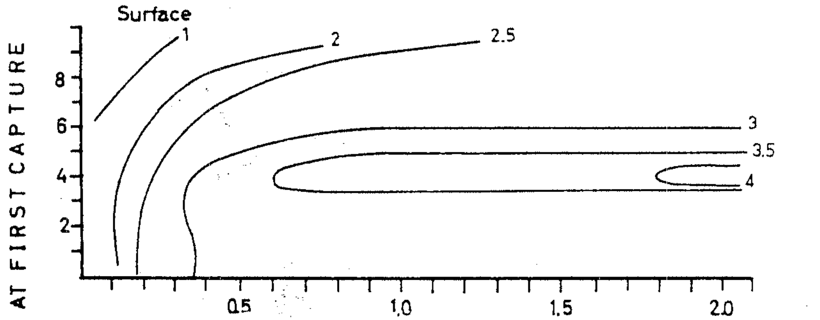

Figure 5.- Isopleths (yield lines) of yield per recruit of the surface fishery of North Atlantic albacore.

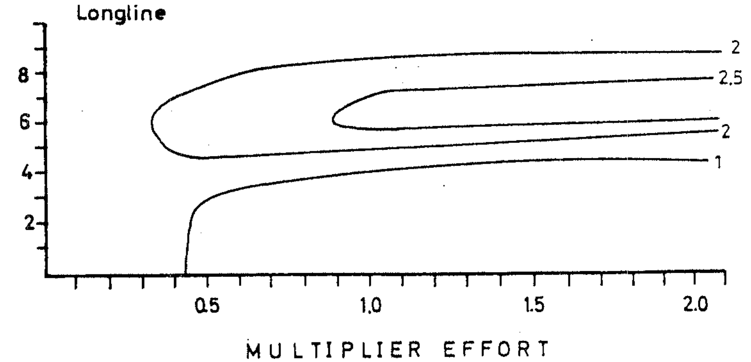

Figure 6.- Isopleths (yield lines) of yield per recruit of the long-line fishery of North Atlantic albacore.