DIRECTOR OF INVESTIGATIONS
INTER-AMERICAN TROPICAL TUNA COMMISSION
c/o SCRIPPS INSTITUTION OF OCEANOGRAPHY
LA JOLLA, CALIFORNIA, 92037

INTER-AMERICAN TROPICAL TUNA COMMISSION

COMISION INTERAMERICANA DEL ATUN TROPICAL

Internal Report - Informe Interno

No.3

PROCEDURES FOR ESTIMATING THE PARAMETERS OF THE SCHAEFER YIELD MODEL FOR YELLOWFIN TUNA

by

William H. Bayliff

La Jolla, California
1967

P R E F A C E

The Internal Report series is produced primarily for the convenience of staff members of the Inter-American Tropical Tuna Commission. It contains reports of various types. Some will eventually be modified and published in the Commission's Bulletin series or in outside journals. Others are methodological reports of limited interest or reports of research which yielded negative or inconclusive results.

These reports are not to be considered as publications. Because they are in some cases preliminary, and because they are subjected to less intensive editorial scrutiny than contributions to the Commission's Bulletin series, it is requested that they not be cited without permission from the Inter-American Tropical Tuna Commission.

P R E F A C I O

Se ha producido una serie de Informes Internos con el fin de que sean útiles a los miembros del personal de la Comisión Interamericana del Atún Tropical. Esta serie incluye varias clases de informes. Algunos serán modificados eventualmente y publicados en la serie de Boletines de la Comisión o en revistas exteriores de prensa. Otros son informes metodológicos de un interés limitado o informes de investigación que han dado resultados negativos o inconclusos.

Estos informes no deben considerarse como publicaciones, debido a que en algunos casos son datos preliminares, y porque están sometidos a un escrutinio editorial menos intenso que las contribuciones hechas en la serie de Boletines de la Comisión; por lo tanto, se ruega que no sean citados sin permiso de la Comisión Interamericana del Atún Tropical.

C O N T E N T S

	Page
INTRODUCTION	1
STATISTICS	1
FITTING LINES TO THE DATA	3
Schaefer lines	4
Bartlett lines	4
Least-squares lines	5
MAXIMUM EQUILIBRIUM YIELD	6
DISCUSSION	8
Data used in previous studies	8
Comparison of Data 1, 2, 3, 4, 5, and 6	8
FIGURES	10
TABLES	12
LITERATURE CITED	19

PROCEDURES FOR ESTIMATING THE PARAMETERS OF THE SCHAEFER YIELD MODEL FOR YELLOWFIN TUNA

by

William H. Bayliff

INTRODUCTION

This report has been prepared for employees of the Tuna Commission because there has been confusion concerning (1) the various series of catch and catch-per-unit-of-effort data and how they have been obtained and (2) the procedures for the calculations necessary for recommending regulations for the fishery. It is suggested that the catch and catch-per-unit-of-effort data in this report be used in all cases until better estimates can be made. The procedures in this report are not necessarily the best, but are close to those which have been used in the past for describing the condition of the fishery and for making recommendations for regulation. It is suggested that these procedures be used until they are improved in a well-documented publication or internal report.

STATISTICS

Several measures of the catch of yellowfin tuna in the eastern Pacific Ocean for 1934-1965 are listed in Table 1.

Records of the landings for each year are available almost from the inception of the fishery (Shimada and Schaefer 1956: Table 10). In some years fish were landed without specification as to whether they were yellowfin or skipjack (Anonymous 1966: Table 1). Orange (1966a) has prorated the landings by species, but these have not been published.

Some of the fish landed early in a given year were actually caught late in the preceding year, while some of those caught late in the given year were not landed until the following year. Beginning in 1958, the Commission has made corrections for the "carryovers," and calculated the actual catches for each year. Orange's (1966a) prorated landings were used to calculate these catches.

It has been argued that the catches of yellowfin tuna by the Japanese longline fishery should not be included with those by the surface fishery for use with the Schaefer model, so they are listed separately in order that they can be subtracted from the total landings or catches.

The catches of yellowfin tuna in the eastern Pacific Ocean are measured as follows:

Column in Table 1	Years	Data	Reference
A	1934-1955	landings, without prorations for species	Schaefer 1956: Table 1, with minor corrections for 1939, 1949, 1951, 1953, and 1955 by Orange 1966a
A	1956-1957	same	Orange 1966a
A	1958-1965	same	Orange 1966b
B	1934-1965	landings, with prorations for species	Orange 1966a
C	1958-1965	catch	Orange 1966b
D	1934-1965	Japanese catch	Orange 1966a
E	1934-1965	A minus D	
F	1934-1965	B minus D	
G	1958-1965	C minus D	

Several measures of the catch per unit of effort of yellowfin tuna in the eastern Pacific Ocean for 1934-1965 are listed in Table 2. The catches per unit of effort are measured as follows:

Column in Table 2	Years	Data	Standardized to	Reference
A	1934-1950	catch per day's absence by baitboats, landed in a given year	catch per standard day's fishing by Class-4 baitboats	Shimada and Schaefer 1956: Table 18
B	1951-1959	catch per day's fishing by baitboats, landed in a given year	catch per standard day's fishing by Class-4 baitboats	Broadhead 1962: Table 10
C	1960-1965	catch per day's fishing by baitboats and purse seiners, caught in a given year	catch per standard day's fishing by Class-4 baitboats	Orange 1966a
D	1951-1965	catch per day's fishing by baitboats, caught in a given year	catch per standard day's fishing by Class-4 baitboats	Orange 1966c
E	1953-1965	catch per day's fishing by purse seiners, caught in a given year	catch per standard day's fishing by Class-3 purse seiners	Orange 1966c

Broadhead (1962) refers to the catch-per-unit-of-effort data by year of landing and by year of catch as "trip" and "logbook" data, respectively. The data are shown in Table 2.

The following data have been used by the Commission for computations involving the Schaefer yield model:

catch -- 1934-1957: Table 1, Column A; 1958-1965: Table 1, Column C;

catch per unit of effort -- 1934-1950: Table 2, Column A; 1951-1959: Table 2, Column B; 1960-1965: Table 2, Column C.

These data are designated as Data 1. The following combinations of catch and catch-per-unit-of-effort data are also considered in this report:

Data 2

catch -- 1934-1957: Table 1, Column E; 1958-1965: Table 1, Column G;

catch per unit of effort - same as above;

Data 3

catch -- 1934-1957: Table 1, Column B; 1958-1965: Table 1, Column C;

catch per unit of effort - same as above;

Data 4

catch -- 1934-1957: Table 1, Column F; 1958-1965: Table 1, Column G;

catch per unit of effort - same as above;

Data 5

catch -- 1959-1966: Table 1, Column C;

catch per unit of effort - 1959-1966: Table 2, Column E;

Data 6

catch -- 1959-1966: Table 1, Column G;

catch per unit of effort -- same as above.

For the last two combinations preliminary estimates of the catch and catch per unit of effort for 1966 were used (Table 4).

FITTING LINES TO THE DATA

The estimation of the parameters for the Schaefer model is based on the functional relationship between the catch per unit of effort and effort. Using Schaefer's notation, this can be expressed by

$$\bar{U} = M - \frac{1}{a}(F) \qquad (1a)$$

where

$\bar{U}$ = catch per unit of effort,

F = effort (catch divided by catch per unit of effort), and

M and a = constants.

Schaefer, however, used

$$F = a(M - \overline{U}) \qquad (1b)$$

in his Figure 1, while in his Figure 3 he used

$$\overline{U} = \frac{1}{a}(aM - C_e/\overline{U}) \qquad (1c)$$

where $C_e/\overline{U} = F$ (at equilibrium).

Schaefer lines

The constants could be evaluated by some simple regression technique, such as that of Bartlett (1949), if the stock were at equilibrium each year, but such is not the case. For instance, if the effort were suddenly increased after several years of relatively low effort the catch per unit of effort would be higher than it would if that effort were employed at equilibrium conditions, and *vice-versa*. Schaefer (1957:253-255) presents a method for evaluating M and a, and also k_2, the coefficient of catchability, under equilibrium conditions. For this calculation values of $\overline{U}$, $C/\overline{U}$, ΔU, and $\Delta U/\overline{U}$ for each year are used, C being the catch and ΔU being calculated by Schaefer's Formula (12). These values for Data 1 and 5 are shown in Tables 3 and 4. For this report for the 1935-1964 data the three constants were evaluated by solving three equations simultaneously, as recommended by Schaefer and Beverton (1963). The first and second of these correspond to Schaefer's (1957) Formula (15) for two equal, or nearly equal, segments of the data. The third corresponds to his Formula (16). The segments for the first two equations include the data for 1935-1949 and 1950-1964, respectively. The calculation is accomplished with computer program CIAT D03 (Psaropulos 1966). The constants in the regressions calculated by the Schaefer method with various catch and catch-per-unit-of-effort data are shown in Table 5. In this report no further use is made of the M, a, or k_2 estimates made by the Schaefer method, so these calculations could have been omitted.

Bartlett lines

When k_2 has been estimated it is possible to estimate ΔP $(= \Delta U/k_2)$, C_e $(= C + \Delta P)$, and $C_e/\overline{U}$. The last of these is a measure of F under equilibrium conditions. Since Schaefer's (1957) value for k_2 of 3.8059×10^{-5} has been consistently used in Tuna Commission publications in preference to those obtained with data for more recent years, for Data 1 through 4 in the present report it is used instead of the new values.

The $\underline{\Delta P}$, $\underline{C_e}$, and $\underline{C_e/\bar{U}}$ values for Data 1 are shown in Table 3.

The averages for $\bar{U}$ for 1960 through 1965 for Class-4 baitboats (Table 2: Column C) and Class-3 purse seiners (Table 2: Column E) are 5,142 and 9,188 pounds, respectively. From this it is calculated that $\underline{k_2}$ for Class-3 purse seiners is $(9,188/5,142) \times 3.8059 \times 10^{-5} = 6.8006 \times 10^{-5}$. This value is used to calculate $\underline{\Delta P}$, $\underline{C_e}$, and $\underline{C_e/\bar{U}}$ for Data 5 and 6. The $\underline{\Delta P}$, $\underline{C_e}$, and $\underline{C_e/\bar{U}}$ values for Data 5 are shown in Table 4.

The Bartlett (1949) method for fitting a line to the regression of $\bar{U}$ on $\underline{C_e/\bar{U}}$ is described by Schaefer (1957:257). Following his procedure, the two extreme groups were taken as those with the 10 highest and 10 lowest values of $\underline{C_e/\bar{U}}$ for the Data 1 through 4 regressions and those with the 2 highest and 2 lowest values of $\underline{C_e/\bar{U}}$ for the Data 5 and 6 regressions. The constants in the regressions calculated by the Bartlett method with various catch and catch-per-unit-of-effort data are shown in Table 5.

$\underline{t}$ tests for linearity, as described by Bartlett (1949), were performed with Data 1 through 4. Low values of $\underline{t}$ were obtained in all cases (Table 5), which indicates that the data do not differ significantly from linearity at the 10-percent level.

Least-squares lines

The least-squares regressions were calculated with computer program CIAT D01 (Psaropulos 1966). The output from this program gives $\underline{M}$ as "B0" and $-1/\underline{a}$ as "B1." Natrella (1963:Chapter 5), who gives a superior discussion of regression, refers to these as "b_0" and "b_1," respectively. The constants in the regressions calculated by the least-squares method with various catch and catch-per-unit-of-effort data are shown in Table 5. The regression lines for Data 1 and 5 are shown in the upper panels of Figures 1 and 2.

What Schaefer (1957) refers to as "standard error of estimate (standard deviation from regression)" and Natrella as "s_Y" is given as "S.D. LINE" in the output. The estimates of this are also shown in Table 5.

The confidence limits of the predicted values of $\bar{U}$ for various values of $\underline{C_e/\bar{U}}$ are obtained by solving the regression with CIAT D01 with the values of $\underline{C_e/\bar{U}}$ punched in columns 41-50 of the control cards. Values of "PRED VAL" ("Y_c" in Natrella) and "S.D.PR VAL" ("s_{Y_c}" in Natrella) are obtained from the output. The 90-percent confidence limits for the predicted values of $\bar{U}$ are calculated by $Y_c \pm t(s_{Y_c})$, the appropriate values of *t* being obtained from a *t* table (Natrella:page 5-44). This is equivalent to the procedure used by Schaefer. (It should be noted that though these confidence limits appear to be straight lines parallel to the regression line in Schaefer's Figure 3, such is not the case, as can be confirmed with a straight edge.) The 90-percent confidence limits of the predicted values of $\overline{U}$ for Data 1 and 5 are shown as dashed lines in the upper panels of Figures 1 and 2.

MAXIMUM EQUILIBRIUM YIELD

At equilibrium Formula (1a) can be written

$$\frac{C_e}{F_e} = M - \frac{1}{a}(F_e), \qquad (1d)$$

and this can be transformed to the parabola

$$C_e = MF_e - \frac{1}{a}(F_e{}^2) \qquad (2)$$

To get the value of F_e which corresponds to the maximum C_e value the first derivative of this equation is set equal to zero and solved for F_e.

$$\frac{dC_e}{dF_e} = M - \frac{2}{a}(F_e) = 0$$

$$\frac{2}{a}(F_{eo}) = M$$

$$F_{eo} = aM/2 \qquad (3)$$

where F_{eo} = effort required to maintain the stock at its "optimum" size.

When *aM*/2 is substituted for F_e in Formula (2) the result is

$$C_{eo} = aM^2/4 \qquad (4)$$

where C_{eo} = equilibrium catch at the optimum stock size = maximum equilibrium catch.

When Formula (4) is divided by Formula (3) the result is

$$C_{eo}/F_{eo} = \overline{U}_o = M/2$$

where $\overline{U}_o$ = catch per unit of effort at the optimum stock size.

The values of $\underline{F_{eo}}$, $\underline{C_{eo}}$, and $\underline{\overline{U}_o}$ for each regression line are shown in Table 5.

The lower panels in Figures 1 and 2 show the transformations of the least-squares regression lines in the upper panels to parabolae, and also the 90-percent confidence limits of the predicted values of $\underline{\overline{U}}$. These show the equilibrium catch and its confidence limits at various values of $\underline{F_e}$, as explained by Schaefer (1957:page 259, Figure 5).

In the procedure above for calculating the confidence limits for the predicted values of $\underline{\overline{U}}$ corresponding to selected values of $\underline{F_e}$, these values were punched in Columns 41-50 of the control cards to get the confidence limits of the predicted $\underline{\overline{U}}$ values. When $\underline{F_{eo}}$ is used the confidence limits of the predicted $\underline{\overline{U}_o}$ are obtained. These, in turn, can be used to obtain the confidence limits of $\underline{C_{eo}}$, using

$$C_{eo(lower)} = F_{eo}\overline{U}_{o(lower)} \qquad (6a)$$

$$C_{eo(upper)} = F_{eo}\overline{U}_{o(upper)} \qquad (6b)$$

STOCK SIZE

At equilibrium Formula (1b) can be written

$$C_e/\overline{U} = a(M - \overline{U}), \qquad (1e)$$

and this can be transformed to the parabola

$$C_e = aM\overline{U} - a\overline{U}^2 \qquad (7)$$

The relation between the stock size and the catch per standard day's fishing is given by

$$P = \overline{U}/k_2 \qquad (8)$$

where $\underline{P}$ = stock size in pounds.

For this calculation Schaefer's (1957) value of 26,275 for $1/k_2$ is used. Using the values of $\underline{M}$ and $\underline{a}$ obtained by the Bartlett method for Data 1, it is determined from Formulae (7) and (8) that the relationship between the equilibrium yield and stock size is expressed by

$$C_e = 2.45614\ P - (8.24905 \times 10^{-9})\ P^2 \qquad (9a)$$

The estimates of the optimum and maximum stock sizes are 148,874,000 and 297,748,000 pounds, respectively.

Using the values of $\underline{M}$ and $\underline{a}$ obtained by the Bartlett method for Data

5, and the value of 14,704 calculated previously for $1/\underline{k_2}$, it is determined that the relationship between the equilibrium yield and stock size is expressed by

$$C_e = 2.68377\ P - (9.05714 \times 10^{-9})P^2 \qquad (9b)$$

The estimates of the optimum and maximum stock sizes are 148,158,000 and 296,315,000 pounds, respectively.

DISCUSSION

Data used in previous studies

The data on the regression of catch per unit of effort on effort have been presented in several different ways in various publications of the Tuna Commission, sometimes without adequate explanation as to how they were derived. In Table 6 the data employed and the methods used for fitting the lines are listed. It should be especially noted that though the Bartlett lines are fitted to points of $(\underline{C_e}/\overline{U}, \overline{U})$, in some of the figures points of $(\underline{C}/\overline{U}, \overline{U})$ are shown with Bartlett lines. The values of $\underline{M}$ and $\underline{a}$ presented by Anonymous (1966) differ slightly from those used in the present report because the 1965 catch data were preliminary when the former line was calculated and because of a different method of dividing the data into three groups for fitting the Bartlett line was employed in the former calculation.

Comparison of Data 1, 2, 3, 4, 5, and 6

It has been argued that the catches of yellowfin tuna by the Japanese longline fishery should not be included with those by the surface fishery for use with the Schaefer model, as the former may not be of the same stock as those caught by the surface fishery. However, the standard errors of estimate of the lines $(\underline{s_Y})$ are slightly lower when the Japanese data are included (Data 1 _versus_ Data 2, Data 3 _versus_ Data 4, and Data 5 _versus_ Data 6), which is the opposite of what would be expected if the fish caught by the Japanese fishery were of a different stock. Therefore it appears that the Japanese data should continue to be included with the surface fishery data.

Prior to 1958 fish landed without specification as to whether they were yellowfin or skipjack were not included in the calculations, while beginning in that year these landings were prorated by species before calculating the catches. The parameters of the model have been calculated using Orange's (1966a) prorations of the landings prior to 1958 (Data 3 and 4). The standard errors of estimate of the lines ($s_{\underline{Y}}$) are slightly higher when the prorated data are included (Data 3 *versus* Data 1 and Data 4 *versus* Data 2). For this reason it is suggested that the data not be changed.

Data 5 and 6 are included only as a matter of interest, since adequate purse-seine data are available for too few years to calculate the parameters with accuracy comparable to that believed to be obtained with Data 1 through 4. It is interesting to note, however, that the maximum equilibrium yields calculated with Data 5 and 6 are close to those calculated with Data 1, 2, 3, and 4.

In conclusion, it is suggested that Data 1 continue to be used until good reasons are found for changing them. These data (1) include the catches by the Japanese longline fishery, (2) exclude the landings prior to 1958 not assigned by species, and (3) use baitboat data for 1934 through 1959 and baitboat and purse-seine data for 1960 through 1965 to standardize the catch per unit of effort to Class-4 baitboat units.

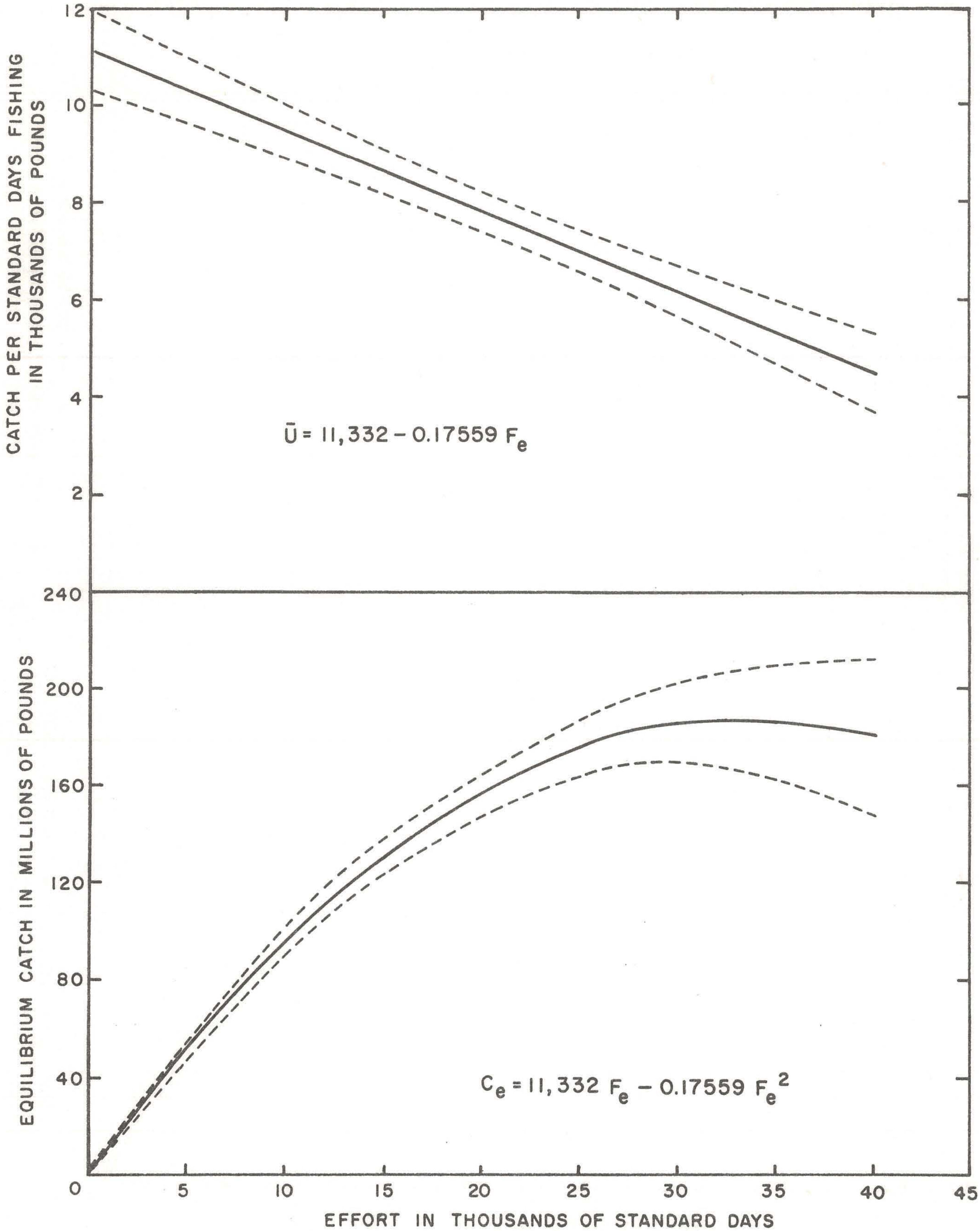

FIGURE 1. Relationships between catch per standard day's fishing and effort (upper panel) and equilibrium catch and effort (lower panel) for Data 1, calculated by the least-squares method.

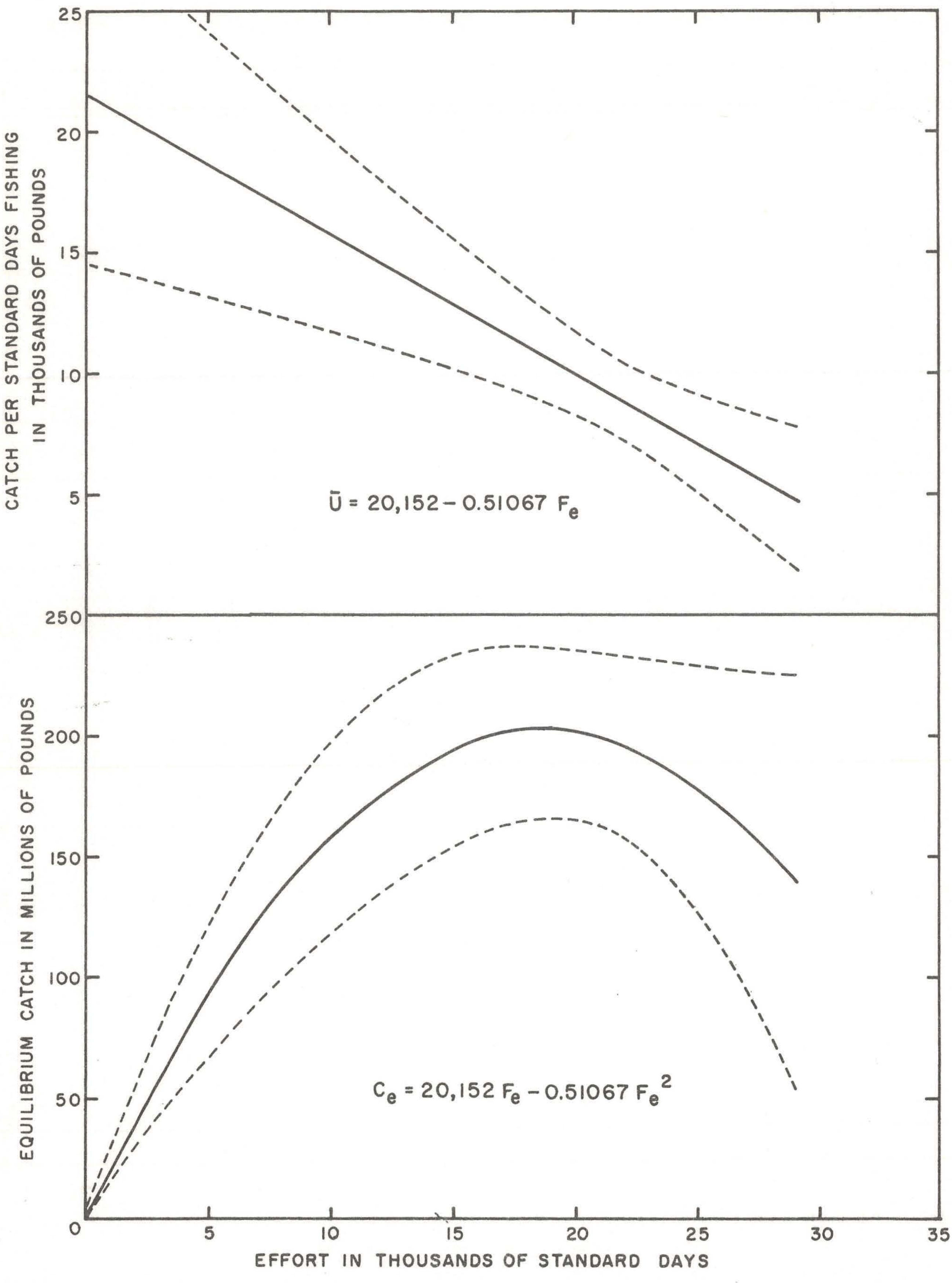

FIGURE 2. Relationships between catch per standard day's fishing and effort (upper panel) and equilibrium catch and effort (lower panel) for Data 5, calculated by the least-squares method.

TABLE 1. Measures of the catch of yellowfin tuna, in thousands of pounds, in the eastern Pacific Ocean during 1934 through 1965. The symbols at the tops of the columns are explained in the text.

	A	B	C	D	E	F	G
1934	60,913	60,913	?	0	60,913	60,913	?
1935	72,294	72,294	?	0	72,294	72,294	?
1936	78,353	78,353	?	0	78,353	78,353	?
1937	91,522	91,522	?	0	91,522	91,522	?
1938	78,288	78,288	?	0	78,288	78,288	?
1939	110,418	110,418	?	0	110,418	110,418	?
1940	114,590	114,590	?	0	114,590	114,590	?
1941	76,841	76,841	?	0	76,841	76,841	?
1942	41,965	41,965	?	0	41,965	41,965	?
1943	50,058	50,058	?	0	50,058	50,058	?
1944	64,094	64,869	?	0	64,094	64,869	?
1945	89,194	89,194	?	0	89,194	89,194	?
1946	129,701	129,701	?	0	129,701	129,701	?
1947	160,134	160,151	?	0	160,134	160,151	?
1948	200,340	206,993	?	0	200,340	206,993	?
1949	192,459	200,070	?	0	192,459	200,070	?
1950	224,810	224,810	?	0	224,810	224,810	?
1951	183,686	186,015	?	0	183,686	186,015	?
1952	192,234	195,277	?	0	192,234	195,277	?
1953	138,919	140,042	?	0	138,919	140,042	?
1954	138,623	140,033	?	0	138,623	140,033	?
1955	140,865	140,865	?	0	140,865	140,865	?
1956	177,026	177,026	?	3	177,023	177,023	?
1957	162,978	163,020	?	11	162,967	163,009	?
1958	149,942	150,195	148,450	1,228	148,714	148,967	147,222
1959	145,422	145,422	140,484	572	144,850	144,850	139,912
1960	234,200	234,500	244,331	2,245	231,955	232,255	242,086
1961	239,772	239,772	230,886	5,077	234,695	234,695	225,809
1962	172,484	172,484	174,063	11,122	161,362	161,362	162,941
1963	144,347	144,347	145,469	7,734	136,613	136,613	137,735
1964	197,734	197,734	203,882	7,336	190,398	190,398	196,546
1965	188,750	188,750	180,086	6,392	182,358	182,358	173,685

TABLE 2. Measures of the catch per unit of effort of yellowfin tuna, in pounds per day, in the eastern Pacific Ocean during 1934 through 1965. The symbols at the tops of the columns are explained in the text.

	A	B	C	D	E
1934	10,361				
1935	11,484				
1936	11,571				
1937	11,116				
1938	11,463				
1939	10,528				
1940	10,609				
1941	8,018				
1942	7,040				
1943	8,441				
1944	10,019				
1945	9,512				
1946	9,292				
1947	7,857				
1948	8,353				
1949	8,363				
1950	7,057				
1951		9,809		10,108	
1952		6,097		5,606	
1953		3,814		3,852	6,508
1954		5,546		5,339	3,492
1955		7,895		8,191	7,551
1956		6,579		6,507	9,711
1957		6,245		6,090	8,962
1958		4,588		4,768	12,679
1959		5,220		4,982	14,004
1960			6,817	7,635	15,966
1961			5,544	7,285	9,654
1962			4,298	7,331	6,117
1963			4,376	9,176	5,982
1964			5,166	6,810	10,042
1965			4,648	7,438	7,365

TABLE 3. Data 1 for calculation of the yield of yellowfin tuna in the eastern Pacific Ocean. The symbols at the tops of the columns are explained in the text.

	C	$\overline{U}$	$C/\overline{U}$	ΔU	$\Delta U/\overline{U}$	ΔP	C_e	$C_e/\overline{U}$
1934	60,913	10,361	5,879					
1935	72,294	11,484	6,295	605.0	0.05268	15,896	88,190	7,679
1936	78,353	11,571	6,771	-184.0	-0.01590	- 4,835	73,518	6,354
1937	91,522	11,116	8,233	- 54.0	-0.00486	- 1,419	90,103	8,106
1938	78,288	11,463	6,830	-294.0	-0.02565	- 7,725	70,563	6,156
1939	110,418	10,528	10,488	-427.0	-0.04056	-11,219	99,198	9,422
1940	114,590	10,609	10,801	-1255.0	-0.11830	-32,975	81,615	7,693
1941	76,841	8,018	9,584	-1784.5	-0.22256	-46,888	29,953	3,736
1942	41,965	7,040	5,961	211.5	0.03004	5,557	47,522	6,750
1943	50,058	8,441	5,930	1489.5	0.17646	39,137	89,195	10,567
1944	64,094	10,019	6,397	535.5	0.05345	14,070	78,164	7,802
1945	89,194	9,512	9,377	-363.5	-0.03821	- 9,551	79,643	8,373
1946	129,701	9,292	13,958	-827.5	-0.08906	-21,743	107,958	11,618
1947	160,134	7,857	20,318	-469.5	-0.05976	-12,336	147,798	18,811
1948	200,340	8,353	23,984	253.0	0.03029	6,648	206,988	24,780
1949	192,459	8,363	23,013	-648.0	-0.07748	-17,026	175,432	20,977
1950	224,810	7,057	31,856	723.0	0.10245	18,997	243,807	34,548
1951	183,686	9,809	18,726	-480.0	-0.04893	-12,612	171,073	17,440
1952	192,234	6,097	31,529	-2997.5	-0.49164	-78,759	113,475	18,612
1953	138,919	3,814	36,423	-275.5	-0.07223	- 7,238	131,680	34,525
1954	138,623	5,546	24,995	2040.5	0.36792	53,614	192,237	34,662
1955	140,865	7,895	17,842	516.5	0.06542	13,571	154,436	19,561
1956	177,026	6,579	26,908	-825.0	-0.12540	-21,677	155,349	23,613
1957	162,978	6,245	26,097	-995.5	-0.15941	-26,157	136,821	21,909
1958	148,450	4,588	32,356	-512.5	-0.11170	-13,466	134,984	29,421
1959	140,484	5,220	26,913	1114.5	0.21351	29,283	169,767	32,522
1960	244,331	6,817	35,841	162.0	0.02376	4,257	248,588	36,466
1961	230,886	5,544	41,646	-1259.5	-0.22718	-33,093	197,793	35,677
1962	174,063	4,298	40,499	-584.0	-0.13588	-15,345	158,718	36,928
1963	145,469	4,376	33,242	434.0	0.09918	11,403	156,872	35,848
1964	203,882	5,166	39,466	136.0	0.02633	3,573	207,455	40,158
1965	180,086	4,648	38,745					

TABLE 4. Data 5 for calculation of the yield of yellowfin tuna in the eastern Pacific Ocean. The symbols at the tops of the columns are explained in the text. The data in parentheses are preliminary.

	C	$\overline{U}$	$C/\overline{U}$	ΔU	$\Delta U/\overline{U}$	ΔP	C_e	$C_e/\overline{U}$
1959	140,484	14,004	10,032					
1960	244,331	15,966	15,303	-2175	-0.13623	-31,981	212,350	13,300
1961	230,886	9,654	23,916	-4924	-0.51005	-72,402	158,484	16,416
1962	174,063	6,117	28,456	-1836	-0.30015	-26,997	147,066	24,042
1963	145,469	5,982	24,318	1962	0.32798	28,849	174,318	29,140
1964	203,882	10,042	20,303	692	0.06891	10,175	214,057	21,316
1965	180,086	7,365	24,452	(79)	(0.01073)	(1,162)	(181,248)	(24,609)
1966	(180,000)	(10,200)	(17,647)					

TABLE 5. Data on the estimation of the parameters of the Schaefer model for yellowfin tuna in the eastern Pacific Ocean. The symbols at the tops of the columns are explained in the text.

Method of fitting line	Source	Input			Results			
		Years	F	$1/k_2$	k_2	$1/k_2$	a	M
Schaefer	Schaefer, 1957	1935-1954	$C/\overline{U}$	-	3.8059×10^{-5}	26,275	6.10366	11,246
	Broadhead, unpublished	1935-1960	"	"	6.19157×10^{-5}	16,151	?	?
	present report, Data 1	1935-1964	"	"	6.34610×10^{-5}	15,758	5.39032	11,587
	" " Data 2	1935-1964	"	"	6.37040×10^{-5}	15,698	5.25466	11,640
	" " Data 3	1935-1964	"	"	6.32446×10^{-5}	15,812	5.39157	11,609
	" " Data 4	1935-1964	"	"	6.34859×10^{-5}	15,752	5.25586	11,662
	" " Data 5	1960-1965	"	"	-	-	-	-
	" " Data 6	1960-1965	"	"	-	-	-	-
Bartlett	Schaefer, 1957	1935-1954	C_e/U	26,275	-	-	6.0884	11,252
	Broadhead and Barrett, 1964	1935-1960	"	26,275	-	-	5.72122	11,309
	Broadhead, unpublished	1935-1960	"	16,151	-	-	5.89703	11,255
	present report, Data 1	1935-1964	"	26,275	-	-	5.69510	11,332
	" " Data 2	1935-1964	"	26,275	-	-	5.53795	11,387
	" " Data 3	1935-1964	"	26,275	-	-	5.70477	11,344
	" " Data 4	1935-1964	"	26,275	-	-	5.54762	11,399
	" " Data 5	1960-1965	"	14,704	-	-	1.95820	20,152
	" " Data 6	1960-1965	"	14,704	-	-	1.83631	20,392
least-squares	Schaefer, 1957	1935-1954	C_e/U	26,275	-	-	6.38153	11,139
	Broadhead, unpublished	1935-1960	"	26,275	-	-	6.04714	11,142
	" "	1935-1960	"	16,151	-	-	5.71224	11,354
	present report, Data 1	1935-1964	"	26,275	-	-	6.02476	11,136
	" " Data 2	1935-1964	"	26,275	-	-	5.86715	11,183
	" " Data 3	1935-1964	"	26,275	-	-	6.04636	11,141
	" " Data 4	1935-1964	"	26,275	-	-	5.89201	11,186
	" " Data 5	1960-1965	"	14,704	-	-	1.74462	21,494
	" " Data 6	1960-1965	"	14,704	-	-	1.64645	21,684

Results								
aM	$\frac{1}{a}$	t	s_Y	$\overline{U}_o$	90-percent confidence limits for $\overline{U}_o$	F_{eo}	C_{eo}	90-percent confidence limits for C_{eo}
68,641	0.16384							
?	?							
62,460	0.18552							
61,162	0.19031							
62,590	0.18547							
61,292	0.19026							
–	–							
–	–							
68,505	0.16425	?		5,626		34,253	192,705	
64,703	0.17479	?		5,655		32,351	182,932	
66,373	0.16958	?		5,628		33,187	186,757	
63,535	0.17559	0.406		5,666		32,268	182,828	
63,060	0.18057	0.287		5,693		31,530	179,516	
64,713	0.17529	0.308		5,672		32,356	183,526	
63,238	0.18026	0.212		5,700		31,619	180,212	
39,462	0.51067			10,076		19,731	198,810	
37,446	0.54457			10,196		18,723	190,900	
71,084	0.15670		1,477	5,570		35,542	197,951	
67,377	0.16537		1,396	5,571		33,668	187,679	
64,857	0.17506		?	5,677		32,428	184,097	
67,093	0.16598		1,331	5,568	4,949-6,187	33,546	186,787	166,019-207,549
65,614	0.17044		1,340	5,592	4,971-6,212	32,807	183,440	163,084-203,797
67,363	0.16539		1,335	5,570	4,950-6,191	33,682	187,623	166,726-208,525
65,909	0.16972		1,345	5,593	4,971-6,216	32,954	184,315	163,814-204,842
37,500	0.57319		1,927	10,747	8,861-12,633	18,750	201,506	166,144-236,869
35,576	0.60737		2,082	1[illegible],842	8,793-12,967	17,788	192,857	156,410-230,756

TABLE 6. Methods used by the Tuna Commission for fitting lines to the relationships of catch per unit of effort and effort of yellowfin tuna.

Reference	Figure	Line	Method of fitting line	Data	Points
Schaefer, 1957	1	dashed	Schaefer	1935-1954	$C/\overline{U}$
Ibid.	3	solid	Bartlett	1935-1954	$C_e/\overline{U}$
Ibid.	3	dashed	least squares	1935-1954	$C_e/\overline{U}$
Schaefer, 1958	4	dashed	Schaefer	1935-1954	$C/\overline{U}$
Schaefer, 1959	4	dashed	Schaefer	1935-1954	$C/\overline{U}$
Schaefer, 1960	4	dashed	Schaefer	1935-1954	$C/\overline{U}$
Schaefer, 1961	3	dashed	Schaefer	1935-1954	$C/\overline{U}$
Schaefer, 1962	4	dashed	Schaefer	1935-1954	$C/\overline{U}$
Schaefer, 1963	4	dashed	Schaefer	1935-1954	$C/\overline{U}$
Ibid.	4	solid	Bartlett	1935-1960	$C/\overline{U}$
Broadhead and Barrett, 1964	10	upper	Bartlett	1935-1954	$C_e/\overline{U}$
Ibid.	10	lower	Bartlett	1935-1960	$C_e/\overline{U}$
Anonymous, 1964	9	dashed	Schaefer	1935-1954	$C/\overline{U}$
Ibid.	9	solid	Bartlett	1935-1960	$C/\overline{U}$
Anonymous, 1965	8	dashed	Schaefer	1935-1954	$C/\overline{U}$
Ibid.	8	solid	Bartlett	1935-1960	$C/\overline{U}$
Anonymous, 1966	1	dashed	Bartlett	1935-1964	$C/\overline{U}$

LITERATURE CITED

Anonymous. 1964. Inter-Amer. Trop. Tuna Comm., Ann. Rep.,1963:89 p.

________. 1965. Ibid., 1964:98 p.

________. 1966. Ibid., 1965:106 p.

Bartlett, M. S. 1949. Fitting a straight line when both variables are subject to error. Biometrics, 5(3):207-212.

Broadhead, G. C. 1962. Recent changes in the efficiency of vessels fishing for yellowfin tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 6(7):281-332.

________, and I. Barrett. 1964. Some factors affecting the distribution and apparent abundance of yellowfin and skipjack tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull.,8 (8):417-473.

Natrella, M. G. 1963. Experimental Statistics. U.S. Department of Commerce, National Bureau of Standards Handbook, 91.

Orange, C. J. 1966a. personal communication.

________. 1966b. Annual tuna landings and catch. Memorandum to Director of Investigations dated 6 October 1966 and amendment dated 29 December 1966.

________. 1966c. Catch rates by seiners and baitboats. Memorandum to Director of Investigations dated 6 October 1966.

Psaropulos, C. T. (editor). 1966. Computer Program Manual. Inter-Amer. Trop. Tuna Comm., Internal Rep., 1.

Schaefer, M. B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 2(6):245-285.

________. 1958. Report on the investigations of the Inter-American Tropical Tuna Commission for the year 1957. Inter-Amer. Trop. Tuna Comm., Ann. Rep., 1957:31-134.

________. 1959. Ibid., 1958:34-121.

________. 1960. Ibid., 1959:39-156.

________. 1961. Ibid., 1960:40-183.

________. 1962. Ibid., 1961:44-171.

________. 1963. Ibid., 1962:34-149.

________, and R. J. Beverton. 1963. Fishery dynamics -- their analysis and interpretation. p.464-483. In M. N. Hill (editor), The Sea--Ideas and Observations on Progress in the Study of the Seas, Vol.2, The Composition of Sea-Water, Comparative and Descriptive

Oceanography. Interscience Publishers, New York:xv + 554 p.

Shimada, B. M., and M. B. Schaefer. 1956. A study of the changes in fishing effort, abundance, and yield for yellowfin and skipjack tuna in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 1(7);347-469.