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MATHEMATICAL TECHNIQUES AND COMPUTER PROGRAMS USED TO CALCULATE BIOMASS INDICES OF TUNAS

by

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P R E F A C E

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P R E F A C I O

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INTRODUCTION

This Internal Report has been compiled to present methods and computer programs used by J. J. Pella and C. T. Psaropulos in analyses of yellowfin and skipjack data reported in IATTC Bulletin 16(4) entitled: Measures of Tuna Abundance from Purse-Seine Operations in the Eastern Pacific Ocean, Adjusted for the Fleet-Wide Evolution of Increased Fishing Power, 1960-1971. That study was prompted by the need to adjust tuna abundance measures for changes in purse-seine fishing technique and equipment which increased the efficiency of the fleet in capturing tunas. The following discussion provides details of methods and computer programs omitted from the publication of the study.

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Program LINFIT

This program computes regression coefficients and sample variance for the relationship between time in set and set size; these are punched onto cards for input to Program PREMEG.

1. Input

Column	Format	Item	Example
Card 1 - sample size			
1-5	I5	number of pairs of observations	113
Card 2 - identification card			
1-5	5X	comment	YEAR=
6-9	I4	year	1965
10-22	13X	comment	SCHOOL TYPE=
23	I1	school type	2 (school fish)
24-35	12X	comment	SIZE CLASS=
36	I1	size class	6
37-45	9X	comment	QUARTER=
46	I1	quarter	4
Card 3,4,... - data cards			
1-6	F6.0	set time for first set	70 (70 minutes)
7-12	F6.1	set size for first set	0 (no catch set)
13-18	F6.0	set time for second set	
	.	.	
	.	.	
	.	.	
61-66	F6.0	set time for sixth set	
67-72	F6.1	set size for sixth set	

continue on additional cards until n pairs of the sample are exhausted. The above cards are repeated for the next school type, size class or quarter. Any number of consecutive problems may be run.

2. Output

Punched cards containing regression coefficients and sample variance of the set time and size of set relationship.

Column	Format	Item	Example
1,2	I2	school type	1 (porpoise-associated)
3,4	I2	size class	4
5,6	I2	quarter	1
7-21	E15.5	$\hat{\alpha}$	2.01453 E 00
22-36	E15.5	$\hat{\beta}$	5.07078 E-02
37-51	E15.5	$\hat{\sigma}^2$	8.96301 E-01
52-57	I6	number of points in sample	82

3. Method

A linear relationship between time in set and size of the set is assumed,

$$y = \alpha + \beta x + \epsilon \qquad \ldots(1)$$

where

y is the time in hours to complete the set

x is the size of the catch in tons

α, β are constants

ϵ is a random variable with mean 0 and variance σ^2.

The following equations are evaluated in the program:

$$\hat{\beta} = \left(\sum_i^n x_i y_i - \sum_i^n x_i \sum_i^n y_i/n\right) \Big/ \left[\sum_i^n x_i^2 - \left(\sum_i^n x_i\right)^2/n\right] \qquad \ldots(2)$$

$$\hat{\alpha} = \sum_i^n y_i/n - \hat{\beta} \sum_i^n x_i/n \qquad \ldots(3)$$

and

$$\hat{\sigma}^2 = \left\{\sum_i^n y_i^2 - \left(\sum_i^n y_i\right)^2/n - \left(\sum_i^n x_i y_i - \sum_i^n x_i \sum_i^n y_i/n\right)^2 \Big/ \left[\sum_i^n x_i^2 - \left(\sum_i^n x_i\right)^2/n\right]\right\} \Big/ (n-2) \qquad \ldots(4)$$

Program PREMEG

The function of this program is to process logbook information on cards and store the output onto magnetic tape for input to Program MEGALO.

1. Input

a) catch and effort data cards sorted by 5° areas on magnetic tape packed 25 cards per physical record

b) single set data cards sorted by 5° areas on magnetic tape packed 25 cards per physical record in the same order as the catch and effort data

c) vessel cruising speed data on cards

d) regression coefficients and sample variances of Program LINFIT on cards.

Column	Format	Item	Example
		Description of purse-seine catch and effort card	
1-8	I6,I2	area	20507525
9	I1	vessel size class	5
10,11	I2	month	06 (June)
12-14	F3.1	days effort	70 (7.0 days)
15-18	F4.1	yellowfin catch	775 (77.5 tons)
19-22	F4.1	skipjack catch	20 (2.0 tons)
23-26	F4.1	yellowfin and skipjack	
27-30	F4.1	yellowfin or skipjack	
31-33	I3	vessel number	122 (Western King)
34-80	47X	remaining information not used	

Description of single set card

1-6	I6	area	030115
7-9	I3	IATTC vessel number	120
10	I1	vessel size class	4
11,12	I2	month	07
13-19	7X	information not used	
20-22	I3	pure yellowfin	025 (25 tons)
23-26	4X	blank	

Column	Format	Item	Example
27-29	I3	pure skipjack	
31-33	I3	yellowfin in mixed schools	
35-37	I3	mixed yellowfin and skipjack unknown ratio	
39-41	I3	skipjack in mixed schools	
42-56	I5X	information not used	
57	I1	type of school	5 (unknown type)
58-60	3X	blank	
61	I1	zero catch with tuna species in school	
62	I1	guess of species of zero catch if unknown	
63-80	I8X	information not used	

Description of the vessel speed cards

1-21	21X	boat name	A A FERRANTE
22-25	F4.1	vessel speed	8.5 (knots)
26-34	9X	blank	
35	I1	vessel size class	3
36-42	7X	blank	
43-45	I3	IATTC vessel number	1

Last vessel speed card is blank.

Description of set time cards

1,2	I2	school type	porpoise-associated (entered as 1)
3,4	I2	vessel size class	3
5,6	I2	quarter of the year	1 (Jan.-Mar.)
7-21	E15.5	$\hat{\alpha}$	1.40935 E+00
22-36	E15.5	$\hat{\beta}$	1.11338 E-01
37-51	E15.5	$\hat{\sigma}^2$	1.43271 E+00
52-57	6X	sample size	65

2. Method

This program outputs to magnetic tape a series of computations using the above input data. Interplay of two magnetic tapes of information and two sets of data decks necessitates describing the computational process generally, before the details of algorithmic procedures are considered. Input information is organized and calculations made as follows:

a) main program reads vessel speed cards and calls subroutine SUCSET

b) subroutine SUCSET reads time in set regression coefficients and sample variances, and single set data from first magnetic tape (storing this information in arrays) continuing until a 5° area change occurs; this causes a return to the main program

c) main program reads catch and effort data from the second magnetic tape and checks if the 5° area designation agrees with the single set 5° area; if they agree, the information for the 5° area is stored in arrays

d) main program calls the second entry point into the subroutine SUCSET which executes the following procedure:

   1) computes estimates of the total numbers of successful sets on pure yellowfin, pure skipjack and mixed schools;

   2) allocates the unknown sets using the number of reported sets;

   3) estimates total number of successful sets on each of the four school categories; namely, porpoise-associated, pure yellowfin, pure skipjack, and mixed sets;

   4) allocates the reported successful and unsuccessful sets into four school categories;

   5) allocates the reported unknown successful and unsuccessful sets into the four school categories (reported successful unknown sets are those for which the species composition is reported,

but no indication was provided in the vessel logs of whether the tuna school was associated with porpoise or debris, free swimming or captured at night);

6) estimates average weight (tonnage) of sets by species and school categories;

7) calculates mean set time and its variance.

e) control returns to the main program which computes successful set probabilities using results at (4) and (5) and expected number of successful sets per day of the four school categories using results at (3) along with the summarized effort;

f) outputs computations onto magnetic tape;

g) initializes the storage arrays in the main program, calls the first entry into the subroutine SUCSET and reads in the next 5° area block of single set information; this process continues until all data are processed.

3. Catch Information

We now discuss how some catch information identified on the single set cards is used to assign the set to one of the four school categories; namely, porpoise-associated schools, pure yellowfin schools, pure skipjack schools, and mixed schools.

The single set cards provide the following information:

Type of school (as punched in column 57 on the single set cards)

1 - school fish
2 - porpoise-associated
3 - night sets
4 - logs (debris)
5 - unknown

Species (as punched in column 61 of the single set card and used only to identify a skunk set; species of successful sets is obtained from catch information in Columns 20-41)

1 - unknown
2 - yellowfin alone
3 - skipjack alone
4 - yellowfin and skipjack
5 - yellowfin and/or skipjack together with other species as bluefin

The type of school and species are categorized into the four school categories by the following rules:

Let the pair (a,b) represent a school of type a and species composition b. Then an (a,b) set is defined as belonging to one of the four school categories by the following rules:

sets on (2,2), (2,3), or (2,4) are on porpoise-associated fish;

sets on (1,2) or (4,2) are on yellowfin school fish;

sets on (1,3) or (4,3) are on skipjack school fish;

sets on (1,4) or (4,4) are on mixed school fish.

The procedure for night sets and unknown school types will be described in the next section.

4. Estimation of the Total Number of Successful Sets

Since individual successful sets are not always reported by the vessels, although total catches by species are available, the following algorithm is used to estimate the total number of successful sets made on pure yellowfin, pure skipjack, and mixed schools using the relationships

$$\begin{aligned} N_1 w_1 + N_3 w_3 &= Y \\ N_2 w_2 + N_3 w_3' &= S \end{aligned} \qquad \ldots(5)$$

where

N_1 is the total number of sets on pure yellowfin, reported or not reported in the vessel log books;

N_2 and N_3 are corresponding numbers of such sets on pure skipjack schools and mixed schools, respectively;

w_1 and w_2 are the mean catch in weight per successful set reported in the log books for pure yellowfin and pure skipjack schools, respectively;

w_3 and w_3' are the mean catch in weight per successful set of yellowfin and skipjack, respectively, caught in mixed schools;

Y and S are the total weights of yellowfin and skipjack caught in the stratum by the size class.

Let

n_1, n_2, and n_3 be the numbers of reported pure yellowfin, pure skipjack, and mixed yellowfin and skipjack successful sets, respectively. If $n_i \neq 0$ for all i, we assume that

$$\frac{n_i}{n_j} = \frac{N_i}{N_j} \qquad \begin{matrix} i = 1,2,3 \\ j = 1,2,3 \end{matrix} \qquad \text{or}$$

$$\frac{n_1}{n_3} = \frac{N_1}{N_3} \quad \text{and} \quad \frac{n_1}{n_2} = \frac{N_1}{N_2} \ .$$

It is no more likely to report sets on pure yellowfin, pure skipjack, or mixed schools.

Then we expect

$$N_3 = N_1 \frac{n_3}{n_1} \qquad\qquad N_2 = N_1 \frac{n_2}{n_1} \ .$$

Substituting into (5) we obtain

$$\begin{aligned} N_1 w_1 + N_1 \frac{n_3}{n_1} w_3 &= Y \\ N_1 \frac{n_2}{n_1} w_2 + N_1 \frac{n_3}{n_1} w_3' &= S \ . \end{aligned} \qquad \ldots(6)$$

Let (6) be written as

$$A N_1 + B N_1 = Y$$

$$D N_1 + E N_1 = S$$

and solving for N_1 by least squares we obtain

$$\hat{N}_1 = \frac{(A+B)\ Y + (D+E)\ S}{(A+B)^2 + (D+E)^2}$$

then

$$\hat{N}_2 = \frac{n_2}{n_1}\hat{N}_1$$

$$\hat{N}_3 = \frac{n_3}{n_1}\hat{N}_1 .$$

If $n_1=0$ but $n_2\neq 0$, solve (1) in N_2

$$0 + N_2\frac{n_3}{n_2}w_3 = Y$$

$$w_2N_2 + N_2\frac{n_3}{n_2}w_3' = S \qquad \ldots(7)$$

Let (7) be written as

$$0 + AN_2 = Y$$

$$DN_2 + EN_2 = S$$

similarly we obtain by least squares

$$\hat{N}_2 = \frac{AY + (D+E)S}{A^2 + (D+E)^2}$$

If $n_1=0$ and $n_2=0$ but $n_3\neq 0$, then

$$0 + AN_3 = Y$$

$$0 + BN_3 = S$$

where $A=w_3$ and $B=w_3'$ then by least squares we obtain

$\hat{N}_3 = \frac{AY + BS}{A^2 + B^2}$; however, $\hat{N}_3 = \frac{Y + S}{A + B}$ was used for 1960-1971. The least squares form will be used in the future.

At this point estimates of the total numbers of successful sets made on pure yellowfin, pure skipjack and mixed schools are available. These totals are then allocated as next described into the four school categories using data on the single set cards.

5. Allocation of Total Estimated Successful Sets

Define for the single set cards for a 5° area, month and size class

m_{ij} = number of sets reported on the single set cards with type of school i and school composition type j.

Set Type	School Composition Type	
school fish	pure yellowfin	m_{11}
	pure skipjack	m_{12}
	mixed	m_{13}
porpoise-associated	pure yellowfin	m_{21}
	pure skipjack	m_{22}
	mixed	m_{23}
night set	pure yellowfin	m_{31}
	pure skipjack	m_{32}
	mixed	m_{33}
log sets	pure yellowfin	m_{41}
	pure skipjack	m_{42}
	mixed	m_{43}
unknown set	pure yellowfin	m_{51}
	pure skipjack	m_{52}
	mixed	m_{53}

Let

$$m_{.1} = m_{11} + m_{21} + m_{31} + m_{41}$$

$$m_{.2} = m_{12} + m_{22} + m_{32} + m_{42}$$

$$m_{.3} = m_{13} + m_{23} + m_{33} + m_{43}$$

$$m^*_{11} = m_{11} + \frac{m_{51}\ m_{11}}{m_{.1}}$$

$$m^*_{12} = m_{12} + \frac{m_{52}\ m_{12}}{m_{.2}}$$ school fish

$$m^*_{13} = m_{13} + \frac{m_{53}\ m_{13}}{m_{.3}}$$

$$m^*_{21} = m_{21} + \frac{m_{51}\ m_{21}}{m_{.1}}$$

$$m^*_{22} = m_{22} + \frac{m_{52}\ m_{22}}{m_{.2}}$$ porpoise-associated

$$m^*_{23} = m_{23} + \frac{m_{53}\ m_{23}}{m_{.3}}$$

and

$$m^*_{41} = m_{41} + \frac{m_{51}\ m_{41}}{m_{.1}}$$

$$m^*_{42} = m_{42} + \frac{m_{52}\ m_{42}}{m_{.2}}$$ logs

$$m^*_{43} = m_{43} + \frac{m_{53}\ m_{43}}{m_{.3}}$$

Let

$$m^*_{.1} = m^*_{11} + m^*_{21} + m^*_{41}$$

$$m^*_{.2} = m^*_{12} + m^*_{22} + m^*_{42}$$

$$m^*_{.3} = m^*_{13} + m^*_{23} + m^*_{43}$$

Then, to estimate total number of successful sets on each school type, the following calculations are performed:

$$\text{porpoise sets} \quad M_1 = \frac{m^*_{21}}{m^*_{.1}} \hat{N}_1 + \frac{m^*_{22}}{m^*_{.2}} \hat{N}_2 + \frac{m^*_{23}}{m^*_{.3}} \hat{N}_3$$

$$\text{yellowfin school fish sets} \quad M_2 = \frac{m^*_{11} + m^*_{41}}{m^*_{.1}} \hat{N}_1$$

$$\text{skipjack school fish sets} \quad M_3 = \frac{m^*_{12} + m^*_{42}}{m^*_{.2}} \hat{N}_2 \qquad \ldots(8)$$

$$\text{mixed school fish sets} \quad M_4 = \frac{m^*_{13} + m^*_{43}}{m^*_{.3}} \hat{N}_3$$

These estimates are subsequently used to estimate the expected number of successful sets per fishing day.

6. Allocation of the Unknown Reported Successful Set Types

In order to estimate proportions of sets which were successful on each school type, only records of vessels which reported operations in detail were used. Even when vessels reported sets in detail, they sometimes neglected to indicate on which particular school type a successful or unsuccessful set was made; these sets were called unknown sets above. When a successful set was reported, but the type of school was not indicated, the 5° area-month stratum was examined to determine which school categories were reported there. On this basis the unknown reported successful set types were allocated as follows:

> Let n_i $(i=1,2,3,4)$ be the number of reported successful single sets on the four school categories. For an unknown yellowfin set (mixed sets use the same procedure with the obvious subscript change) we check if $n_1 \neq 0$ and $n_2 = 0$ (reported porpoise

and no pure yellowfin sets) in which case we add the unknown yellowfin set to the porpoise category; otherwise, if $n_1=0$ and $n_2\neq 0$, the unknown yellowfin set is added to the pure yellowfin category. If $n_1\neq 0$ and $n_2\neq 0$ (reported porpoise and pure yellowfin sets for the stratum), we check if $M_1 > n_1$, i.e. that the estimated number of porpoise categories exceeds the reported number of porpoise sets, in which case the set is added to the porpoise category. Otherwise, if $M_2 > n_2$, the set is added to the pure yellowfin category. This procedure of checking n_1 and n_2 is alternated so the unknown sets are equally likely to be placed in either category if the proper conditions are met.

When an unsuccessful set is reported, Column 61 gives the zero catch information, and Column 62 provides a guess of species if the zero catch set is unknown.

The zero catch sets with known type of school, and known or guessed species were allocated as described above for the successful set types. When the type of school is unknown, sets were allocated in the same ratio as the known successful sets for the 5°, month, and size class stratum.

7. Successful Set Probabilities and Expected Numbers of Sets per Fishing Day

Successful set probabilities were estimated for the four school categories by the appropriate ratios of estimated successful to total sets attempted. For each 5° area, month and size class, let

n_i represent the number of reported and allocated unknown successful sets on each school category $\underline{i}$,

and

u_i be the number of reported and allocated unknown unsuccessful sets (Page 12) on each school category $\underline{i}$, for $i=1,2,3$ and 4.

Then, successful set probabilities were estimated

$n_i/(n_i+u_i)$.

In some cases data were lacking in a particular 5° area and month with which to make these estimates of successfully setting. We then chose the appropriate estimates from an adjacent stratum, either in area or time, for which such data were adequate.

The expected number of successful sets per fishing day on each of the four school types are estimated as:

> $E_i = M_i/B$ where M_i is the estimate equation (8) of the total number of successful sets made on school category i, and B was the actual number of boat days expended by the size class in a 5° area and month stratum.

When only unknown school types were in the above 5° area, month and size class stratum, the estimated number of successful sets could not be computed, hence it was set to zero. The program checks for this, and if so computes the expected number of successful sets per day using the number of reported successful sets divided by the boat days. This situation can happen rarely because of the allocation procedure for the reported unknown school types described above.

8. Set Times

The mean and variance of the time spent in each of the 8 set states (successful and skunk sets on the four school categories) were estimated for each 5° area, quarter and size class (see Pella and Psaropulos, 1975). The equations used to calculate the mean and variance of the set times for each school type are the expressions:

$$\hat{Y} = \hat{\alpha} + \hat{\beta}\bar{x}$$

and

$$\sigma_y^2 = \hat{\sigma}^2 + \hat{\beta}^2 \hat{\sigma}_x^2$$

where

$\bar{x}$ was the mean catch per set for school type

$\hat{\beta}$ equation (2)

$\hat{\alpha}$ equation (3)

$\hat{\sigma}^2$ equation (4) the estimated variance about the linear model (1)

y was the time in the set

σ_y^2 was the estimated variance of this waiting time

σ_x^2 was the variance of the mean set size in the stratum.

Program MEGALO

This program accepts from magnetic tape the output of Program PREMEG. Part of this information is used to compute through the model for purse-seining (Pella and Psaropulos, 1975) a measure of abundance by 5° area, month, size class, and school category. The other information is listed in the output along with the measures of abundance computed by this program.

The program is long and complex, so we will only give the reader a general idea of the sequence of steps to determine the indices of school densities for strata.

1. Input

First, we will list the input information as written onto magnetic tape by Program PREMEG, and whether the data are used in computation of indices:

a) 5° area designation (used)

b) month of year (used)

c) size class of vessels fishing in the strata (used)

d) school category (used)

e) the portion of the 5° area occupied, i.e. the number of one degree squares occupied by size class of vessel divided by 25 (not used)

f) the portion of the 5° area occupied by all size classes for the same area-month stratum (not used)

g) mean size of set made on the school category (used)

h) mean set time of a successful set on the school category (used)

i) mean set time of a skunk set on the school category (used)

j) variance of the mean set time of a successful set (used)

k) variance of the time of a skunk set (used)

l) average weight of yellowfin per successful set (used)

m) average weight of skipjack per successful set (used)

n) number of successful reported sets (used)

o) estimate of expected number of successful sets per fishing day (used)

p) successful set probability (used)

q) number of boat days (used)

r) weighted vessel speed (used)

s) total weight of yellowfin (used)

t) total weight of skipjack (used)

Given the above input for each school type in a 5° area-month stratum - the successful set probability, waiting time parameters in the set state, and the expected number of successful sets per fishing day along with chosen values for the recovery probabilities, we first replace the constants of the purse-seine model by these estimates to calculate indices of school densities (schools per unit area) of each school type in the stratum. These school density indices are scaled by biomass per school measure; these products are summed over the four school types to obtain the species biomass index.

The following is the outline of the computational procedure used by this program:

> MAIN Program reads in the set power factors from cards. Next, MAIN Program reads in from magnetic tape the data generated by Program PREMEG by a 5° area, month, and size class stratum for the four school categories. Subroutine LAMETA is called with values for the recovery probabilities, expected number of sets per day, successful set probabilities, and mean set times and their variances for the four school categories. The equation system (19) of Pella and Psaropulos (1975) is solved for the unknown densities, λ.

Return from this subroutine gives indices of school densities, λ, and a check for accuracy of the solution to equation system (19).

Next, the school density indices are converted to biomass indices. Subroutine ABUND is called which computes the biomass indices, $\hat{Y}_k$ of equation (30) of Pella and Psaropulos (1975), from the school density indices, average weights per successful set, and set power factor. This subroutine outputs the catch per effort and the biomass indices on cards. Upon return to the MAIN program, the input and computed information are printed out for the stratum. The program is ready for the next set of values, i.e. the next stratum.

Subroutine LAMETA defines limits of convergence for the mathematical model of the fishing process using Subroutine MATINV (Garbow, 1963) and calls Subroutine SANDMIN (Beisinger and Bell, 1963) to solve equation system (19) of Pella and Psaropulos (1975) for density indices. To check the accuracy of the solution, Subroutine CZECK is used. If the solution is not accurate, the final values from Subroutine SANDMIN are used as starting values in Subroutine GSHSF (D. A. Meeter, 1966).

2. Output

The above program returns to the main program for output.

Subroutine SANDMIN determines a minimum of an arbitrary function of n variables. This subroutine was made available through the UCSD subroutine library. There was a modification made to this program that set a maximum time available for searching for the density indices solution.

Subroutine ABUND outputs cards with the identification of the 5° area, month, size class, year, and the catch per day's fishing along with the biomass indices for the stratum. This information is used subsequently by Program BMDO2R which performs a stepwise regression analysis.

Subroutine GSHSF obtains least squares estimates of parameters entering nonlinearly into our mathematical model when the solution from SANDMIN was unsatisfactory. This subroutine was also made available through the UCSD subroutine library.

Subroutine CZECK checks for accuracy of the school density solutions determined by either Subroutine MIN or GSHSF.

Subroutine WHICH gives the number of school categories present. This determines which version of the mathematical model for purse-seining shall be used; there is a separate model for each case as the number of school categories present varies from 1 to 4; this was done for greater efficiency.

Subroutines FØF1, FØF2, FØF3, FØF4 are the mathematical models that compute the expected successful sets per day given parameters of waiting time in set states, recovery probabilities, successful set probabilities, and guesses of school densities for the number of school categories present in the time and area stratum.

FUNCTION FØX1, FØX2, FØX3, FØX4 calls the appropriate Subroutine FØF above which evaluates the expected number of successful sets for the number of school categories. This function is used by Subroutine MIN.

3. Method

The MAIN program reads in the data from magnetic tape and calls Subroutine LAMETA which defines the bounds for the unknown density parameters $\lambda=(\lambda_1,\lambda_2,\lambda_3,\lambda_4)$ of the model. We will begin with the case where only one school type was present. With all parameters (including expected number of successful sets per day) fixed except λ_1, the density of the school, and η_1, the recovery probability, we note that as $\hat{\eta}_1$ increases, $\hat{\lambda}_1$ must decrease. Therefore, if we say $\eta_1=0$, i.e., no chance of recovery, $\hat{\lambda}_1$ would be maximal, the upper bound for our search.

Now the total search time available for the average seiner per day in a 5° area and month stratum was

$$t = 12 \text{ hours of daylight} - (\text{total sets attempted})\begin{pmatrix}\text{average duration in}\\ \text{hours of a set}\end{pmatrix}.$$

The total sets attempted is approximately

$$\frac{S_1}{\nu_1}$$

where S_1 is the number of successful sets per day on the school type, and ν_1 is the probability of making a successful set. The average duration of a set is a weighted average

$$\bar{\mu} = \nu_1 \mu_1 + (1 - \nu_1) \mu_2$$

where μ_1 is the mean time in a successful set, and μ_2 is the mean time in an unsuccessful set.

If the density of tuna schools was λ_1, then if we search for $\underline{t}$ hours without stopping to set, we should find $\lambda_1 t$ schools by definition. If there is no chance of recovery on a missing school, and S_1 school are caught in a day then we expect

$$\nu_1 \lambda_1 t = S_1$$

i.e., we searched $\underline{t}$ hours, the density was λ_1, we should have found $\lambda_1 t$ schools, and should have caught a fraction ν_1 of these. The result should be S_1 schools caught. But obviously, if we solve for λ_1, the result is too large because some of the successful sets may have been recovered schools. We know η_1 might be greater than 0. Therefore,

$$\hat{\lambda}_{\text{Bound}} = \frac{S_1}{\nu_1\left(12 - \bar{\mu}\frac{S_1}{\nu_1}\right)} = \frac{S_1}{12\,\nu_1 - \mu\, S_1}$$

is too large, but possibly a good upper bound. We took a lower bound of $0.01\hat{\lambda}_{Bound}$ and a guess of $0.75\hat{\lambda}_{Bound}$ as an initial guess for Subroutine MIN.

For two school types the search time available is

$$t = 12 - \bar{\mu}_1\begin{pmatrix}\text{total sets attempted}\\ \text{on type 1}\end{pmatrix} - \bar{\mu}_2\begin{pmatrix}\text{total sets attempted}\\ \text{on type 2}\end{pmatrix}$$

where

$$\bar{\mu}_i = (1-\nu_i)\,\mu_{i2} + \nu_i\mu_{i1} \qquad i = 1,2 \text{ (schools)}$$

$\bar{\mu}_i$ is the average duration of a set for school type i

μ_{i1} is the mean time in a successful set for school type i

μ_{i2} is the mean time in an unsuccessful set for school type i

again we expect

$$\nu_1\lambda_1 t = s_1$$

$$\nu_2\lambda_2 t - s_2$$

if no chance exists for recovery of missing schools. Also, if no recovery possibility exists we expect,

$$\frac{\lambda_1}{\lambda_2} = \frac{s_1 / \nu_1}{s_2 / \nu_2}$$

i.e., the ratio of total sets on each school type should be equal to the ratio of the densities. Combining we have

$$\nu_1\left(12 - \bar{\mu}_1\frac{s_1}{\nu_1} - \bar{\mu}_2\frac{s_2}{\nu_2}\right)\lambda_1 = s_1$$

$$\nu_2\left(12 - \bar{\mu}_1\frac{s_1}{\nu_1} - \bar{\mu}_2\frac{s_2}{\nu_2}\right)\lambda_2 = s_2$$

and

$$\frac{s_1}{\nu_1} = \frac{s_2}{\nu_2}\cdot\frac{\lambda_1}{\lambda_2}$$

hence

$$\nu_1 \left(12 - \bar{\mu}_1 \frac{s_1}{\nu_1} - \bar{\mu}_2 \frac{s_1}{\nu_1} \frac{\lambda_2}{\lambda_1}\right) \lambda_1 = s_1$$

$$\nu_2 \left(12 - \bar{\mu}_1 \frac{s_2}{\nu_2} \frac{\lambda_1}{\lambda_2} - \bar{\mu}_2 \frac{s_2}{\nu_2}\right) \lambda_2 = s_2$$

or

$$(\bar{\mu}_1\ s_1 - 12\nu_1)\ \lambda_1 + (\bar{\mu}_2\ s_1)\ \lambda_2 = -s_1$$

$$(\bar{\mu}_1\ s_2)\ \lambda_1 + (\bar{\mu}_2\ s_2 - 12\nu_2)\ \lambda_2 = -s_2$$

which is a linear equation system in (λ_1, λ_2).

The same methods work for 3 and 4 schools present. Next Subroutine MATINV solves the linear model for the upper bounds. Lower bounds are determined and an initial value of 0.75 of the upper bound forms the initial guess for Subroutine MIN which is now called to solve the mathematical model of the fishing process. The solution for school densities is tested for accuracy by calling Subroutine CZECK which substitutes the estimates into the equation system to check the percentage error between the observed E_i, the estimated expected successful sets per day from logbook records of successful sets and fishing days, and F_i the predicted expected successful sets per day on school type _i_ from the model using $\hat{\lambda}$ values. If we have

$$\frac{F_i - E_i}{E_i} < .005 \qquad i = 1,2,3,4 \ , \qquad \ldots(9)$$

the solution was judged satisfactory and a return to the MAIN program is executed with the value of $\hat{\lambda}$ (school densities). Otherwise, Subroutine GSHSF is called with the initial guesses that were the closest solution determined by Subroutine MIN. The reason for using two different subroutines to accomplish the same goal was for efficiency. This solution is tested for convergence by calling Subroutine CZECK, using equation (9). The program returns control to the MAIN program with these $\hat{\lambda}$ and calls Subroutine ABUND. This subroutine computes for the 5° area, month, and size class stratum $\hat{\gamma}$ (yellowfin and skipjack biomass indices), equation (30) of Pella and Psaropulos (1975).

The variables of equation (40) of Pella and Psaropulos (1975) are punched onto cards in the following way:

Column	Format	Item	Example
1-6	I6	area	205080
7-9	I3	month	6 (June)
10,11	I2	size class	5
12-19	F8.3	catch per day yellowfin	5.000 (5 tons)
20-28	F9.3	catch per day yellowfin squared	25.000 (25 tons)
29-36	F8.3	catch per day skipjack	1.500 ($1\frac{1}{2}$ tons)
37-45	F9.3	catch per day skipjack squared	2.250 ($2\frac{1}{4}$ tons)
46-55	F10.3	catch per day yellowfin times catch per day skipjack	7.500 ($7\frac{1}{2}$ tons)
56-65	F10.7	yellowfin biomass index	0.1671727
66-75	F10.7	skipjack biomass index	0.0210402
76-80	I5	year	1970

All above data was right adjusted in their respective fields.

The procedure for computing the biomass indices corrected for efficiency between vessels were described by Pella and Psaropulos, (1975).

The above punched cards were inputed into BMD 02R (Dixon). This program computed a sequence of multiple linear regression equations in a stepwise manner. We compute by simple least squares, estimates by size class and year of the model

$$\hat{\gamma}_y = \beta_1 CPD_y + \beta_2 CPD_y^2 + \beta_3 CPD_s \text{*}$$

* Equation (40) referenced above.

where the subscripts y and s refer to yellowfin and skipjack tuna respectively. A similar equation was used for skipjack tuna with the y and s interchanged.

Once these annual coefficients of ($\hat{Y}$, CPD) data points that were beyond three standard deviations. These pairs of values were deleted and the coefficients were recalculated using BMD02R. The significant coefficients at the 5% level of testing were retained and were used in the next step of this analysis in Program FINAL.

Program FINAL

Input data to this program include the annual regression coefficients computed by BMDO2R along with a list of 5° areas to be analyzed, and the catch and effort information on magnetic tape (as described in Program PREMFG). This program computes the CPD-values for each size class, and transforms them independently to $\hat{\varphi}$-values, biomass indices corrected for efficiency differences between vessel classes.

1. Input

Column	Format	Item	Example
Card 1 - number of years to be analyzed			
1-6	6X		Years=
7-8	I2	years to be analyzed	02 (2 years)
Card 2 - annual regression coefficients yellowfin tuna for first year			
1-4	I4	year	1961
5	1X	blank	
		size class 3	
6-15	F10.5	$\hat{\beta}_1$	.02154
16-25	F10.5	$\hat{\beta}_2$	-.00018
26-35	F10.5	$\hat{\beta}_3$	0
		size class 4	
36-45	F10.5	$\hat{\beta}_1$	.02018
45-55	F10.5	$\hat{\beta}_2$	-.00007
56-65	F10.5	$\hat{\beta}_3$	0

Card 3 - annual regression coefficients yellowfin tuna for first year

Has the same format as Card 2 for size class 5 and 6.

Card 4 - annual regression coefficients skipjack tuna for first year

Has the same format as Card 2 for size class 3 and 4.

Card 5 - annual regression coefficients skipjack tuna for first year

Has the same format as Card 2 for size class 5 and 6.

This order continues (Cards 2 through 5) until all the years to be analyzed are represented.

2. Output

Output from this program is a listing by 5° areas, month, and size class of the $\hat{Y}$-values for yellowfin and skipjack tuna along with the effort expended. This information was used in the estimation of annual abundance of tunas using Program LINHYP.

3. Method

The catch-per-day-values of yellowfin and skipjack tuna for a 5° area, month, and size class were transformed to $\hat{Y}$-values using equation (40) with the parameter values of Tables 9 and 10 (Pella and Psaropulos, 1975). Yellowfin CPD-values were transformed only for the unregulated period of each year since CPD-values during the closure are of little value in assessing abundance. Skipjack CPD-values were transformed for both regulated and unregulated periods using the appropriate coefficients of Table 10.

Program LINHYP (General Linear Hypothesis)

Values of $\hat{\gamma}$-indices and effort are extracted from output of Program FINAL and placed on cards for input into this program to estimate parameters of linear model equation (43) Pella and Psaropulos (1975), and values for missing $\hat{\gamma}$-biomass indices.

This program has the flexibility for combining areas, if desired, in estimating the missing biomass indices.

1. Input

Column	Format	Item	Example
Card 1			
1-9	9X	comment	NO.
10,11	I2	number of areas to combine	01 (no combining)
Card 2 - area identification card			
1-6	6X	comment	YEARS=
7-8	I2	number of years	13
9-16	8X	comment	MONTHS=
17,18	I2	number of months	12
19-32	14X	comment	SIZE CLASSES=
33,34	I2	number of size classes	04
35-49	15X	comment	NO. OF INDICES=
50-52	I3	number of $\hat{\gamma}$-indices	103
53-70	3A6	comment	00075 SKIPJACK
71-74	I4	number of the first index	1
75	1X	blank	
76-79	I4	number of the last index	103
Cell index cards			
1-6	3I2	first cell index	111 3 (1st year, 11th month, 3rd size class*)
7-12	5I2	second cell index	2 4 4 (2nd year, 4th month, 4th size class)

Continuing through Column 78 of each card until all the cell indices have been specified.

---

* Size classes 3 through 6 are indexed 1 through 4 respectively.

Column	Format	Item	Example
		$\hat{Y}$-biomass index cards	
1-6	F6.5	first $\hat{Y}$-index corresponding to the first cell index	02712(0.02712)
7-12	F6.5	second $\hat{Y}$-index corresponding to the second cell index	35940(0.35940)

Continuing through Column 78 of each card until all the $\hat{Y}$-indices have been specified.

Effort cards

1-6	F6.1	first effort corresponding to the first cell index	10 (1.0 days)
7-12	F6.1	second effort corresponding to the second cell index	240 (24.0 days)

Continuing through Column 78 of each card until all the effort has been specified.

Zero cards (contain effort and no catch, e.g. Y-values = 0)

1-9	9X	comment	NO.ZEROS=
10-12	I2	number of cell indices	183

No catch cell index cards

1-6	3I2	first cell index	2 5 2 (2nd year, 5th month, 2nd size class)
7-12	3I2	second cell index	2 5 3 (2nd year, 5th month, 3rd size class)

Continuing through Column 78 of each card until all the cell indices have been specified.

No catch effort cards

1-6	F6.1	first effort corresponding to the first cell index	30 (3.0 days)
7-12	F6.1	second effort corresponding to the second cell index	25 (2.5 days)

Continuing through Column 78 of each card until all the effort has been specified.

2. Method

This program reads in the data cards, stores them into appropriate arrays, weights the $\hat{Y}$-indices by the fishing effort and uses the technique of a general linear model to estimate the missing $\hat{Y}$-index values.

Combining areas. The technique of combining areas will be explained by presenting the following example:

```
 NO.AREAS=02
 YEARS=12,MONTHS=12,SIZE CLASSES=03,NO.OF INDICES=042 00085 YELLOWFIN 1, 42
<Index cards>
<Ŷ-biomass cards>
<Effort cards>
 NO.ZEROS=49
<Index cards>
<Effort cards>
 YEARS=12,MONTHS=12,SIZE CLASSES=03,NO.OF INDICES=020 00090 YELLOWFIN 92, 111
<Index cards>
<Ŷ-biomass cards>
<Effort cards>
 NO.ZEROS=32
<Index cards>
<Effort cards>
 etc.
```

The number following YELLOWFIN, Columns 71-74 and Columns 76-79 correspond to the number of indices starting at 1, and ending at 42 for the first area. The second area have the numbers 92 and 111 punched in the respective columns. These are the continuing indices when as in the above example two areas are combined. These numbers are derived by adding 42 plus 49 (the number of zeros) = 91, the next index in the series is 92 and the last is 91 + 20 = 111. This procedure is continued for as many area that one wishes to combine.

3. Output

Output from this program includes two tables for each 5° area by year and month strata of the $\hat{Y}$-indices. The first table has the weighted mean values of the $\hat{Y}$-indices, if there was no effort expended during a particular year and month strata, the estimated value from the linear model equation is inserted. If the zero cards showed that some fishing occurred with no catch, then it is assumed a low density of fish exist and a zero is inserted in the table.

The second table is made up of the estimated values from the linear model. Both tables have monthly and annual average.

Additional output of this program consists of

a) Analysis of variance with size class classification

b) Analysis of variance without size class classification

PROCEDURE FOR COMPUTING THE BIOMASS INDICES

1. Sorting of data cards

There are 3 data decks to be sorted; the catch and effort cards, the single set cards, and the purse-seine set cards (used for the years prior to 1969).

Catch and effort cards are sorted by area, i.e. Columns 6 through 1.

Single set cards are sorted by area, i.e. Columns 6 through 1.

Purse-seine set cards are sorted by area and month, i.e. Columns 12, 11, and 6 through 1.

2. Card to tape procedure

The catch and effort and single set cards are put on magnetic tapes using the 3600 Computer. The data is packed on tape, 25 card images per physical record to be used by Program PREMEG.

3. Time in set cards

The set times are paired values of the time a vessel spent in a set state and the size of the set. Program LINFIT computes the regression coefficients and sample variance for the relationship between time in set and set size; these are punched onto cards for input into Program PREMEG.

4. Boat cards

For each year there is a set of boat cards with the information of vessel name, speed, capacity, size class, and IATTC vessel number. These cards are for input into Program PREMEG.

5. Program PREMEG

The function of this program is to process the logbook information and store the output onto magnetic tape for input to Program MEGALO.

The following is the description of the deck set up needed to execute this program on the Burrough's 6700 Computer.

Systems cards start in Column 1:

```
IT11/
Password
? NAME=PREMEGALO/PSAROPULOS
? BEGIN
? COMPILE PREMEG/PROGRAM FORTRAN [COMPOK] LIBRARY
? FILE FILE10(EXTMODE=BCL,PARITY=NONSTANDARD,
  INTMODE=EBCDIC,LABELTYPE=OMITTEDEOF,BLOCKSIZE=2000,
  UNITS=CHARACTERS,MAXRECSIZE=80)
```

Note: Single set data tape information

```
? FILE FILE20(EXTMODE=BCL,PARITY=NONSTANDARD,
  INTMODE=EBCDIC,LABELTYPE=OMITTEDEOF,BLOCKSIZE=2000,
  UNITS=CHARACTERS,MAXRECSIZE=80)
```

Note: Catch and effort data tape information

```
? FILE FILE30(KIND=DISK,MAXRECSIZE=105,BLOCKSIZE=2520,
  AREASIZE=50,AREAS=15,FLEXIBLE,UNITS=CHARACTERS,
  TITLE=PREMEG/1973NR,PROTECTION=SAVE)
```

Note: Output data tape information

```
? DATA
FILE 10=TC002,RECORD=14,BLOCKING=25,UNLABELED
FILE 20=TC009,RECORD=14,BLOCKING=25,UNLABELED
FILE 30(KIND=DISK,MAXRECSIZE=105,BLOCKSIZE=2520,
   1AREAS=15,FLEXIBLE,UNITS=CHARACTERS,'PREMEG/1973NR',
   2PROTECTION=SAVE)
  <FORTRAN SOURCE CARDS>
```

Note: Data Set #1

```
? IF COMPOK ISNT COMPILEDOK THEN GO TO ABORT
? RUN SERVICE/OPINFO;DATA
TC002=TC002   (NS) 7/556 NORING NO PURGE UL
TC009=TC009   (NS) 7/556 NORING NO PURGE UL
? RUN PREMEG [RANOK]
? DATA
FILES SKIP ON SS=02,C+E=13
```

Note: Data Set #2

```
   <BOAT CARDS>
   <BLANK CARD>
```

Note: Data Set #3

```
   <REGRESSION COEFFICIENTS AND SAMPLE VARIANCES>
```

Note: Data Set #4

```
? IF RANOK ISNT COMPLETEDOK THEN GO TO ABORT
? RUN SERVICE/OPINFO;DATA
PSA002  (NS) 9/800 RINGIN PURGE OU
? COPY PREMEG/= TO PSA002 [COPYOK]
? IF COPYOK ISNT COMPLETEDOK THEN GO TO ABORT
? REMOVE PREMEG
? ABORT:
? END JOB
```

The above systems cards will take the Single Set data from magnetic tape TC002 (in this example from the 3rd file indicated on Data Set #2 which instructs the computer to skip the first two files) and the Catch and Effort data from TC009 (in this example from the 14th file indicated on Data Set #2 which instructs the computer to skip the first 13 files) run the program and process the output data onto disk. Then Program PREMEG and the output of the program are stored onto tape PSA002 with the labels PREMEG/PROGRAM and PREMEG/1973NR. Then the information is removed from the disk library. Tape PSA002 is now ready to be processed by Program MEGALO.

6. Program MEGALO

This program reads the output information of Program PREMEG from tape PSA002 (in this example) and computes through the model for purse-seining (Pella and Psaropulos, 1975) a measure of biomass for yellowfin and skipjack by year and size class adjusted for efficiency changes.

The following is the description of the deck setup needed to execute this program on the Burrough's 6700 Computer.

Systems cards start in Column 1:

```
IT11/
Password
```

```
? NAME=POLYMEGALO/PSAROPULOS
? BEGIN
? COMPILE MEGALO/PROGRAM FORTRAN [COMPOK] LIBRARY
? FILE FILE20(KIND=DISK,MAXRECSIZE=105,BLOCKSIZE=2520,
  AREASIZE=50,AREAS=15,FLEXIBLE,UNITS=CHARACTERS,
  TITLE=MEGALO/1973NR,PROTECTION=SAVE)
? FILE FILE30(KIND=DISK,MAXRECSIZE=105,BLOCKSIZE=2520,
  AREASIZE=50,AREAS=15,FLEXIBLE,UNITS=CHARCTERS,
  TITLE=PREMEG/1973NR,PROTECTION=SAVE)
? DATA
   <FORTRAN SOURCE CARDS>                          Note: Data Set #1
? IF COMPOK ISNT COMPILEDOK THEN GO TO ABORT
? RUN SERVICE/OPINFO;DATA
PSA002 (NS) 9/800 RINGOUT NOPURGE AUTO
? COPY PREMEG/1973NR FROM PSA002
? RUN MEGALO/PROGRAM [RANOK]
? DATA
   <Set power factors for 1973>                    Note: Data Set #2
? IF RANOK ISNT COMPLETEDOK THEN GO TO ABORT
? RUN SERVICE/OPINFO;DATA
PSA004 (NS) 9/800 RINGIN PURGE OU
% PLEASE SEND CARDS TO PSAROPULOS S.W.F.C. THANKS....
? COPY MEGALO/= TO PSA004 [COPYOK]
IF COPYOK ISNT COMPLETEDOK THEN GO TO ABORT
? REMOVE MEGALO
? ABORT:
? END
```

The above systems cards will take the block of data from PSA002; namely, PREMEG/1973NR, store onto disk, process the information (computing the school densities and biomass indices), storing the results onto tape PSA004 with the labels MEGALO/PROGRAM and MEGALO/1973NR. This program punches out a set of data cards with the catch per effort information and the biomass indices which are next used by Program BMDO2R.

7. Program BMDO2R (Dixon)

This program is stored on the Burrough's 6700 Computer library and the following control cards gain access to this program.

Systems cards start in Column 1:

```
IT11/
Password
? NAME=BMDO2R/PSAROPULOS
? BEGIN
? EXECUTE STATPAK/BMDO2R
? DATA
   <Data cards punched by Program MEGALO>
FINISH
? END JOB
```

This program computes a sequence of multiple linear regression equations in a stepwise manner. The significant coefficients on the 5% level of testing are retained and used in the next step of this analysis in Program FINAL.

8. Program FINAL

Input data into this program include the annual regression coefficients computed above and the catch and effort information on magnetic tape (PSAO18 in this example).

System cards start in Column 1:

```
IT11/
Password
? NAME=FINAL/PSAROPULOS
? BEGIN
? RUN SERVICE/OPINFO;DATA
PSAO18=PSAO18 (NS) 7/556 NORING NOPURGE UL
```

```
? COMPILE FINAL FORTRAN
? FILE FILE10(EXTMODE=BCL,PARITY=NONSTANDARD,
  INTMODE=EBCDIC,LABELTYPE=OMITTEDEOF,BLOCKSIZE=2000,
  UNITS=CHARACTERS,MAXRECSIZE=80)
? DATA
FILE 10=PSA018,RECORD=14,BLOCKING=25,UNLABELED
   <PROGRAM SOURCE DECK>
? DATA
   <Data, regression coefficients>
? END JOB
```

This program computes and prints out the CPD-values and transforms them to $\hat{Y}$-values. These are biomass indices corrected for efficiency differences between size classes.

9. Program LINHYP

Input data into this program on computer cards were extracted from Program FINAL printout. This program generates values for missing $\hat{Y}$-indices.

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