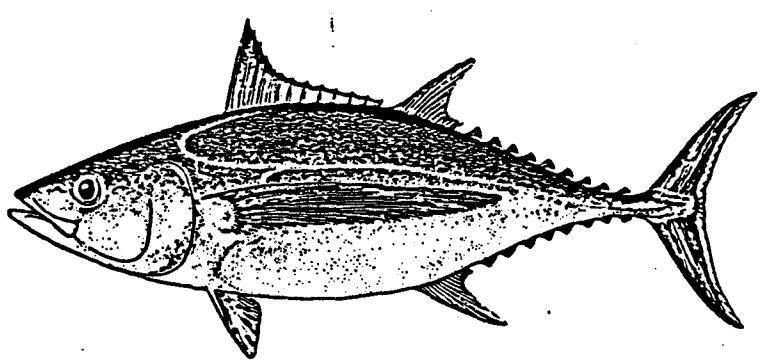


REVIEW OF GARCIA'S ESTIMATORS AND STEP BY STEP STOCK ASSESSMENT OF SOUTH PACIFIC ALBACORE

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Review of Garcia's estimators
and
step-by-step stock assessment of south Pacific albacore*

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ABSTRACT

Two simple methods for estimating maximum sustainable yield (MSY) based on well-known Schaefer and Fox surplus production model respectively, were suggested by Garcia et al (1989). Estimated MSY was expressed in terms of natural mortality, current catch and current biomass.

This paper points out that estimated MSY by Garcia's methods will always be greater than the current catch. Hence, a miss-leading strategy of fishery management would always be occurred. This is caused by the assumption that current catch is always in equivalent state and optimal fishing mortality (F_s) equal to the natural mortality (M). By Garcia's method, two other assumptions are necessary: 1. Natural mortality is knowable by other method. 2. Current biomass must be given (always by guess-estimate).

A new method for estimating maximum sustainable yield is suggested in this paper. It needs only one or more current catch and effort data. These methods based on the theory of Schaefer, Pella-Tomlinson and Fox models are derived respectively. As an numerical example, South Pacific albacore catch data exploited by tuna longline fisheries are used to estimate MSY and optimal fishing efforts and the results are compared to those estimated by the method of least squares. The results reveal that average of MSY and optimal fishing efforts estimated in this paper are very similar to those estimated by the method of least squares.

The merits of step-by-step method are summarized as follows.

1. Only one or more current catch and effort data are necessary.
2. Annual fluctuation of MSY and optimal fishing effort can be detected and used in fishery management year by year.
3. Calculation is very simple.

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1. INTRODUCTION

If long time series of catch and effort data are available, maximum sustainable yield can be estimated by surplus production model and used to manage the exploitation of fishery resources. Regretly, reliable long-term catch statistics are always unavailable. For example, large-mesh gill net fishery starts in south Pacific ocean from a few years ago, hence no long-time series of catch and effort data can be accumulated. Although catch and effort data of Taiwanese, Japanese and Korean tuna longline fisheries are reported from many years ago, some problems are exists in data processions (Wang 1989) and fishery biologists are alway worried to get reliable catch and effort data. Hence, it is necessary to develop a rapid method using to estimate maximum sustainable yield without long-time series of catch and effort data.

Gulland (1971) proposed a method to estimate the potential yield of unexploited fish stock, and Cadima (in Troadec 1977) proposed another method for exploited fish stock. Garcia et al (1989) showed that although these two methods were not so accurate and precise, the simplicity and ease of application contributed to their extended use in estimation of MSY. Based on Schaefer and Fox surplus production models, Garcia et al (1989) proposed two equations for rapid estimating the maximum sustainable yield.

This paper tries to reconsider Garcia's equations and show that it is very dangerous if Garcia's equations are used to estimate maximum sustainable yield and be used as an index in fishery management.

2. A REVIEW OF GARCIA'S ESTIMATORS

In data-limited situations, two equations are proposed by Garcia et al (1989) based on two well-known surplus production models, Schaefer model (194) and Fox model (1970) as follows.

Two surplus production models are given by follows:

$$\text{Schaefer: } Y_e = aF - bF^2 \quad \text{or} \quad Y_e/F = a - bF \quad \text{-----(1.1)}$$

$$\text{Fox: } Y_e = F \exp[c - dF] \quad \text{or} \quad \ln[Y_e/F] = c - dF \quad \text{-----(1.2)}$$

where a, b, c, d : constants

F : fishing mortality rate

Y_e : equivalent catch

Set $F = Y_e/B_e$ or $Y_e/F = B_e$ and $B_e =$ equivalent biomass under exploitation, then:

$$\text{Schaefer: } B_e = a - b(Y_e/B_e) \quad \text{-----(2.1)}$$

$$\text{Fox: } \ln(B_e) = c - d(Y_e/B_e) \quad \text{-----(2.2)}$$

If current catch is in equivalent state, that is, $B_c = B_e$ and $Y_c = Y_e$, and set $F_s =$ optimal fishing mortality, then:

$$\text{Schaefer: } B_c = a - b(Y_c/B_c) \quad \text{and} \quad F_s = a/2b \quad \text{-----(3.1)}$$

$$\text{Fox: } \ln[Bc] = c - d(Yc/Bc) \quad \text{and} \quad F_s = 1/d \quad \text{----- (3.2)}$$

Solved for a, b, c and d constants, respectively, then:

$$\text{Schaefer: } a = \frac{2}{(2F_s Bc - Yc)}$$

$$b = \frac{Bc}{(2F_s Bc - Yc)} \quad \text{----- (4.1)}$$

$$\text{Fox: } c = \ln[Bc] + Yc / (Bc F_s)$$

$$d = 1/F_s \quad \text{----- (4.2)}$$

Hence, maximum sustainable yield (Y_s) can be expressed as follows.

$$\text{Schaefer: } Y_s = a^2 / 4b = (F_s Bc)^2 / (2F_s Bc - Yc) \quad \text{----- (5.1)}$$

$$\text{Fox: } Y_s = \exp(c-1) / d = F_s Bc \exp[Yc / (F_s Bc) - 1] \quad \text{----- (5.2)}$$

If $F_s = M$ with $M =$ natural mortality, then the estimators become:

$$\text{Schaefer: } Y_s = \frac{2}{(2MBc - Yc)} \quad \text{----- (6.1)}$$

$$\text{Fox: } Y_s = MBc \exp[Yc / (MBc) - 1] \quad \text{----- (6.2)}$$

If current catch (Y_c), current biomass (B_c) and natural mortality (M) are available then equations (6.1) and (6.2) can be used as a roughly estimator of maximum sustainable yield when time series catch and effort data are not available.

These estimators depend on follows. (1) Current state (B_c, Y_c) is in equivalence. This assumption is always not true unless fish stock is effected by human exploitation instantaneously. Also, Y_c is always lower than or equal to Y_s by the definition of maximum sustainable yield. But, Y_c must be larger than Y_s by the definition of overfishing. (2) Unbias estimate of B_c . When time series catch data are not available, no suitable method can be used to estimate B_c till now. (3) Assumption of $F_s = M$. Generally, it is not true. For example, $F_s = 0.5$ and $M = 0.361$ of bigeye tuna, i.e. $F_s = 1.385 M$ (Kume 1979) and $F_s = 0.196$ and $M = 0.223$ of spanish mackerel, i.e. $F_s = 0.879 M$ (Doi 1988). The difference between F_s and M is generally rather large. As shown in Table 1, the difference between the MSY estimated by equations (5.1) and (6.1) depends on the difference between F_s and M and absolute value of F_s . (4) Unbias estimate of M . It is very difficult to get an unbiased estimate of M if time series catch and effort data are not available.

3. RECONSIDERATION OF GARCIA'S ESTIMATORS

Set $Y_s / F_s = B_s$ and replaced Y_c by Y_e and B_c by B_e , then equation (5.1) and (5.2) can be rewritten as follows:

$$\text{Schaefer: } Y_s / (F_s B_e) = 1 / \{2 - Y_e / (F_s B_e)\} \quad \text{or}$$

$$B_e / B_s = 2 - (Y_e / Y_s) (B_s / B_e) \quad \text{----- (7.1)}$$

$$\text{Fox: } Y_s = F_s B_e \exp[Y_e / (F_s B_e) - 1] \quad \text{or}$$

$$Y_s / F_s = B_e \exp[Y_e / (F_s B_e) - 1] \quad \text{or}$$

$$B_s / B_e = \exp[(B_s / B_e) (Y_e / Y_s) - 1] \quad \text{----- (7.2)}$$

Since $U = qB$ with $U = \text{catch per unit of fishing effort}$ and $q = \text{constant catchability}$, it implies:

$$\text{Schaefer: } U_e / U_s = 2 - (Y_e / Y_s) (U_s / U_e) \quad \text{----- (8.1)}$$

$$\text{Fox: } U_s / U_e = \exp[(U_s / U_e) (Y_e / Y_s) - 1] \quad \text{----- (8.2)}$$

or

$$\text{Schaefer: } Y_e / Y_s = 1 - (1 - U_e / U_s)^2 \quad \text{----- (9.1)}$$

$$\text{Fox: } Y_s / Y_e = (U_s / U_e) / \{1 + \ln[U_s / U_e]\} \quad \text{----- (9.2)}$$

Equations (9.1) and (9.2) imply that current catch $Y_c = Y_e$ must always be less than or equal to the estimated maximum sustainable yield Y_s (Fig. 1.1 and Fig. 1.2). This means that no matter how large the current catch is, the estimate Y_s is always greater than Y_c , i.e. fish stock is always in under-exploitation. It is very dangerous if making fishery management decision is based on such a result. A wrong assessment of fish stock which is always considered to be in under-exploitation could be concluded a continuous increasing fishing effort till the fish stock is extinguished.

On the other hand, parabola relationship between the relative equivalent catch (Y_e / Y_s) and relative abundance index (U_e / U_s) implies that two equivalent catch levels conclude the same MSY estimate; one is under fishing ($B_e > B_s$) and the other one is overfishing ($B_e < B_s$). Also, a miss-leading fishery management might be carried out due to the lack of fishing information. In the case of south Pacific albacore stock, a highly efficient fishery, gill netter, was introduced and increased strictly during a very short time period. No sufficient information can be used to judge whether or not it is overfishing.

However, if the assumption $Y_c = Y_e$ is acceptable and U_e and U_s can be obtained, then Y_s can be estimated by following equations.

$$\text{Schaefer: } Y_s = Y_e / \{1 - (1 - U_e / U_s)^2\} \quad \text{----- (10.1)}$$

$$\text{Fox: } Y_s = Y_e (U_s / U_e) / \{1 + \ln[U_s / U_e]\} \quad \text{----- (10.2)}$$

Here, $U_e = U_c$ and $Y_e = Y_c$ are available from current catch and only U_s must be given.

It is reasonable to assume that $U_m = aqB_v$ with $B_v = \text{Biomass of unexploited fish stock or carrying capacity}$, $U_m = \text{maximum catch per unit of fishing effort}$ and $a = \text{constant ratio}$. Since $B_s = B_v / 2$ for

Schaefer model and $B_s=B_v$ for Fox model, U_s can be set by $U_s=aU_m/2$ in (10.1) and $U_s=aU_m$ in (10.2) for more than one current catch data being available. As given in equations (10.1) and (10.2), if $U_s=U_e$ with the special case $a=1$ then $Y_s=Y_e$. If only one current catch data can be obtained, then $U_m=U_e$. In this case, it is meaningless for Schaefer model (10.1) with $U_e/U_s=2$ (equivalent to the state of unexploited fish stock), and $Y_s=Y_e$ for Fox model (10.2) (equivalent to the optimal exploited fish stock). If U_e is greater than or equal to $2U_s$ then equation (10.1) is meaningless for minus estimate of MSY. If U_s is less than or equal to U_e/e , i.e. U_s is less than or equal to $0.3679U_e$, then equation (10.2) also concludes the minus estimate of MSY. For other case, equations (10.1) and (10.2) can be used to estimate MSY if the fish stock follows Schaefer and Fox model respectively.

As pointed above, reliable results estimated by equations (6.1) and (6.2) of Garcia's estimators are always doubtful. The reasons are concluded as follows. (1) Current catch must be in equivalent state. Update, no sufficient data can be used to detect whether or not this assumption is true. Generally, catch and fishing efforts depend on many factors. And, almost all of them are not followed the strategy decided by the reliable results of fish stock assessment, especially for those of lacking time series catch and effort data. (2) Optimal fishing mortality rate (F_s) must be equal to the natural mortality rate (M). Regretly, this is inconsistent with the basic assumption of Garcia's estimator. F_s and M are always estimated from time series catch and effort data. And Garcia's estimator are basically developed from Schaefer and Fox production model. If time series catch and effort data are available, then Garcia's estimators become nonsense. If they are not available then the assumption of $F_s=M$ becomes a guess-estimate only. (3) Unbiased estimate of natural mortality rate must be given. (4) Current biomass must be given. However, how to estimate unbiased natural mortality and current biomass still confused the fishery biologist. Reliable and long-term time series catch and effort data are necessary to accomplish these works. If no time series catch and effort data can be obtained then estimate of unbiased natural mortality rate and current biomass are yet meaningless.

4. STEP-BY-STEP STOCK ASSESSMENT

As pointed out by Garcia et al (1989), reliable and long-term catch and effort data are always not available. However, fish stock might be damaged hardly or evenly exterminated by the rapid development of modern fishing gear and fishing method during a very short time period. Hence, it is necessary to develop a method to estimate the maximum sustainable yield without time series catch and effort data. Here, a method of step-by-step stock assessment will be proposed as follows. This method is based on the assumption that the fish stock follows the Schaefer or Fox surplus production model with a constant catchability q , and it can be extended to Pella-Tomlinson's generalized production model as follows.

Pella-Tomlinson's generalized production model was given by equation (1.3). Here, the curve parameter m must be given.

$$\frac{dB}{dt} = rB \left(1 - \frac{B^m}{B_v}\right) - Y$$

Similarly, following equation (10.3) can be derived from Pella-Tomlinson's generalized production model:

$$\text{Pella-Tomlinson: } Y_s = mY_e (U_s/U_e) / [m+1 - (U_e/U_s)^m] \quad \text{----- (10.3)}$$

For an unexploited fish stock, following processes can be used to carry out the fishery management.

- Step-1. Determine the model which will be used to assess the fish stock.
- Step-2. Set the initial point (X_0, Y_0) (guess-estimate by fishery biologist) as an assumed target point. Here, X =fishing effort.
- Step-3. Use X_1 to exploit fish stock actually and Y_1 will be yield.
- Step-4. Calculate $U_0 = Y_0/X_0$ and $U_1 = Y_1/X_1$,
- Step-5. Substitute (U_0, Y_0) and (U_1, Y_1) in equations (11.1), (11.2) or (11.3) for which one of Schaefer model, Fox model or Pella-Tomlinson model be used.

Schaefer model:

$$Y_s = Y_0 / \{1 - (1 - U_0/U_s)^2\}$$

$$Y_s = Y_1 / \{1 - (1 - U_1/U_s)^2\} \quad \text{----- (11.1)}$$

Fox model:

$$Y_s = Y_0 (U_s/U_0) / \{1 + \ln[U_s/U_0]\}$$

$$Y_s = Y_1 (U_s/U_1) / \{1 + \ln[U_s/U_1]\} \quad \text{----- (11.2)}$$

Pella-Tomlinson:

$$Y_s = mY_0 (U_s/U_0) / \{m+1 - (U_0/U_s)^m\}$$

$$Y_s = mY_1 (U_s/U_1) / \{m+1 - (U_1/U_s)^m\} \quad \text{----- (11.3)}$$

Step-6. Solved U_s and Y_s by following equations.

Schaefer model:

$$U_s = \frac{U_1 X_0 - U_0 X_1}{2(X_0 - X_1)} \quad \text{----- (12.1)}$$

$$Y_s = \frac{(X_0 U_1 - X_1 U_0)^2}{4(X_0 - X_1)(U_1 - U_0)} \quad \text{----- (13.1)}$$

Fox model:

$$U_s = e^{-1} \frac{X_1/(X_1 - X_0)}{U_0} \frac{X_0/(X_0 - X_1)}{U_1} \quad \text{----- (12.2)}$$

$$Y_s = e^{-1} \frac{X_1/(X_1 - X_0)}{U_0} \frac{X_0/(X_0 - X_1)}{U_1} \frac{X_0 - X_1}{\ln(U_1/U_0)} \quad \text{----- (13.2)}$$

Pella-Tomlinson model:

$$U_s = \left[\frac{X_0^m U_1 - X_1^m U_0}{(m+1)(X_0 - X_1)} \right]^{1/m} \quad \text{----- (12.3)}$$

$$Y_s = \left[\frac{X_0^m U_1 - X_1^m U_0}{(m+1)(X_0 - X_1)} \right]^{1/m} \left[\frac{m(X_0^m U_1 - X_1^m U_0)}{(m+1)(U_1 - U_0)} \right] \quad \text{----- (13.3)}$$

or expressed by current catch and effort as follows.

Schaefer model:

$$U_s = \frac{Y_0 X_1 - Y_1 X_0}{2X_0 X_1 (X_1 - X_0)} \quad \text{----- (14.1)}$$

$$Y_s = \frac{(Y_0 X_1 - Y_1 X_0)^2}{4X_0 X_1 (X_1 - X_0) (Y_0 X_1 - Y_1 X_0)} \quad \text{----- (15.1)}$$

Fox model:

$$U_s = e^{-1} \left(\frac{Y_0}{X_0} \right) \frac{X_1/(X_1 - X_0)}{X_1} \frac{Y_1}{X_1} \frac{X_0/(X_0 - X_1)}{X_1} \quad \text{----- (14.2)}$$

$$Y_s = e^{-1} \left(\frac{Y_0}{X_0} \right) \frac{X_1/(X_1 - X_0)}{X_1} \frac{Y_1}{X_1} \frac{X_0/(X_0 - X_1)}{X_1} \frac{X_0 - X_1}{\ln(X_0 Y_1 / X_1 Y_0)} \quad \text{----- (15.2)}$$

Pella-Tomlinson model:

$$U_s = \frac{1}{X_0 X_1} \left[\frac{X_0^{m+1} Y_1 - X_1^{m+1} Y_0}{(m+1)(X_0 - X_1)} \right] \quad (14.3)$$

$$Y_s = \left[\frac{X_0^{m+1} Y_1 - X_1^{m+1} Y_0}{(m+1)(X_0 - X_1)} \right] \frac{1/m \cdot m(Y_0 X_1^{m+1} - Y_1 X_0^{m+1})}{(m+1) X_0 X_1 [(Y_0 X_1^m) - (Y_1 X_0^m)]} \quad (15.3)$$

Step-7. Calculate X_s by Y_s/U_s , or

$$\text{Schaefer: } X_s = \frac{U_0 X_1 - U_1 X_0}{2(U_0 - U_1)} \quad (16.1)$$

$$\text{Fox: } X_s = \frac{X_0 - X_1}{\ln(U_1/U_0)} \quad (16.2)$$

$$\text{Pella-Tomlinson: } X_s = \frac{m(U_0 X_1^m - U_1 X_0^m)}{(m+1)(U_0 - U_1)} \quad (16.3)$$

or expressed by current catch and efforts as follows:

$$\text{Schaefer: } X_s = \frac{Y_0 X_1^2 - Y_1 X_0^2}{2(Y_0 X_1 - Y_1 X_0)} \quad (17.1)$$

$$\text{Fox: } X_s = \frac{X_0 - X_1}{\ln(X_0 Y_1 / X_1 Y_0)} \quad (17.2)$$

$$\text{Pella-Tomlinson: } X_s = \frac{m(Y_0 X_1^{m+1} - Y_1 X_0^{m+1})}{(m+1)[(Y_0 X_1^m) - (Y_1 X_0^m)]} \quad (17.3)$$

Step-8. Set $(X_0, Y_0) = (X_1, Y_1)$ and $(X_1, Y_1) = (X_s, Y_s)$

Step-9. Go to Step-3.

As stated above, at least one of current catch and effort data can be obtained, then the step-by-step stock assessment can be carried out.

5. NUMERICAL EXAMPLE: SOUTH PACIFIC ALBACORE

Maximum sustainable yield of South Pacific albacore was estimated by Wang et al (1988) by generalized production model. Nominal fishing efforts was adjusted to the effective fishing efforts by Honma's method (Honma 1974) and then adjusted to five years moving average. Estimated optimal catch was $Y_s=31222$ metric tons with optimal fishing efforts $X_s=207$ million hooks by Schaefer model and $Y_s=32033$ metric tons, $X_s=222$ million hooks by Pella-Tomlinson model with $m=2$, and $Y_s=32687$ metric tons, $X_s=148$ million hooks calculated by Fox model. In order to compare with the results estimated by step-by-step method, the optimal catch and efforts are also estimated and listed in Table 1 without any adjustment of fishing efforts ($k=1$).

Theoretically, if generalized production model are applicable in stock assessment, then the relationship between effort and catch per unit of fishing effort must be in decreasing trend as shown in Fig. 1. If it shows a increasing trend, then minus estimations might be appeared. As shown in Fig. 2, the relationship of catch and effort data between 71/72, 73/74, 74/75, 75/76 and 81/82 shows an increasing trend, respectively, hence the generalized production model is not usable. The increasing trend means that the higher fishing intensity implies higher abundance index under exploitation. In this case, minus MSY or efforts will be calculated and here, they are denoted by "err". For other time periods, MSY and optimal fishing efforts are calculated and listed in Table 1.

As shown in Table 1, the results are very appreciable. For Schaefer model, average estimated MSY is $Y_s=44108$ MT with efforts $X_s=625399$ thousand hooks in this paper. They are very near to the results estimated by method of least squares $Y_s=38687$ MT and $X_s=429026$ thousand hooks with $k=1$ (Wang et al, 1988). If 1972/73 catch data are excluded for the reasons of unclear decreasing trend (Fig. 2), then the average MSY is $Y_s=46645$ MT with $X_s=393220$ thousand hooks.

For Pella-Tomlinson model, mean value of MSY is $Y_s=55653$ MT and efforts $X_s=498141$ thousand hooks in this paper. If 1972/73 current catch data are excluded, then the mean values are $Y_s=38635$ MT and $X_s=343696$ thousand hooks, respectively. Compared to the results $Y_s=39295$ MT and $X_s=385408$ thousand hooks estimated by the method of least squares with $k=1$ and curve parameter $m=2$ (Wang et al, 1988), the difference is lower than 2% for MSY and 11% for fishing efforts.

It shows a violent variation if Fox model is used to assess the fish stock by step-by-step method. But, if the 1972/73, 1983/84 and 1984/85 current catch data are excluded, then the estimated MSY and optimal fishing efforts are very similar too.

Fig. 3 shows the results estimated by Schaefer model. Current catch data which has a decreasing trend of CPUE and efforts relations are denoted by "o" and MSY estimated in this paper are denoted by black pots. The result of equivalent catch curve estimated by method of least squares are shown in broken line and MSY denoted by the symbol "x". Figure 3 reveals that maximum sustainable yields are not stable during a long time period. Year by year fluctuation of maximum sustainable yield are clearly evident from this figure.

Generally, they are always following a constant maximum sustainable yield based on the theory of production model in fishery management. But, it seems more reasonable to admit that any fish stock has a never ceased fluctuation influenced by bio- and/or abiotic factors in nature. Although, we can not grasp how they varied under the complicated changes of ecosystem, the results estimated by step-by-step method seems to provide some information of the varied trend of fish stock. 79/80, 80/81 and 82/83 data show the similar type of equivalent catch curve. And, 76/77, 78/79, 83/84 and 84/85 data belong to the other type of equivalent catch curve.

6. CONCLUSION

The results may be summarized as follows. By Garcia's method, some assumptions are doubtful: 1. The current catch can not be assured in equivalent state. 2. No suitable method can be used to estimate the current biomass B_c . 3. The assumption of $F_s=M$ is always doubtful. 4. It is difficult to estimate natural mortality when no time series catch and effort data are available.

Garcia's method are amended and a new method is suggested in this paper. By the step-by-step method, 1. Only one or more current catch and effort data are necessary to assess the fish stock under human exploitation. 2. This method can be used to assess the rapid development of new type fishery, although no time series catch and effort data are not available. 3. This method provides the annual fluctuation of maximum sustainable yield and optimal fishing effort, and hence the annual variation of optimal abundance index. It implies that the annual fluctuation of fish stock influenced by environmental factors can be detected from the annual change of the equivalent catch curve and optimal abundance index. 4. The calculation is very simple. The use of computer is not necessary.

South Pacific albacore exploited by tuna longline fisheries during 1971-1985y are used as an numerical example. The results are compared to those estimated by the method of least squares. The results reveal that: 1. Mean values of MSY and optimal fishing effort estimated in this paper are very similar to those by method of least squares. 2. Theoretically, if current catch data show the increasing trend in the relation of CPUE and effort, then production model can not be used in fish stock assessment. The method suggested in this paper does reflect this constraint by the appearance of minus MSY or optimal fishing effort. 3. South Pacific albacore shows three types of equivalent catch curve. During 78/79y, 80/81y and 82/83y, they show a comparatively dull reflection under human exploitation. They can bear with a heavier fishing intensity. During 76/77y, 78/79y, 83/84y and 84/85y, they show a significant reflection under human exploitation. A little change of fishing effort could caused a strict variation of fish stock. The middle type can be found in 77/78y. Although the difference of MSY and optimal fishing effort among these three types are not so large, the different type of equivalent catch curve implies that the quantity and quality of south Pacific albacore stock both are changed influence human exploitation and environmental factors.

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Table 1. Estimated MSY of south Pacific albacore by step-by-step method.

year	Xc	Yc	CPUE Uc	Schaefer model			Fox model			Pella-Tomlinson model (m=2)		
	x1000H	(M.T.)	kg/100H	Xs	Us	Ys	Xs	Us	Ys	Xs	Us	Ys
1971	210117	38479	18.313	err	err	err	err	err	err	err	err	err
1972	213226	39147	18.359	2482831	9.592	23812	4730297	7.065	334217	1733699	11.063	191800
1973	257436	46824	18.189	err	err	err	err	err	err	err	err	err
1974	219031	33039	15.084	err	err	err	err	err	err	err	err	err
1975	134572	16290	12.105	err	err	err	err	err	err	err	err	err
1976	234692	32202	13.721	158682	26.336	41791	80596	69.295	62086	181836	21.206	38561
1977	220468	35455	16.082	428419	10.827	46383	647759	8.315	53860	355350	12.125	43086
1978	197954	32914	10.661	122982	42.325	52053	39670	891.591	353693	151120	26.835	40553
1979	213913	23590	11.031	731820	6.459	47271	1176290	4.867	57253	584040	7.324	42820
1980	357852	34927	9.760	756405	6.392	48350	1172410	4.872	57122	617795	7.192	44434
1981	322772	32460	10.057	err	err	err	err	err	err	err	err	err
1982	311735	28130	9.024	708209	5.785	40970	1157525	4.340	50301	558980	6.573	36743
1983	204392	20236	9.901	124036	28.114	34871	38958	691.626	269444	152513	17.511	26706
1984	213483	16737	7.840	115205	53.358	61471	18996	219168	41633051	147329	24.554	36175
1985	209184	20565	9.831	-	-	-	-	-	-	-	-	-
mean*	234695	30007	13.004	625399	21.021	44108	1007945	24539	4763447	498141	14.931	55653
mean				393220#	22.450#	46645#	848716@	18.339@	56124@	343696#	15.415#	38635#
* : Mean values of all available data.				@ : Mean values with 1972/73, 1983/84, 1984/85 excluded.								
# : Mean values with 1972/73 excluded.				- : No data. err: Minus estimated optimal catch and efforts.								
Note: Estimated optimal catch by method of least squares:												
Efforts are adjusted to five years moving average: k=5												
Schaefer : Xs=207305, Us=15.061, Ys=31222						Efforts without adjustment: k=1						
Pella-Tomlinson (m=2): Xs=222144, Us=14.420, Ys=32033						Xs=429026, Us= 9.017, Ys=38687						
Fox : Xs=148430, Us=22.021, Ys=32687						Xs=385408, Us=10.196, Ys=39295						
						Xs=620231, Us= 6.747, Ys=41846						

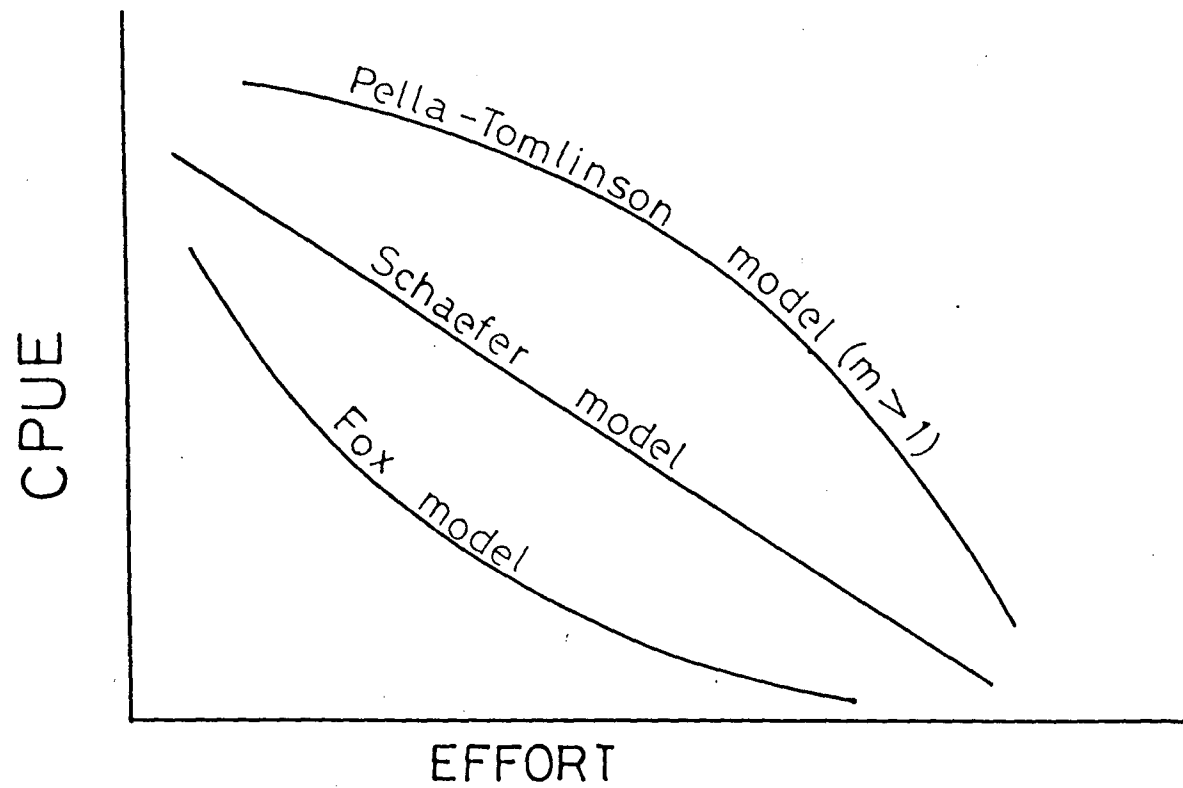


Fig. / Relationship between fishing efforts and catch per unit of fishing effort.

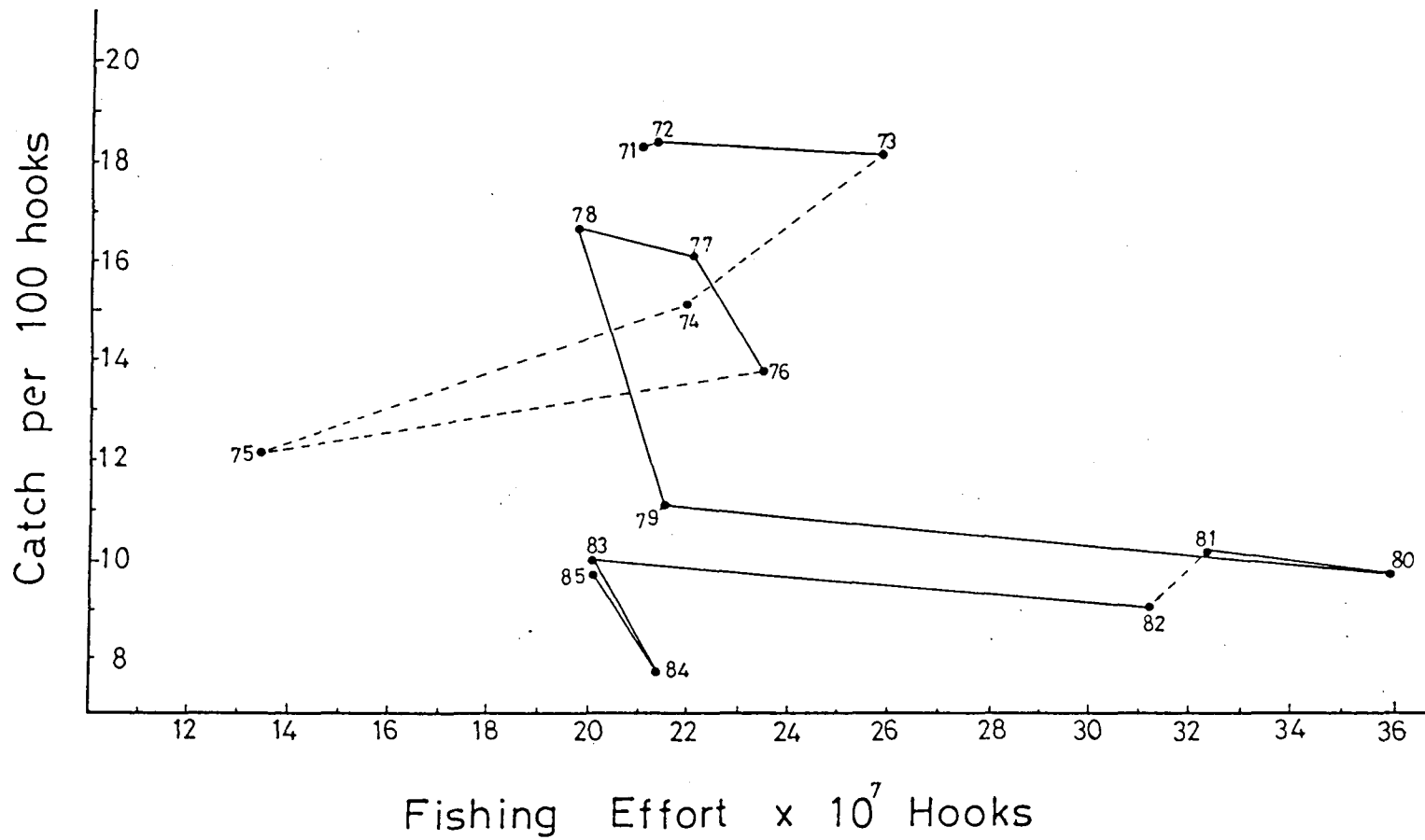


Fig. 2 Relationship between fishing effort and catch per unit of fishing effort of south Pacific albacore.

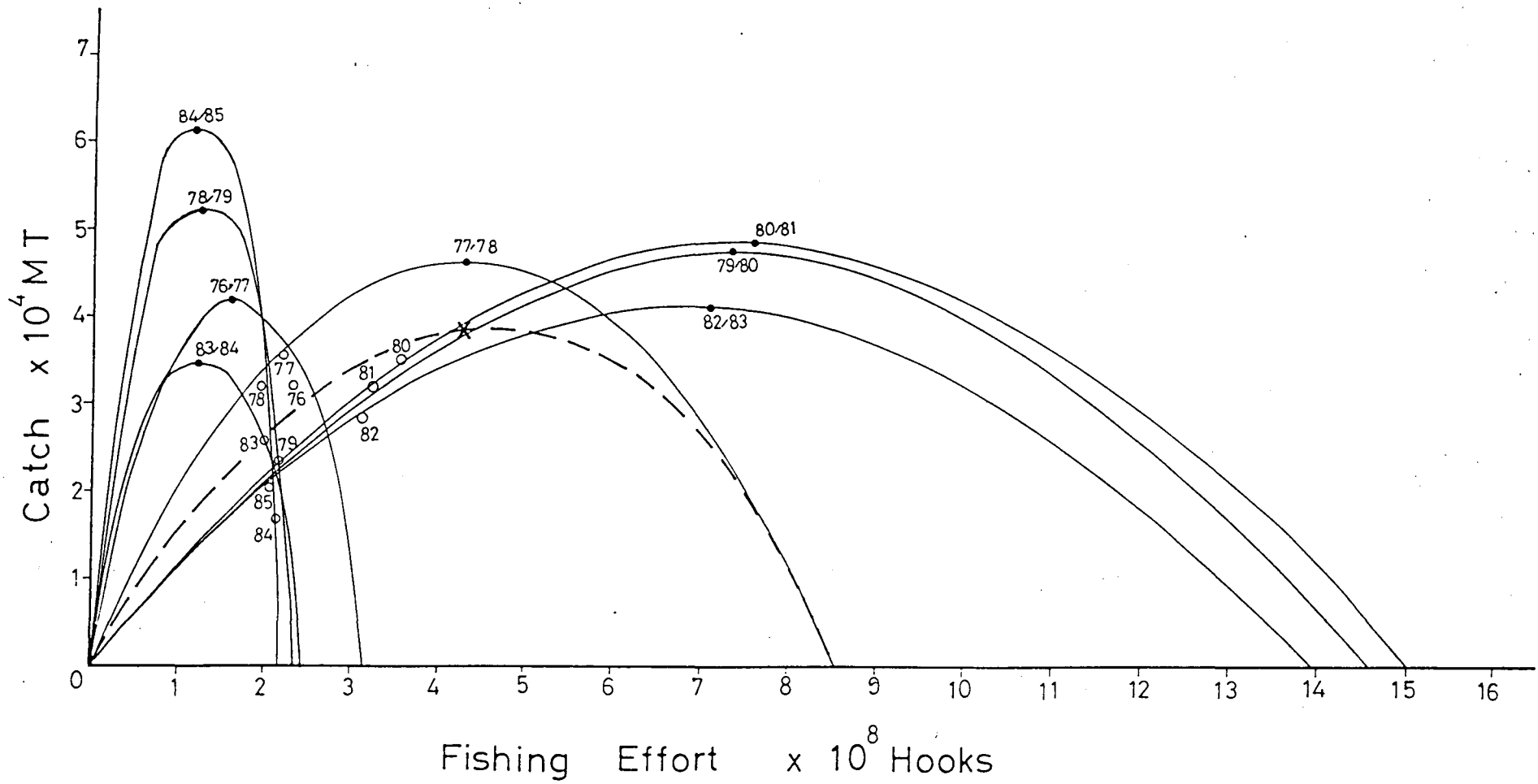


Fig.3 Comparison of MSY estimated by Schaefer model.
 o: Current catch and effort,
 .: MSY estimated by step-by-step method if two current catch data are used,
 x: MSY estimated by method of least squares (Wang et al 1988).