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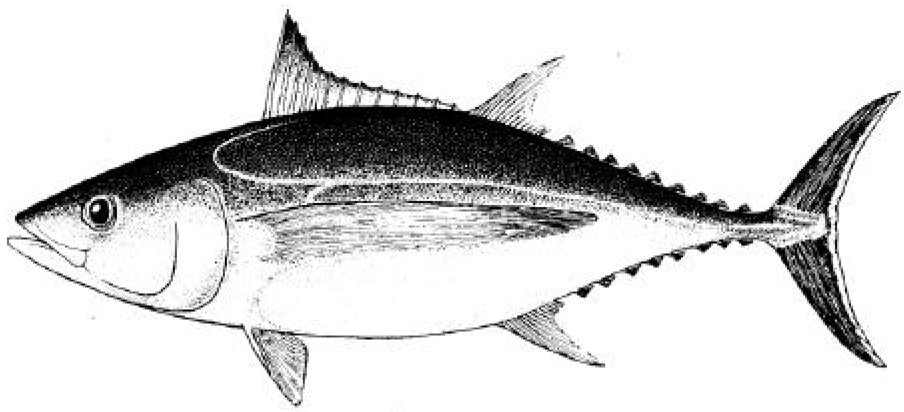
Comparing the results of the south Pacific albacore stocks assessed by four methods



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Title:

Comparing the results of the south Pacific albacore stocks assessed by four methods.

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ABSTRACT

Based on Schaefer's surplus production, four methods were applied to assess south Pacific albacore stocks. Method-1 is based on the assumption of catch at equilibrium. Method-2 is Schnute's method. Method-3 is Walters and Hilborn's method. Both are of catch at non-equilibrium. Method-4 is a generalized method suggested by Wang. All of these methods are very simple and need the catch and effort data only. Method-1 provides the estimation of MSY, but no information about the parameters; intrinsic growth rate *r*, catchability *q*, and carrying capacity *K*. Method-2 and method-3 provide the estimation of *r, q and K,* but no information about MSY. Method-4 provides the estimations of *r, q,* carrying capacity of the virgin stock and of current year.

Keywords: equilibrium, non-equilibrium, generalized method.

Introduction

Schaefer's surplus production model (Schaefer 1954) is a simple, useful and convenient method for assessing fish stocks. Without fishing, it was expressed as follows.

$$f = \frac{dB_t}{dt} = rB_t(1-\frac{B_t}{K}) \qquad (1)$$

Under exploitation, it can be rewritten as follows.

$$f = \frac{dB_t}{dt} = rB_t(1-\frac{B_t}{K}) - F_t B_t \qquad (2)$$

When applied this model in assessing fish stocks, only catch and effort data are necessary. Generally, it was based on the assumption of catch at equilibrium or non-equilibrium.

Method-1

Based on catch at equilibrium, $dB_t / dt = f = 0$, it implied that

$$U_t = qK - \frac{q^2 K}{r} X_t \qquad (3)$$

Where, *U=CPUE=catch per unit of fishing effort, r=intrinsic growth rate, B=biomass, K=carrying capacity, q= catch ability, X=fishing effort, F=qX=fishing mortality rate, t=time.*

This is a linear equation. If catch and effort data are available, then it can be used to estimate *MSY=rK/4* (maximum sustainable yield). However, this equation can be applied only if CPUE decreased continuously under the increasing of the fishing effort. If CPUE increased under the increasing of the fishing effort, then this is a failure model. Further more, by this equation, the parameters *r, q and K* are generally unavailable.

Method-2

The assumption of catch at non-equilibrium were commonly based on following equation.

$$B_{t+1} = B_t + f = B_t + \{rB_t(1 - \frac{B_t}{K}) - F_t B_t\} \qquad (4)$$

Schnute (1977) showed that equation (4) could be transformed into following dynamic equation.

$$\ln(\frac{U_{t+1}}{U_t}) = r - \frac{r}{qK}(\frac{U_t + U_{t+1}}{2}) - q(\frac{X_t + X_{t+1}}{2}) \qquad (5)$$

If catch and effort data are available, then this equation can be used to estimate the parameters, *r, q and K*. However, no information of MSY can be obtained from it, directly. If information of MSY is necessary, then it need to estimate by other method.

Method-3

Based on equation (4), Walters and Hilborn (1976) derived the following equation.

$$\frac{U_{t+1}}{U_t} - 1 = r - \frac{r}{qK} U_t - qX_t \qquad (6)$$

Similarly, only catch and effort data are necessary. This equation can provide the estimations of the parameters, *r, q and K*, but no information of MSY. If MSY is necessary, then it also needs to estimate by other method. Sometimes the negative parameters of biological meaningless results might be obtained. Hilborn and Walter (1992) said that this indicated model failure, that the assumption of the model were just too simple, and that by not explicitly incorporating lags to recruitment.

Above three methods are inevitably assuming the constant carrying capacity. It seems the basic and necessary assumption of Schaefer's model.

Method-4

When applying Schaefer's model in assessing fish stocks, the assumption of catch at equilibrium or not seems not an absolutely necessary condition. Evenly, it does not need to assume the constant carrying capacity. Wang (2000, 2001, 2002) tried to suggest a generalized method of the Schaefer's model. No matter of catch at equilibrium or not and no matter carrying capacity is constant or not, if catch and effort data are available, then there are many parameters, including *r, q, carrying capacity of the virgin stock and current stocks* can be estimated. By Schaefer's model, a theoretical catch curve can be given as follows.

$$Y_t = F_t K_t [1 + \frac{1}{r} \ln(\frac{U_{t-1} + U_t}{U_t + U_{t+1}}) - \frac{F_t}{r}]$$

It implies that

$$U_t = qK_t [1 + \frac{1}{r} \ln(\frac{U_{t-1} + U_t}{U_t + U_{t+1}}) - \frac{q}{r} X_t] \qquad (7)$$

By equation (7), *r and q* can be determined. Defined the index a_t by

$$a_t = B_t / K_t = U_t / qK_t \qquad (8)$$

then it implied that

$$a_t = 1 + \frac{1}{r} \ln(\frac{U_{t-1} + U_t}{U_t + U_{t+1}}) - \frac{q}{r} X_t \qquad (9)$$

Hence, by equation (9), the index a_t can be evaluated. Finally, by the definition of $a_t = B_t / K_t = U_t / qK_t$, current carrying capacity K_t can be calculated year by year. Experimently, by the relationships

$$K = a + b\ a + g\ a^2 \qquad (10)$$

of K_t *and* a_t, the carrying capacity of the virgin stock *Kv can be obtained by setting* a=1.

Numerical example

Based on 1967~2001's catch and effort data of overall tuna long line fisheries operating in the south Pacifc albacore stocks (SPC, 2002), and the logbook data of Taiwanese tuna longline fishery provided by OFDC, total catch, effort and standardized CPUE of the south Pacific albacore stocks are listed in Table 1. Figure 1 showed the relationships between the NCPUE and ECPUE. The trends are similar.

Table 2 showed 4 different methods derived from Schaefer's model. They are used to assess the south Pacific albacore stocks. The results are listed in Table 3.

Method-1: catch at equilibrium.

By method-1, MSY is estimated as 35093 mt. By this method, the parameters *r, q and K* are unknown.. How to estimate these parameters is the first problem. From equation (3), it needs to prove that catch is always at equilibrium. How to prove it is the second problem. Furthermore, the net production is given as $f_t = rB_t(1 - B_t / K)$. It means that this is growing without the fishery. Hence, fishery should enter the fishing grounds just after finished the recruitment of this amount. Moreover, it will exploited such amount in a very short time period. Hence it was applicable for some special type of fishery only. Like as tuna long line fishery, they are operating around the year. How to have MSY is the third problem.

As stated above, equation (3) shows the decreasing trend only. If it showed the increasing trend, then how to assessing fish stocks is the forth problem. Inevitably, some years show the increasing CPUE with the increasing effort. How to reduce the influence of these unusable points in assessing fish stocks is the fifth problem. Hence, even if the MSY can be estimated by this method, it is still doubtful. Finally, this method is based on the assumption of catch at equilibrium. Theoretically, CPUE is the well defined index of abundance. Catch at equilibrium and constant carrying capacity implied the stable biomass. Hence, this method is applicable only if CPUE is approximately closing constant. As shown in Table1, CPUE varied in the ranges of 18.288~75.118. It is difficult to accept the assumption of equilibrium. This is the sixth problem.

Method-2: Schnute's method.

As shown in Table 3, the estimations are *r=0.30612, q=1.37691E-09, and K=356668 mt*. Generally, the estimation of MSY is unavailable. How to prove the existence of MSY from equation (5) is the first problem. If there is, then how to estimate it is the second problem. Theoretically, Schnute's method can be obtained from Wang's method by setting

$$K_t = K = \text{constant}$$
$$B_{t,b} = B_t$$
$$B_{t,e} = B_{t+1}$$
$$U_t = (U_t + U_{t+1})/2$$
$$X_t = (X_t + X_{t+1})/2$$

The third problem is how to prove the constant carrying capacity? The forth problem is why to represent the initial biomass and the ended biomass by the biomass of two successive years, respectively. The fifth problem is why to represent the annual CPUE and annual effort by the average of two successive years, respectively. By method-1, *MSY=rK/4* is obtained. If it is acceptable, then it implies that only *MSY=35093mt* can be obtained by $B_{msy} = 178334$ mt . The ratio of the net production to the biomass is about $MSY / B_{msy} = 19.68\%$. It seems too low. Maybe this is why the estimation of *r=0.30612* is so low..

Method-3. Walters and Hilborn's method.

As shown in Table 3, the estimations of parameters are *r=0.1492, q=-1.0637E-09, K=-2451641mt*, respectively. As pointed by Hilborn and Walters (1992), this method always give the biologically impossible results, i.e., the negative estimations. They described that "this indicated model failure, that the assumption of the model were just too simple and that by not explicitly incorporating lags to recruitment, and so on, these simple biomass dynamic models were failing to capture some important aspects of the data". Maybe they are right, but why only this method give the negative estimations? This is the first problem. Similar to above two methods, it also assumed the constant carrying capacity. Hence, the same problem is how to prove that the carrying capacity is cnstant.

As stated above, the same method can be obtained by setting

$$K_t = K = \text{constant}$$

$$\ln(\frac{B_{t,e}}{B_{t,b}}) = \frac{U_{t+1}}{U_t} - 1 = \frac{U_{t+1} - U_t}{U_t} = \frac{B_{t+1} - B_t}{B_t}$$

in equation (18). The third problem is why to represent the survival rate (the ratio of the end biomass to the biginning biomass) by the growth rate (the ratio of the increament to the biomass). They are quite different. Maybe this is the main reason of the negative estimations.

Method-4: Wang's method.

As shown in Table 3, the parameters are given as *r=1.53311*, *q=6.83355E-09*. Current carrying capacities and the useful index $a_t = B_t / K_t$ are shown in Figure 2 and 3, respectively. K_t varied in the ranges of *49297mt ~ 213077mt* with the mean carrying capacity *86549mt*. The index of $a_t = B_t / K_t$ varied in the ranges of *0.1329~0.8778* with the mean index *a=0.5195*.

The mean index of *a=0.5195* is very closing 1/2. It seems providing an interesting ecological meanings of the fish stocks. Without exploitation, Schaefer's model revealed that the maximum net production can be obtained at biomass just equal to half of the carrying capacity. Under long terms and continuous exploitation of fishery, the virgin stocks are generally unavailable. Hence, it seems reasonably assuming that in order to maintain the population, they always tried to keep the biomass at the levels of having the maximum net production, i.e., *a=0.5*.

Experimentally, the relationships between carrying capacity and index a_t can be expressed by $K = a + b\ a + g\ a^2$. For the south Pacific alabcore stocks, it revealed that $K = 272191 - 706750\,a + 605078\,a^2$ with $R^2 = 0.8335$ (Figure 4a, 4b). The relationships are rather appreciated. Theoretically, the carrying capacity of the virgin stock can be obtained by setting *a=1* in this equation. It implies that the carrying capacity of the virgin stock is about *Kv=170519 mt*.

If the estimation of the most stable carrying capacities is necessary, then it was suggested the mean *a=0.4765* during 1972~2000. Since the mean biomass is about 82950mt, hence the most stable carrying capacity is about *Ks=174080mt*.

If method-1 is acceptable, then MSY is about 65356mt. It was evaluated by *Kv*. However, the carrying capacity varied year by year. Theoretically, larger carrying capacity can provide more catch. Hence, MSY of method-1 seems meaningless here unless the management of the environmental condition is possible.

Discussions and conclussions

The Schaefer's model is a very simple and useful model for assessing fish stocks if reliable catch and effort data are available. Among four methods, Wang's method seems a generalized method of Schaefer's model. Other three methods are special cases of the generalized method only.

Generalized method has some merits. It doesn't need to assume whether or not catch is at equilibrium. It doesn't need to assume whether or not environmental conditions is constant. It is based on theoretical development of the Schaefer's model. There are so many parameters can be obtained. Up to now, no biological impossible results were obtained. Similarly, only catch and effort data are necessary. Calculation is still very simple and very easy.

Because the estimations of r, q, K_v, K_t, K_s and a_t are possible and so easy, the potential of research in the field of biology, of ecology, of evolution, and of course in the field of fishery science is deeply expected.

Table 1. Catch and effort data of overall south Pacific albacore tuna longline fishery.

YEAR	TOTAL LL catch (mt)	ECPUE kg/100H	NCPUE kg/100H	EFFORT *10^7 H
1967	40318	75,118	83,77	5,367
1968	29051	62,788	70,87	4,627
1969	24360	58,452	64,19	4,168
1970	32590	62,325	75,27	5,229
1971	34708	42,760	54,92	8,117
1972	33842	42,836	55,71	7,900
1973	37649	35,405	49,21	10,634
1974	30985	22,388	38,65	13,840
1975	26131	31,829	38,43	8,210
1976	24106	30,314	49,90	7,952
1977	34849	33,734	52,31	10,331
1978	34858	31,011	54,15	11,241
1979	28739	24,288	41,99	11,833
1980	31027	25,771	41,94	12,040
1981	32632	18,715	32,93	17,436
1982	28339	21,079	38,93	13,444
1983	24303	24,088	45,31	10,089
1984	20340	18,225	33,71	11,160
1985	27138	21,665	43,17	12,526
1986	32641	23,735	56,39	13,752
1987	26877	19,808	45,12	13,569
1988	31531	23,569	42,04	13,378
1989	22238	18,288	34,91	12,160
1990	22624	25,077	27,08	9,022
1991	24706	21,273	26,00	11,614
1992	30248	26,707	36,14	11,326
1993	29987	23,105	35,90	12,979
1994	33233	24,229	38,48	13,716
1995	25652	32,872	44,18	7,804
1996	24129	25,889	43,44	9,320
1997	32689	32,158	28,27	10,165
1998	39202	22,027	34,31	17,797
1999	39512	25,974	34,67	15,212
2000	41595	19,340	35,19	21,507
2001	45708	20,044	31,66	22,804

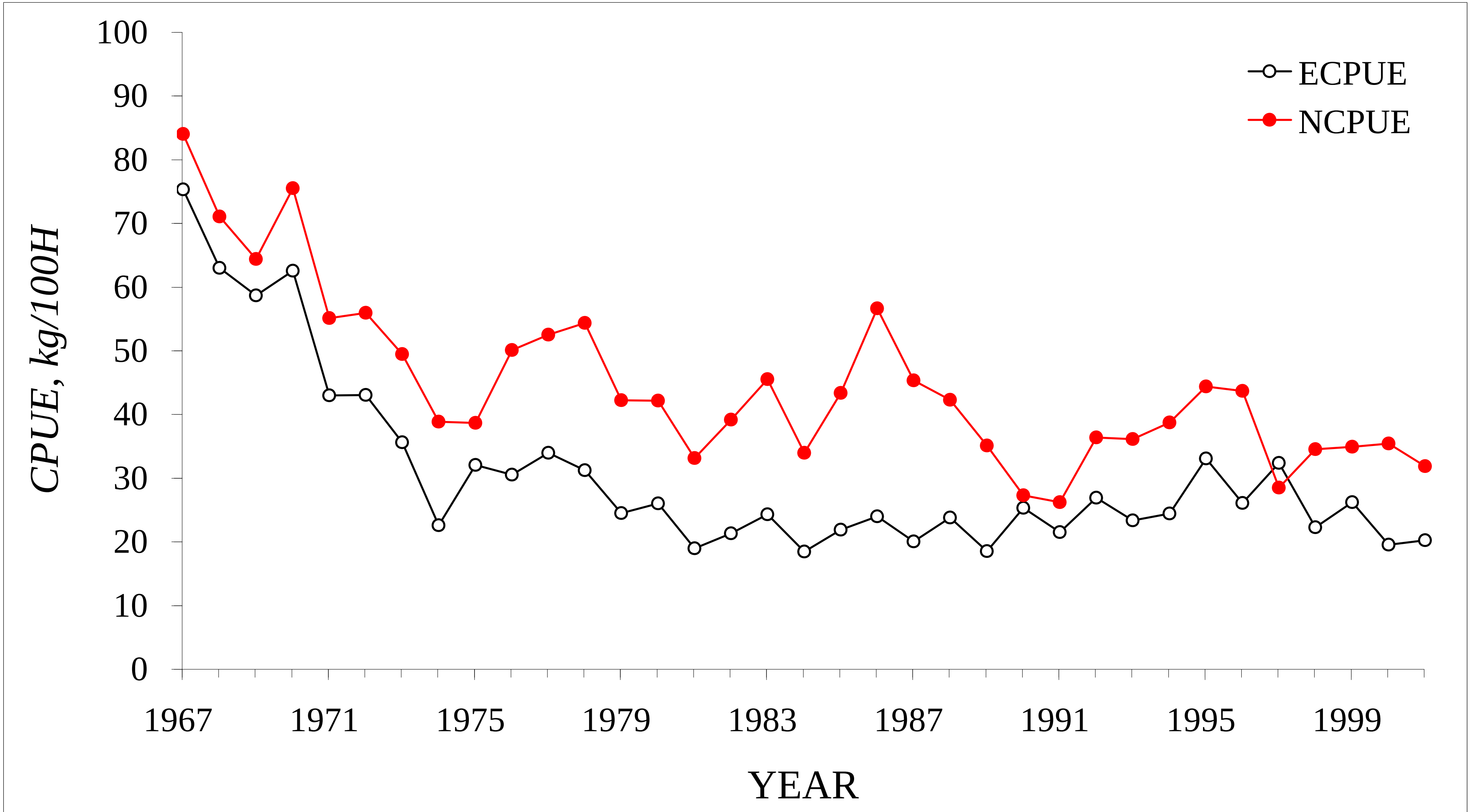

Figure 1. Comparisons of NCPUE and ECPUE.

Table 2. Comparisons of four different methods derived from Schaefer's model.

Method	Assumption	Equation	Obtainable information	Note
1. Catch at equilibrium	Equilibrium *K, q, and r* are constant	$U_t = qK - \frac{q^2 K}{r} X_t$	$MSY = rK/4$	*q, r, K are not available*
2. Schnute's method	Non-equilibrium *K, q, and r* are constant	$\ln(\frac{U_{t+1}}{U_t}) = r - \frac{r}{qK}(\frac{U_t + U_{t+1}}{2}) - q(\frac{X_t + X_{t+1}}{2})$	*q, r, K* *MSY=?*	
3. Walters and Hilborn's method	Non-equilibrium *K, q, and r* are constant	$\frac{U_{t+1}}{U_t} - 1 = r - \frac{r}{qK} U_t - qX_t$	*q, r, K* *MSY=?*	*Negative estimations are obtained*
4. Wang's method	*q and r* are constant.	$U_t = qK_t[1 + \frac{1}{r}\ln(\frac{U_{t-1} + U_t}{U_t + U_{t+1}}) - \frac{q}{r} X_t]$ $a_t = \frac{B_t}{K_t} = \frac{U_t}{qK_{t\,t}}$ $a_t = 1 + \frac{1}{r}\ln(\frac{U_{t-1} + U_t}{U_t + U_{t+1}}) - \frac{q}{r} X_t$ $K_t = a + b\ a_t + g\ a_t^2$	q, r, $K_t, t = 1.....T$ $a_t, t = 1.....T$ K_v K_s	

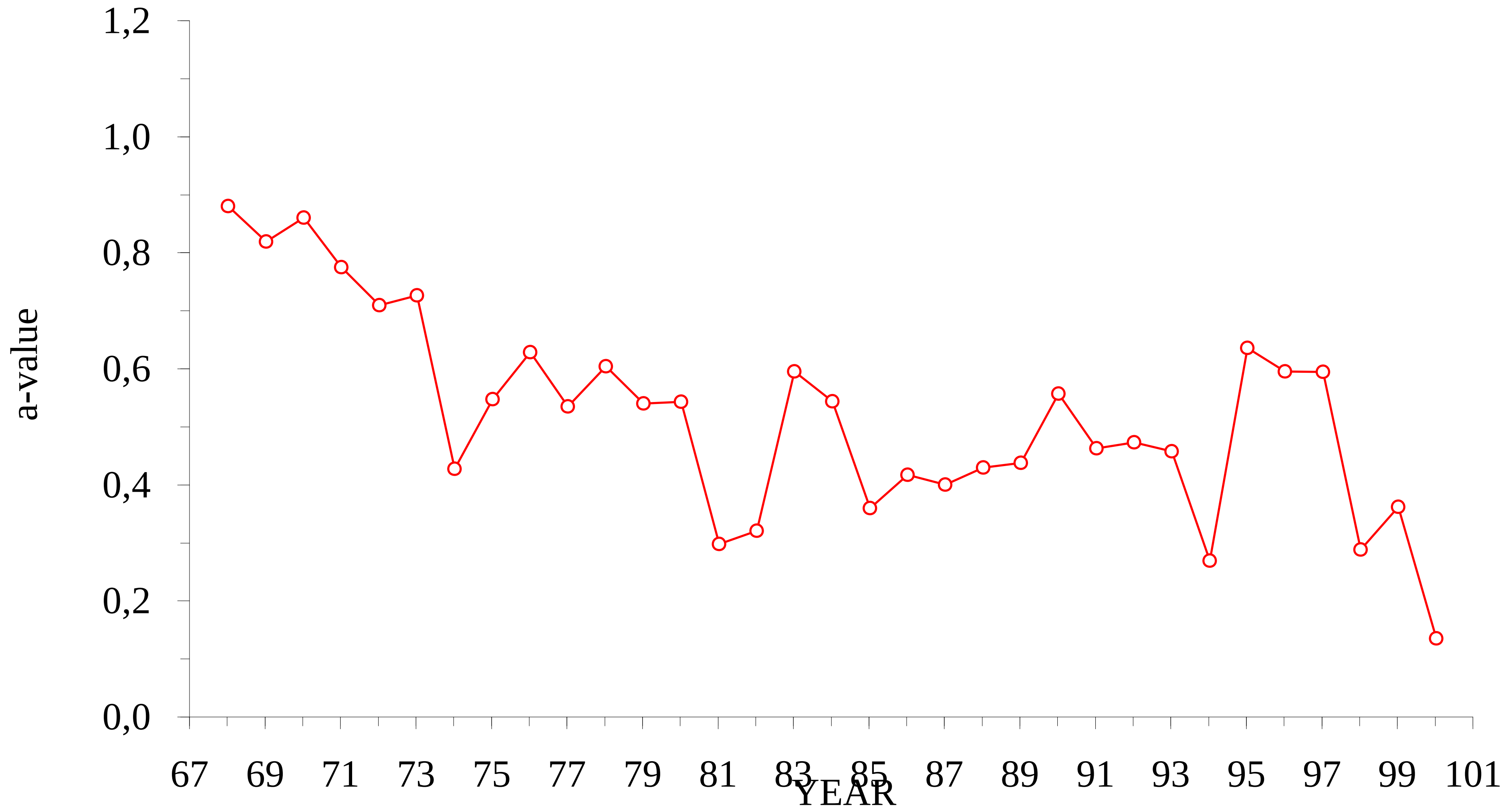

Figure 2. Variation of curent index, a.

Table 3. Comparisons of the results estimated by four different methods.

Method	Results	Note
M-1. Catch at equilibrium	*MSY=35093 mt*	*q, r, K are not available*
M-2. Schnute's method	*r=0.30612, q=1.37691E-09, K=356668 mt* *MSY=27296 mt*	*MSY is estimated by M-1.*
M-3. Walters and Hilborn's method	*r=0.1492, q=-1.06367E-09, K=-2451641 mt* *MSY=-91436 mt*	*Negative estimations are obtained* *MSY is estimated by M-1.*
M-4. Wang's method	*r=1.53311, q=6.83355E-09,* K_{avg}*=86549 mt,* K_{max}*=213007 mt,* K_{mim}*=49297 mt* a_{max}*=0.8778* a_{min}*=0.1329* a_{avg}*=0.5195* K_v*=170519 mt,* K_s*=174080 mt,* a_s*=0.4765* *MSY=65356 mt*	*MSY is estimated by M-1.*

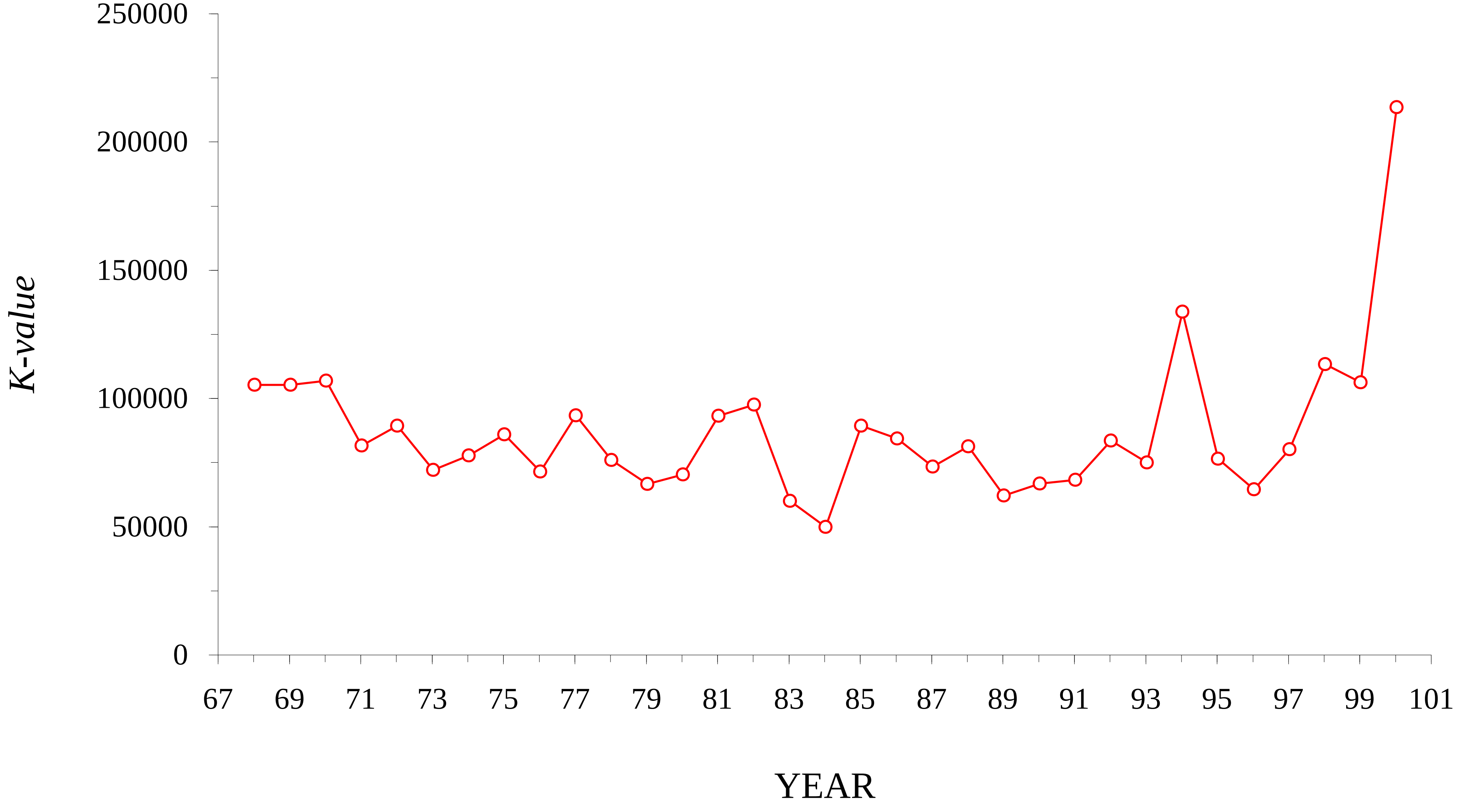

Figure 3. Variations of current capacities, K.

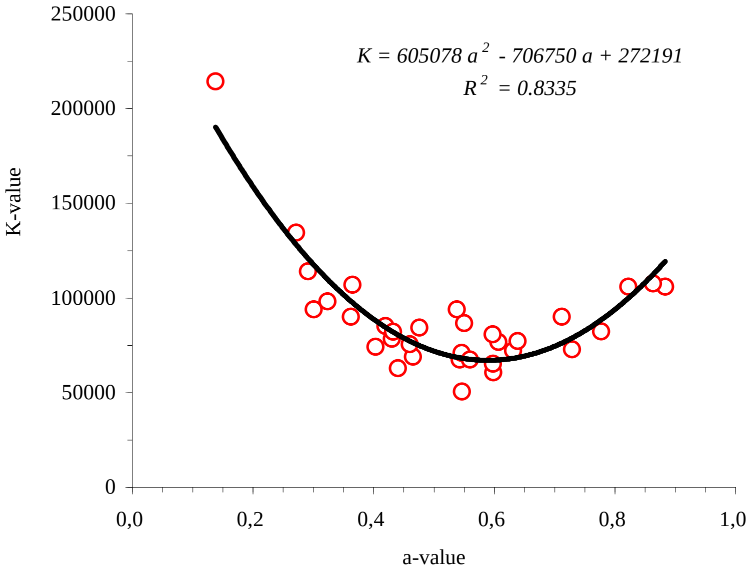

Figure 4a . Relationships between K and a, 2001 included.

170519 R^2 = 0,8335 r= 0,9130

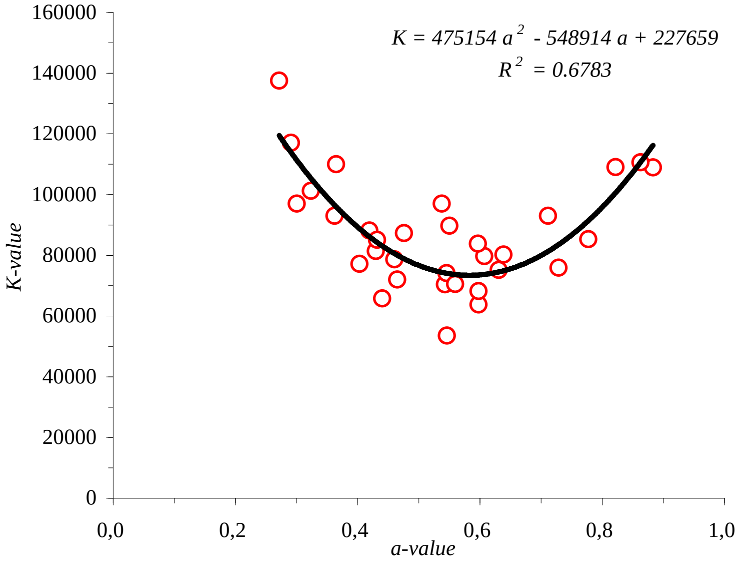

Figure 4b. Relationships between K and a, 2001 excluded.

153899 R^2 = 0,6783 r= 0,8236

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