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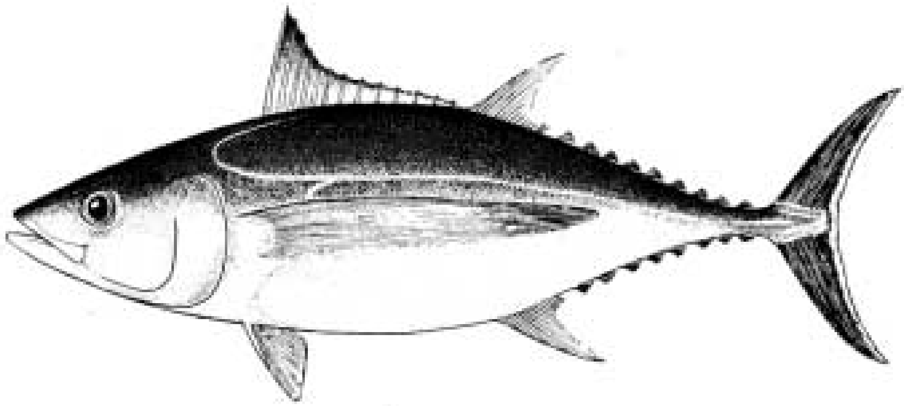
Assessing south Pacific albacore stocks by improved Schaefer model



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ABSTRACT
Five data sets of standardized efforts and CPUE can be obtained from tuna longline fisheries operating in the south Pacific Ocean. They are used to fit the improved Schaefer model for assessing the south Pacific albacore stocks. The results revealed that the best estimations of the south Pacific albacore stocks might be as follows; intrinsic growth rate $r=2.9479$, catchability $q=1.2766E\text{-}08$, carrying capacity of the virgin stock $Kv=106.5$ thousand metric tons, current carrying capacity varied in the ranges of 29.3~112.1 thousand metric tons with the average 46.3 thousand metric tons, MSY varied in the ranges of 21.6~82.6 thousand metric tons with the average 34.1 thousand metric tons.

Keywords: south Pacific albacore, stock assessment, improved Schaefer model

Introduction
South Pacific albacore stock was mainly exploited by tuna longline fisheries. Before 1990, almost all of albacore are exploited by distant-water fleets of Japan, Taiwan and Korea. Since 1990, domestic longline fleets of Pacific island countries expanded and developed quickly. Mainly, they are of small-scale longline fisheries. New Zealand's trolling was target on juvenile albacores.

In 2002, total catch has been over 50,000 mt. Longline gear still accounts for the majority of the catch, about 46,000 mt. Among them, rapid increasing of American Samoa, Fiji, French Polynesia, New Zealand, Western Samoa, and Tonga are noticeable. On the other hand, Korean's catch has decreased to lower than 1, 000 mt only, about 5.8% of 1986's catch (SPC, 2003).

This paper attempts to assessing south Pacific albacore stocks by improved Schaefer model (Wang, 2003a).

Materials
Five different data procedures were used to estimate the standardized fishing efforts and CPUE.

Taiwan-1: Similar to 16th -SCTB meeting (Wang, 2003b), based on 2002's Taiwanese logbook data provided by OFDC, 2004's effective CPUE can be obtained. Hence, 1967~2002's effective CPUE can be obtained by adding this point. Here, assuming that total longline south Pacific albacore stocks were exploited by the same type of fishery, standardized to the Taiwanese type. Hence, total effectives fishing efforts can be calculated as follows.

$$\text{total fishing efforts} = \frac{\text{total catch}}{\text{effective CPUE}}$$

Taiwan-2: Similar to Taiwan-1, but Honma's effective index were re-calculated based on the revised Taiwanese logbook data..

SPC-1: Based on SPC's data, (SPC, 2003), main tuna longline fishing countries data were be use to estimate the standardized nominal CPUE (number/100 Hooks) as follows.

$$\text{standardized CPUE} = (\text{nominal CPUE}) * \frac{\text{mean of Taiwan's CPUE}}{\text{mean of another country's CPUE}}$$

Next, the weighted mean of the standardized CPUE was evaluated as follows.

$$\text{weighted mean of CPUE} =$$
$$\text{sum of } [\frac{\text{country's catch}}{\text{total catch}} * (\text{country's standardized CPUE}]$$

Based on Taiwan's logbook data, mean weight of individuals was evaluated as follows.

mean weight=(catch in weight) /(catch in number)

Finally, effective CPUE in weight can be calculated as follows.

$$(\text{effective CPUE}) = (\text{weighted mean of CPUE}) * (\text{mean weight}) * (\text{Honma's index as given in Taiwan - 1})$$

SPC-2: Similar to SPC-1, but based on the Honma's effective index as given in Taiwan-2.

SPC-3: Similar to SPC-2, but

$$(\text{effective CPUE}) = (\text{weighted mean of CPUE}) * (\text{mean weight})$$

i.e., CPUE and efforts are not adjusted by Honma's effective index.

In SPC's Year book, CPUE was estimated from WCPO region (SPC, 2003). Fortunately, only Japan, Korea and Taiwan's catch data are different from SPO region. In order to make the above calculation more meaningful, Taiwanese data was replaced by the data of SPO region. Japan and Korea's CPUE are simply assuming to be equal to SPO region due to unavailable of the detail logbook data and they are not target on albacore stocks. For other countries, since the catches are the same in both regions, hence, they are naturally assumed to be equal to the CPUE in SPO region. If the annual catch is lower than 1000 mt, then those data are excluded in evaluating the weighted mean of CPUE.

Table 1 shows the total catch of the south Pacific albacore stocks, including all of tuna longline fisheries (SPC, 2003). Taiwan's distant longline catch and nominal CPUE, in both weight and number, and mean weight of individuals are evaluated from the logbook data provided by OFDC.

Above five data sets were used to fit the "improved Schaefer model" for estimating the parameters.

Methods

Improved Schaefer model was applied to estimate the parameters (Wang, 2002, 2003b). Without fisheries, any fish stocks follows equation-1.

$$\frac{dB_t}{B_t dt} = m_t \qquad .....(1)$$

Where, m= *net production rate.* Positive m means biomass is increasing. Negative m means biomass is decreasing. Zero m means biomass is stable. Contrast to Schaefer model, it implied that $m_t = r(1 - B_t / K)$.

Under exploitation, fish stock is always disturbed by fishery. Hence, equation-1 should be rewritten as follows.

$$\frac{dB_t}{dt} = rB_t(1-\frac{B_t}{K_t}) - F_tB_t \qquad \text{.....(2)}$$

For $i \le t < i+1$, i.e., during one year, F and K can be assumed to be constant. By integration, the annual catch (Y) of this year can be obtained as follows (Wang, 2002, 2003).

$$Y = FK[1+\frac{1}{r}\ln(\frac{B_t}{B_{t+1}}) - \frac{q}{r}X] \qquad \text{....(3)}$$

Where, *$F=qX$, q=catchability, X=fishing effort, B_t=the biomass at the beginning of this year, and B_{t+1}=the biomass at the end of this year*. Actually, *Y, F, X and K* might be different year by year. For *i-year,* equation (3) can be rewritten as follows.

$$Y_i = F_iK_i[1+\frac{1}{r}\ln(\frac{B_{i,t}}{B_{i,t+1}}) - \frac{q}{r}X_i] \qquad \text{.....(4)}$$

or

$$U_i = qK_i[1+\frac{1}{r}\ln(\frac{B_{i,t}}{B_{i,t+1}}) - \frac{q}{r}X_i] \qquad \text{.....(5)}$$

Where, *$U_i=Y_i/X_i$=catch per unit of fishing effort.* Clearly, equation (5) shows a series parallel curve. Curvature is depending on r and q but independent on K_i. They are the same as equation (6) with any constant parameter K_c.

$$U_t = Kc[1+\frac{1}{r}\ln(\frac{B_t}{B_{t+1}}) - \frac{q}{r}X_t] \qquad \text{.....(6)}$$

As shown in equation, if catch and effort data are available, then it can be used to determine the parameters *r and q*. If *r and q* are available, then by equation (5), each year's carrying capacity can be calculated as follows.

$$K_i = U_i / \{q[1+\frac{1}{r}\ln(\frac{B_{i,t}}{B_{i,t+1}}) - \frac{q}{r}X_i]\} \qquad \text{.....(7)}$$

And, annual fishing mortality rate can be calculated by $F=qX$. Theoretically, the carrying capacity of the virgin stock K_v can be obtained before fishery entered the fishing grounds, i.e., $F=0$. Hence, it can be calculated by setting $F=0$ in the relationships between Kt and F_t.

According to above improved Schaefer model, merits of the Schaefer model are maintained. Demerits are removed. Similarly, only catch and effort data are needed in assessing fish stocks. No additional parameter or assumption of catch at equilibrium or not is needed. But, more and more information can be obtained, including *r, q, K_v and Kt,* and then m_t, Bt, Ft, and MNP (maximum net production) depending on F_t, etc. By comparing the difference $d_t = m_t - F_t$, and the current biomass to the biomass corresponding to *MNP*, decision making of fisheries management can be easily accomplished. It needs only to keep the difference, $d_t=m_t-F_t$, always positive, i.e., biomass is always in increasing. As to how large, it is depending on human's willing.

Results

Table 2 showed the results estimated by improved Schaefer model based on different data sets. Clearly, larger intrinsic growth rate implied the lower carrying capacity, and vise versa. If MSY=rK/4 is acceptable for the south Pacific albacore stocks, then various MSY can be evaluated depending on the various carrying capacities. No matter what data set used in estimating the parameers, MSY are quite consistent. For the virgin stocks, MSY, or the maximum net production, is about 54~78 thousand metric tons. MSY based on the average carrying capacity is about 32~33 thousand metric tons. The results are quite consistent with other researches (Skillman, 1975, Wetherall et al, 1979, Wetherall and Yong, 1984, 1987, Wang et al, 1988)

As shown in Figure 1~5, the relationships between the estimated carrying capacity and fishing mortality rate are quite appreciable. Among them, the results based on SPC-1 data set might be the best one. Due to unknown reasons, there is one abnormal point in the data set of Taiwan-1 and -2. The correlation of SPC-2 is clearly worse than SPC-1. In Figure 5, some strange points can be found for the larger fishing mortality rate.

If the results estimated by SPC-1 data set is the most acceptable, then the carrying capacity of the virgin stock is about 106 thousand metric tons. The average of the current carrying capacity is about 46,324mt with the ranges of 29,310~112,136mt. Intrinsic growth rate is about 2.9479 with the catchability q=1.2766E-08.

As shown in Figure 6, the nominal CPUE estimated from Taiwan's logbook data are quite consistent with the effective CPUE estimated by SPC-1 method. The deviations in 1976~1989 and 2001~2002 are remarkable. It might be depending on the changes of fishing grounds, fishing gear, target species and other unknown reasons.

Discussions

Here, it is based on the catch and effort data of tuna longline fisheries only. As shown in Table3, before 1984, other fishing types occupied a little percentage of the total catch only. After 1984, the influences of the other fishing types can not be ignored, especially in 1988~1991. Due to quickly development of the drift gill nets, the percentage of the other fishing types increased remarkably. The problem is also related to the quickly development of the trolling. Before 1978, total catch of the trolling is lower than one thousand metric tons. 1n 1989, it has been 8370 metric tons. After this year, it varied in the ranges of 3391~7805 metric tons (SPC, 2003). As shown in Table 3, catch of the other fishing types has been over 10% of the total catch in the recent years. Before an acceptable method can be found to standardize all different fishing gears, including troll, gill nets, pole-and-line, etc., it is simply based on tuna longline catch and effort data only.

Caddy (1998) suggested that the biological basis for fisheries management would minimally cover 15 procedures; including feasible management actions, stock structure, prey-predator relationships, distribution, spawning areas, stock-recruitment relationships, etc. Really, such researches are helpful and useful for knowing the fluctuations of the fish stocks and naturally for successful fisheries management. If fisheries management is target on preserving the fish stocks and exploiting it as large as possible, then the improved Schaefer model seems a powerful tool for assessing fish stocks. It needs catch and effort data only. Really, Caddy's suggestions are helpful and useful for successful fisheries management, but not absolutely necessary. Moreover, such researches are generally insufficient and need much time, money and/or manpower.

Maunder (2003) suggested to discard the Schaefer model from the stock assessment scientist's toolbox. Mainly, his suggestion was based on Prager's comparisons (Prager, 2002). As stated above, after a little improvement of the Schaefer model, a powerful tool can be obtained in assessing fish stocks. At least, the Input/Output ratio of this model might be the best one. The problem is how to make the efforts and CPUE more reliable and meaningful.

Up to now, MULTIFAN-CL model might be the most complicated and expensive model. It cost much time, money and manpower, etc.. Furthermore, it needs many assumptions to finish the whole calculations. Unfortunately, the results seems being doubtful. As shown in Table 4, the estimated fishing mortality rates are quite different (Hampton and Fournier, 2000, Bigelow, et al., 2001, Hampton, 2002, 2003). Theoretically, they should be similar.

In 15th–meeting, estimation of 1975's fishing mortality rate is about 0.050. It is about 25 times (0.100/0.004=25.0) of that estimated in 16th–meeting. For 1995's fishing mortality rate, it is about 0.018 in 13th-meeting. But, it is about 0.210 in 16th–meeting. The difference is about 11.67 (=0.21/0.018) times..

Not only the estimations, but the tendency is also different. In 13th–meeting, the maximum value appeared in 1995. But, it appeared in 1997 for other meetings.
In 16th –meeting, the minimum value appeared in 1976. It appeared in 1975 for other meetings. Moreover, the minimum estimation is almost equal to the maximum value of the pre-year's estimation. The results are quite doubtful.

Furthermore, Hampton (2003) showed that the biomass index decreased continuously and strictly during 1980~1993 (about from 1.25 to 0.75; Figure 18 on p28 of Hampton, 2003). However, the longline catch in the same time period maintained in a rather stable level. They decreased from 1980's 31027mt to 1984's 20340mt, and then increased to 1993's 29987mt (Table 79 on P156 of SPC, 2003). Similarly, they are target on adults.

Hampton's results revealed that the biomass has been decreased continuously to the rather low level. It implied that the biomass might be in dangerous low conditions. Strangely, his results revealed that the ratios of *F/Fmsy and B/Bmsy* are still in very high level, 4~7 for *B/Bmsy* and 0.05~0.10 for *F/Fmsy*, (Figure 21 on P30 of Hampton, 2003), i.e., the fish stocks are still in very good conditions, probably in very low exploitation. After long term exploitation, albacore tuna long line fisheries are sufficient development in the South Pacific Ocean. It seems impossible to reveal that stocks are still in very low exploitation but the biomass decreased so strictly and continuously.

Conclusions

Improved Schaefer model seems being a very powerful tool for assessing fish stocks. Merits are maintained but demerits are removed. It needs catch and effort data only. It didn't care the catch at equilibrium or not. The input/output ratio might be the biggest one. It might be the most simple, convenient, and easy method in assessing fish stocks. Maunder (2003) said that "The only substantial reason that I can think of to use a generalized model in place of an age-structure model is that the age-structure model may not described all the important density-dependence processes (e.g. density-dependent natural mortality or density-dependent growth). The generalized model (Pella &Tomlinson, 1969) combines these processes together into a single functional form, and may provide a better approximation to reality". Really, this is the main and common merit of the Schaefer model, and hence, the improved Schaefer model.

He said continuously that "However, this would require the ability to obtain a reliable estimate of the shape parameter from the data, which is not possible in most cases". Of course, if the shape parameter in generalized model is necessary, then just as he said, a reliable estimation of the parameter is necessary. However, if this parameter is not absolutely necessary then this requirement should be ignored. Equation-3 implied $\frac{dB_t}{dt} = -\frac{r}{K}[B_t - \frac{K(r-F)}{2r}]^2 + \frac{K(r-F)^2}{4r}$. If the main purpose of the shape parameter of generalized production model is target on changing the size and position of the mode, then this equation is good enough to describe it without the shape parameter..

Really, Schaefer model is so simple. Because it is too simple, so the merits of this model became the demerits of this model. It was always blamed that it is too simple to represent the complex phenomenon of the population. However, the demerits might be the merits of this model. Because it is too simple, so it can avoid the interaction or correlation among different parameters and/or assumptions. This is always unavoidable in other complicated model, like as age-structured model, MULTIFAN-CL model, etc.

He said continuously "Nevertheless, it may provide a more accurate representation of the uncertainty, particularly if annual residuals are also included". As stated above, estimation of the net production rate m_t is possible. It is helpful to know the accurate representation of the uncertainty. As stated above, m_t is the net production rate, it represents the change rate in nature excluding the influence of the fishery. Like as natural mortality rate, it implies the influences of the fish stocks under the changes of the environmental conditions. However, it is different from the natural mortality rate. Natural mortality rate means the decreasing rate of the same year class. Hence, it is always positive. But, m_t means the change rate of the biomass. Hence, it might be positive or negative. It is depending on the relative size of the goodness of the environmental conditions and the intrinsic increasing power of the biomass.

Theoretically, Schaefer model implied that the population always has increasing power if the biomass is lower than the carrying capacity. This increasing power is depending on the abundance and with compensation. Hence, it formed the MSY theory. However, it is based on constant environmental conditions, i.e., m_t is constant.

If fishery is entered, then anyway fishery is one of the factors affecting the environmental conditions of the fish stocks. Hence, constant m_t and carrying capacity are generally not available under exploitation. This is why it needs to replace $m_t = r(1 - \frac{B_t}{K})$ by $m_t = r(1 - \frac{B_t}{K_t})$. The information of m_t is possible and helpful for knowing the more accurate representation of the uncertainty. This parameter can be estimated as stated above (Wang, 2002, 2003b).

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Table 1. Catch statistics of the South Pacific albacore stocks.
(1967~2002)

	all LL	Taiwan		Taiwan		
	in SPO	DLL	Tai/SPO	Nom-U=	Nom-U=	Wt/No=
year	catch (mt)	catch (mt)	in %	No/100H	Kg/100 H	Kg/ind
1967	40318	11497	28.52	5.41	80.40	14.87
1968	29051	12254	42.18	4.01	59.12	14.76
1969	24360	9503	39.01	4.70	70.40	14.98
1970	32590	14484	44.44	4.30	64.56	15.01
1971	34708	15871	45.73	3.79	56.21	14.84
1972	33842	16674	49.27	3.22	47.72	14.81
1973	37649	17741	47.12	3.33	48.59	14.60
1974	30985	16857	54.40	2.42	35.64	14.74
1975	26131	16056	61.44	2.05	30.44	14.87
1976	24106	13206	54.78	2.74	41.03	15.00
1977	34849	21429	61.49	3.01	44.72	14.84
1978	34858	20702	59.39	3.83	55.65	14.55
1979	28739	14987	52.15	2.81	42.19	14.99
1980	31027	17998	58.01	2.68	40.02	14.95
1981	32632	14390	44.10	2.37	32.81	13.82
1982	28339	12634	44.58	2.71	40.87	15.08
1983	24303	12069	49.66	3.28	46.32	14.14
1984	20340	11155	54.84	2.32	33.99	14.63
1985	27138	9601	35.38	2.95	43.50	14.76
1986	32641	11913	36.50	4.08	58.78	14.40
1987	26877	15009	55.84	2.91	43.41	14.93
1988	31531	17120	54.30	2.99	42.74	14.31
1989	22238	10867	48.87	1.36	19.65	14.40
1990	22624	11619	51.36	1.33	22.67	17.03
1991	24706	16508	66.82	1.77	23.65	13.38
1992	30248	20956	69.28	2.69	35.74	13.30
1993	29987	17701	59.03	2.51	34.55	13.75
1994	33235	19731	59.37	2.69	35.96	13.36
1995	25653	12775	49.80	2.48	34.13	13.75
1996	24120	11909	49.37	3.24	44.91	13.86
1997	32392	15662	48.35	3.58	51.37	14.34
1998	40141	13812	34.41	2.46	39.98	16.22
1999	36023	13684	37.99	2.05	27.39	13.35
2000	39838	15917	39.95	1.67	24.05	14.36
2001	45886	12026	26.21	1.11	16.49	14.85
2002	45969	7850	17.08	0.87	12.24	14.08

Note:
LL= longline fishery
SPO= south Pacific Ocean
DLL= Distant longline fishery
Nom-U=nominal CPUE

Table 2. Results estimated by improved Schaefer model based on different data sets

unit: mt

data sets*	Taiwan-1	Taiwan-2	SPC-1	SPC-2	SPC-3
MSY by K_{max}=	85604	98240	82641	50802	68759
MSY by K_{min}=	23664	21609	21601	21505	21684
MSY by K_{avg}=	32673	33091	34140	33031	34768
MSY by K_v=	70178	74012	78482	54380	64753
MSY by K_l=	27530	33386	28085	30466	30510
K_{max}=	266732	282669	112136	58122	32308
K_{min}=	73734	62175	29310	24604	10189
K_{avg}=	101807	95212	46324	37791	16337
K_v=	218667	212957	106492	62216	30426
K_c=	97985	90756	44489	37311	16000
r=	1.2837	1.3902	2.9479	3.4962	8.5129
q=	6.0212E-09	6.5691E-09	1.2766E-08	1.6813E-08	3.9329E-08
R^2=	0.7362	0.7261	0.6994	0.6563	0.7069
** F=	43.261	41.094	36.067	29.604	37.389
df1=	2	2	2	2	2
df2=	31	31	31	31	31

* refert o contents

Table 3. Catch statistics of the south Pacific albacore stocks.
(1967~2002)

unit: mt

	longline fisheries		other fisheries		total
year	catch	%	catch	%	catch
1967	40318	99.99	5	0.01	40323
1968	29051	99.95	14	0.05	29065
1969	24360	100.00	0	0.00	24360
1970	32590	99.54	150	0.46	32740
1971	34708	99.71	100	0.29	34808
1972	33842	98.86	390	1.14	34232
1973	37649	98.37	625	1.63	38274
1974	30985	94.78	1707	5.22	32692
1975	26131	97.22	746	2.78	26877
1976	24106	99.48	125	0.52	24231
1977	34849	97.97	721	2.03	35570
1978	34858	95.13	1786	4.87	36644
1979	28739	96.92	914	3.08	29653
1980	31027	95.19	1569	4.81	32596
1981	32632	93.98	2090	6.02	34722
1982	28339	92.07	2441	7.93	30780
1983	24303	96.88	783	3.12	25086
1984	20340	82.33	4364	17.67	24704
1985	27138	83.95	5190	16.05	32328
1986	32641	89.21	3949	10.79	36590
1987	26877	89.74	3073	10.26	29950
1988	31531	76.70	9579	23.30	41110
1989	22238	42.30	30338	57.70	52576
1990	22624	60.52	14758	39.48	37382
1991	24706	72.63	9308	27.37	34014
1992	30248	81.97	6654	18.03	36902
1993	29987	87.10	4440	12.90	34427
1994	33235	81.95	7320	18.05	40555
1995	25653	76.34	7951	23.66	33604
1996	24120	76.15	7553	23.85	31673
1997	32392	87.02	4833	12.98	37225
1998	40141	86.27	6390	13.73	46531
1999	36023	90.91	3603	9.09	39626
2000	39838	86.70	6109	13.30	45947
2001	45886	88.77	5803	11.23	51689
2002	45969	90.39	4889	9.61	50858
mean	31113	89	4452	11	35565

Table 4. Fishing mortality rates estimated by MULTIFAN-CL model

items	1975	1995	minimum	year	maximum	year
13th-SCTB meeting	0.004	0.018	0.004	1975	0.018	1995
14th-SCTB meeting	0.016	0.051	0.016	1975	0.056	1997
15th-SCTB meeting	0.050	0.150	0.050	1975	0.200	1997
16th-SCTB meeting	0.100	0.210	0.065	1976	0.240	1997

Table 5. Fishing mortality rate estimated by improved Schaefer model.

items	TAI-1	TAI-2	SPC-1	SPC-2	SPC-3
maximum	1.2815	1.502	2.3967	2.8114	6.6792
minimum	0.2509	0.2694	0.5322	0.7142	1.5237
average	0.6699	0.7197	1.4984	1.7754	3.9138
1975	0.4943	0.5346	1.3501	1.396	6.6592
1995	0.5528	0.5985	1.2304	1.2422	2.5204

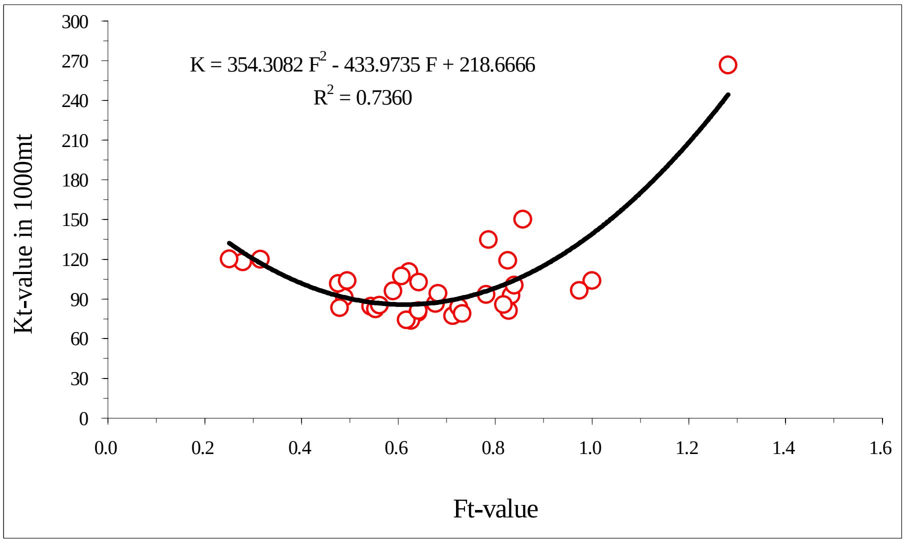

Figure 1. Relationships between estimated *Kt* and *Ft* . Taiwan-1

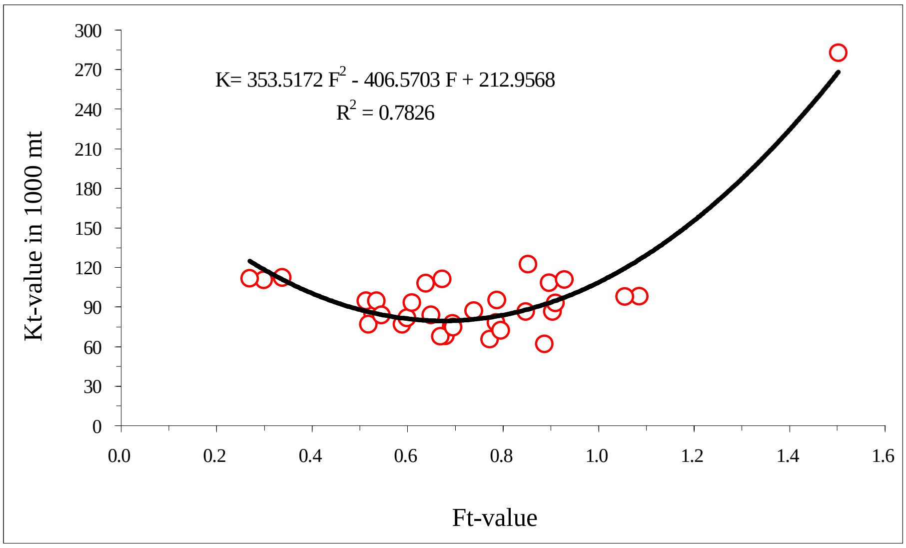

Figure 2. Relationships between estimated *Kt* and *Ft* . Taiwan-2

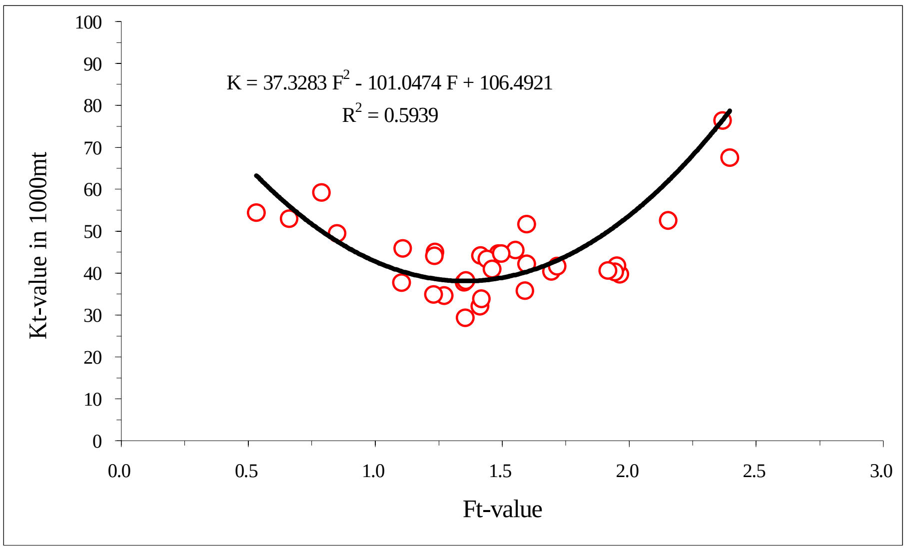

Figure 3. Relationships between estimated *Kt* and *Ft* . SPC-1

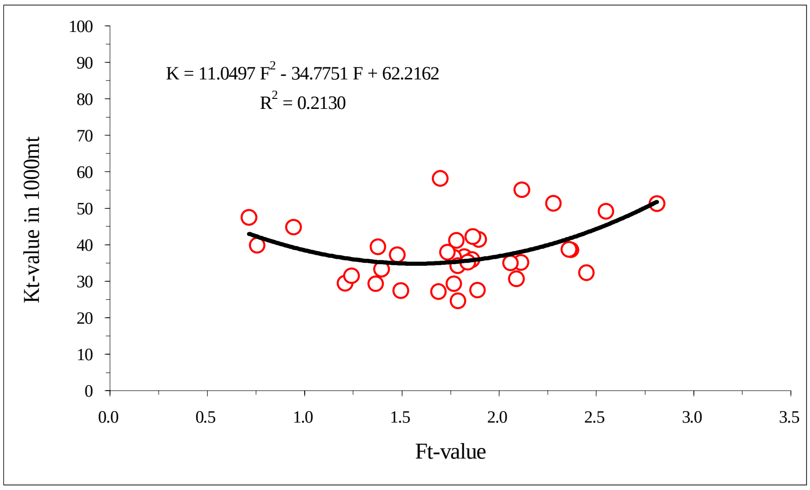

Figure 4. Relationships between estimated *Kt* and *Ft* . SPC-2

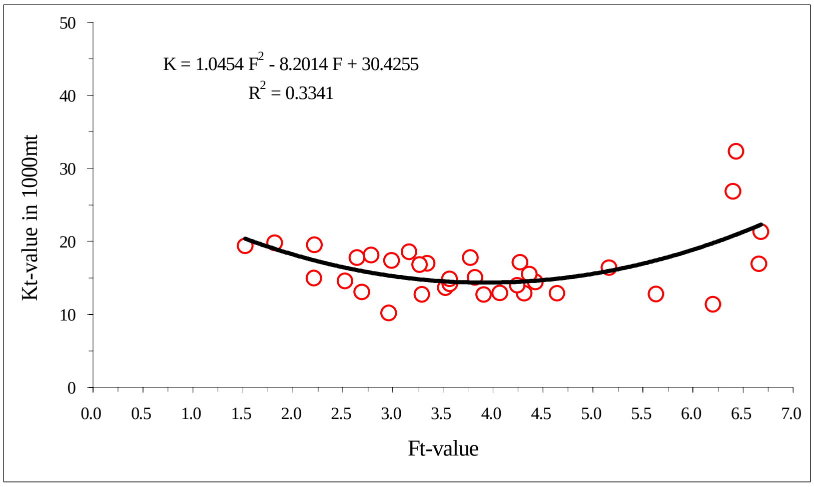

Figure 5. Relationships between estimated *Kt* and *Ft* . SPC-3

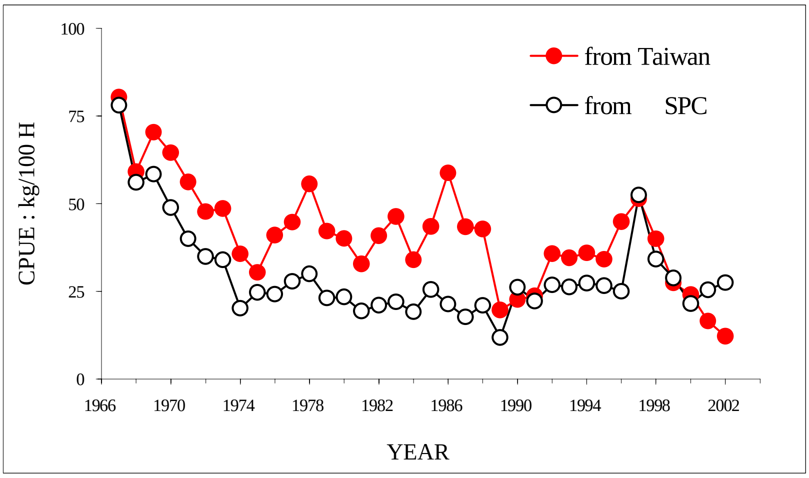

Figure 6. Comparisons of nominal (from Taiwan) and effective CPUE (from SPC).