Broodstock Assessment and the Relationship between Length and Fishing Mortality Coefficient of Giant Tiger Prawn (*Penaeus monodon* Fabricius) in Trang Province, Thailand by Sommani's Method.

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ABSTRACT

The assessment of giant tiger prawn (*Penaeus monodon* Fabricius) broodstock resource in Trang Province, Thailand using length-composition data from sampling and total catch in number by shrimp trawl during 1999 – 2000 was investigated. Sommani's length-based cohort analysis revealed that there were approximately 339,121 males and 558,060 females in natural broodstock and the recruitment was 62,328 males and 131,226 females. It might be concluded that the reliability in this method depends on the appropriate input of the natural mortality coefficient (M) rather than the fishing mortality coefficient (F). The relationship between the carapace length (CL) and the fishing mortality coefficient (F) under the Sommani's model is $F=0.64e^{-5.41/(CL-41.02)}$, $S_{y.x} = 0.003$ in the male and $F=0.76e^{-19.84/(CL-47.06)}$, $S_{y.x} = 0.001$ in the female. The curve was an asymmetric sigmoid that fishing mortality coefficient increased rapidly after the recruitment of the broodstock to the fishing ground. Then the increasing rate declined slightly until reaching to the maximum fishing mortality coefficient at the maximum carapace length.

INTRODUCTION

In the classical fisheries assessment, fishery biologists usually assumed that the growth and mortality parameters are constant including the assumption of constant fishing mortality (F) at any age or length of fish (Beverton and Holt, 1957). In contrast with Ricker (1958, 1975), he allowed the F vary seasonally. He divided the fish's life span into very short intervals, computed the yield separately and then summed up to get the total yield from the cohort. But in general, such assumption is not actually true in many cases of fishes and fisheries. The F is likely depend on the length of fish due to the selectivity of fishing gears. As the works of Murphy (1965, 1966) and Gulland (1965) which applied to estimate the mortality rate by iterative method when the fishing mortality varies with age. Unfortunately, such methods have not been widely used because of the time consuming to work 'by hand'. Pope (1972) developed an easy technique and has been proved as a well-known tool in fish stock assessment called 'Pope's age-based cohort analysis' and Jones later developed to 'Jones' length-based cohort analysis' based on the principle of Virtual Population Analysis (VPA) (Jones, 1981). However, both methods have the same limitation that the approximation to VPA is valid for the values of F and natural mortality rate (M) less than 1.2 and 0.3 per year respectively (Sparre and Venema, 1992). This makes it difficult or even impossible to apply to tropical fisheries for whom age determination are often unreliable and high rate of growth and mortality.

Sommani (1987, 1988) modified the Gulland-Murphy technique and combined with the method of estimating the F by itrative method. He proved his method by length frequency data of lizardfish, *Saurida elongata*

(Temminck & Schlegel), who is the economic demersal species of Thailand. He also concluded that F varied with length. Jutagate and Thapanand (1998) used Sommani's methods predicted the relationship between F and length in pelagic fish namely Indian mackerel, *Rastrelliger kanagurta* (Cuvier). The result showed a little bit different curve from Sommani (1988) according to their life histories.

Though the two papers suggested how profitable of Sommani's methods in fish - vertebrate- but there is not any trial in invertebrates before. In this study, the giant tiger prawn, *Penaeus monodon* Fabricius, broodstock was used as a representative for testing Sommani's methods in crustacean because of its valuable resource for producing the post-larva in shrimp culture. The output from this paper may be useful for ones who want to estimate the number of natural fisheries stock and F at each length under the condition of high rate of growth and mortality.

MATERIALS AND INPUT DATA

The total catch in number for *P. monodon* broodstock in Trang Province, the Andaman Sea, used in this study were taken from Songrak (2001). The sampling strategies and the analysis of some important data may be read for more details from his study.

The growth parameters were taken from Khan *et al* (1994) are as follows: the maximum carapace length (L_∞) = 77.52 mm, and K = 0.1 per month for the male and L_∞ = 82.99 mm, and K = 0.142 per month for the female respectively. The F-value was re-calculated by the method of Jones and van Zalinge (1981) using Songrak's length frequency data as for F = 0.4409 per month in male and F = 0.26 per month in female respectively.

As an ordinary tropical invertebrate species, it is impossible to estimate the M-value by Pauly's empirical formula in *P. monodon* because of the limitation only in fishes (Sparre and Venema, 1992). In this study, I assumed that M is equal to K or the M-K ratio is unity because the average fishable life span in the natural tropical population is likely to be short, probably about one year. Furthermore, the M was set up to be constant after recruitment for all size group.

The estimation of the total number of natural *P. monodon* broodstock and the F-value of each length class by Sommani's VPA was made iteratively by microsoft EXCEL. Working backwards, from the large size to the smallest.

The Sommani's catch curve was used to determine the relationship of F via length according to the following equation:

$$F_i = \alpha e^{-\frac{\beta}{(L_i - L_0)}}$$

As the lack of reference of L_0, the length at which the F is zero, I assumed that L_0 is the largest size before be caught by the fishing gear as for the input estimate because of its definition. The estimation of the constants; α, β and L_0; were obtained by nonlinear regression analysis by SPSS for windows.

RESULT AND DISCUSSION

From the Sommani's VPA, the F and broodstock size of *P. monodon* were shown in Table 1.

Table 1 : The fishing mortality coefficient (F) and the broodstock size of *P. monodon* at Trang Province (L_∞ = 77.52 mm, and K = M = 0.1 per month for the male and L_∞ = 82.99 mm, and K = M = 0.142 per month for the female)

	Male			**Female**	
Lower limit (mm)	**F_i (per month)**	**N_i**	**Lower limit (mm)**	**F_i (per month)**	**N_i**
40.0	0.0074	62328	45.0	0.0005	131226
42.0	0.0219	58850	49.0	0.0044	116739
44.0	0.0941	54821	53.0	0.0354	103255
46.0	0.1922	48651	57.0	0.1404	86330
48.0	0.3838	40171	61.0	0.2358	61889
50.0	0.4906	28631	65.0	0.3241	36250
52.0	0.5199	18337	69.0	0.3342	15859
54.0	0.4152	11057	73.0	0.3232	5117
56.0	0.3281	6996	77.0	0.8696	956
58.0	0.4031	4608	81.0+	**0.2600***	439
60.0	0.5824	2675			
62.0	0.3706	1170			
64.0	0.5499	612			
66.0+	**0.4409***	214			
Total		339121			558060

* estimated from Jones and van Zalinge (1981)

The class length of both sexes were re-grouped from Songrak (2001) due to the assumption of a 'pseudo-cohort' which based on the assumption of a constant parameter system (Sparre and Venema, 1998). From Table 1, it can be said that the recruitment of the broodstock were approximately 62,328 males and 131,226 females. For the estimated broodstock size, since the data is total catch in number, the result showed that there were about 339,121 males and 558,060 females in the natural. It is quite different from the study of Songrak (2001). The effect may cause by the input value of M. In general, it is obvious that a high input for M will result in lower estimate for F. The lower estimate for F will result in the underestimate of the exploitation rate and hence an 'overestimate' of the broodstock size (Sommani, 1987; Jones, 1981). In my opinion, it should be better if we can find a reliable value of M or started with the unity of M-K ratio as this study if we cannot use the Pauly's empirical formula. As the personal contact with Jutagate, he suggested that Pauly's empirical formula is sometimes applied to invertebrate which is under the isometric growth condition. For *P. monodon* and other invertebrates who have moulting process for growth, the von Bertalanffy's growth function (VBGF) usually be 'stepwise' and therefore the average growth curve of a cohort becomes a smooth curve as VBGF (Sparre and Venema, 1992). By this condition, Songrak (2001) used Pauly's empirical formula with his own growth parameters predicted the M and it was 0.1425 per month in male and 0.1567 per month in female which somewhat different from his K-values (0.1083 per month in male and 0.14 per month in female). When I used Pauly's empirical formula with the growth parameters of Khan *et al* (1994), the empirical M of *P. monodon* is 0.1218 per month and 0.1649 per month in male and female which were slightly higher than K-values. However, I did not use such empirical M because of the effect of input M as the earlier mentioned.

Songrak used Jones and van Zalinge's method for estimating the overall F, and then he used Jones' length-based cohort analysis estimating the F at each length class and the number of recruitment. The difference value of F between his study and here caused by the difference of growth parameters and decision making of the co-ordinates used in regression analysis. The reason that I used the growth parameters from Khan *et al* (1994) is such data collected from the set bagnet but the data of Songrak (2001) covered only the size of broodstock which the growth nearly stable and its growth rate is nearly zero. Nevertheless, the variation of F do not have much effect than the M. For the survival rate, it usually decreases while the exploitation rate increases as the size of the broodstock increases. There are caused by the increase with size of the F and the time required for the broodstock to grow from the lower limit to the upper limit of the length class.

The data from Table 1 revealed that F tend to increase 'decreasingly' as the size increase. By the Sommani's model, the constants were estimated by regression analysis between $\ln F_i$ and the reciprocal of (L_i-L_0) where L_0 is 39.0 mm in male and L_0 = 46.0 mm in female. Then all of the constants; α, β and L_0; were used as an input estimators in Gauss-Newton's nonlinear regression analysis by SPSS for Windows. The iteration will stop if the different between successive parameters estimates is less than 10^{-8}. The relationships between F and the mid-points of the male and female broodstock are shown in Figure 1 and 2 and the equations describes as follows:

$$F_i = 0.64e,^{-\frac{5.41}{(L_i-41.02)}} \quad S_{y.x} = 0.003 \qquad \text{in male, and}$$

$$F_i = 0.76e,^{-\frac{19.84}{(L_i-47.06)}} \quad S_{y.x} = 0.001 \qquad \text{in female, respectively.}$$

From the models, the highest possible F is reached when the broodstock attained its L_∞. In this case, these F are estimated to be 0.547 and 0.435 per month for the male and the female. Thus, the maximum total mortality coefficient (Z) will be 0.6471 per month for the male and 0.5766 per month for the female respectively.

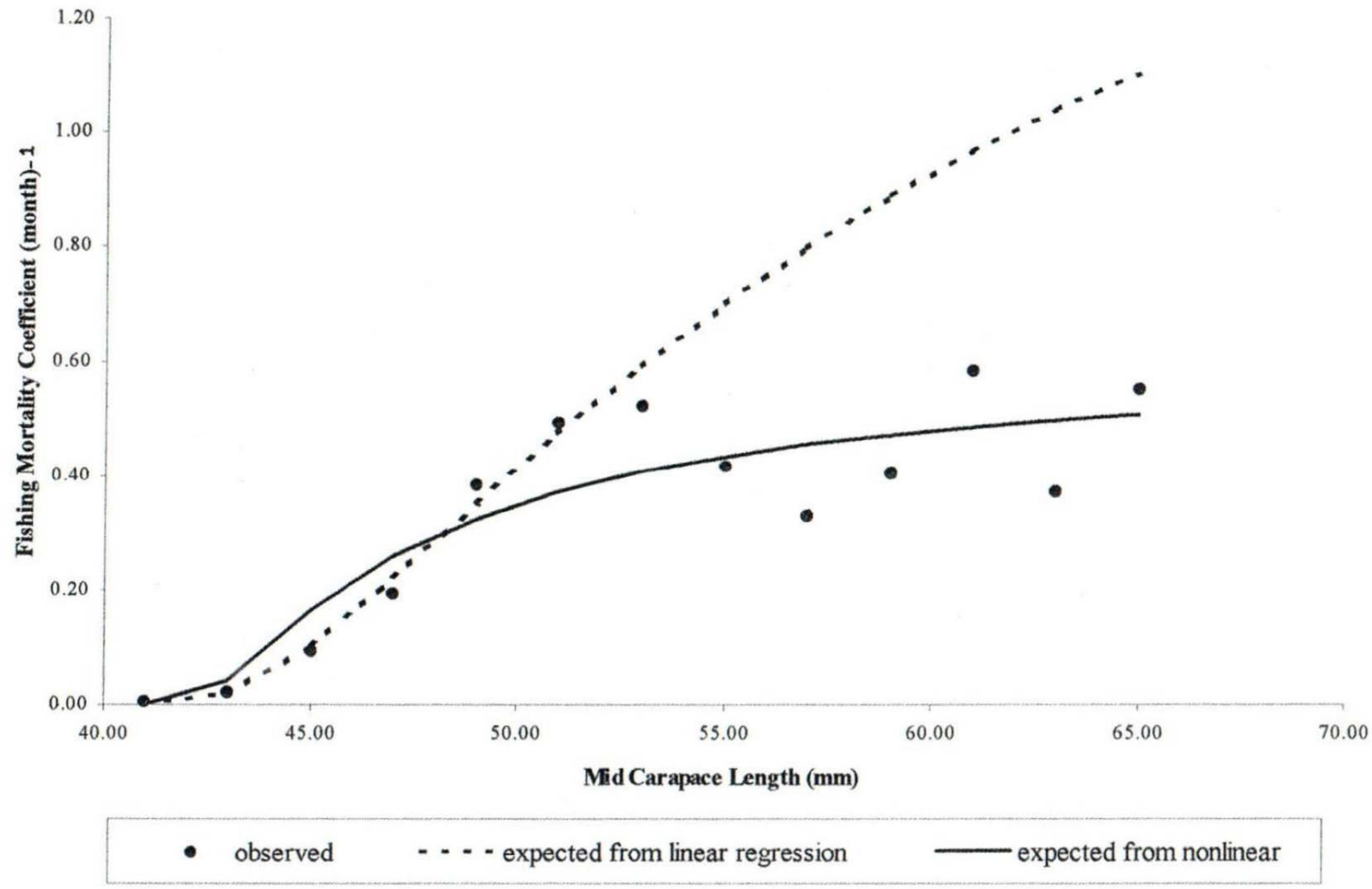

Figure 1 : The Relationship of Male *P. monodon*

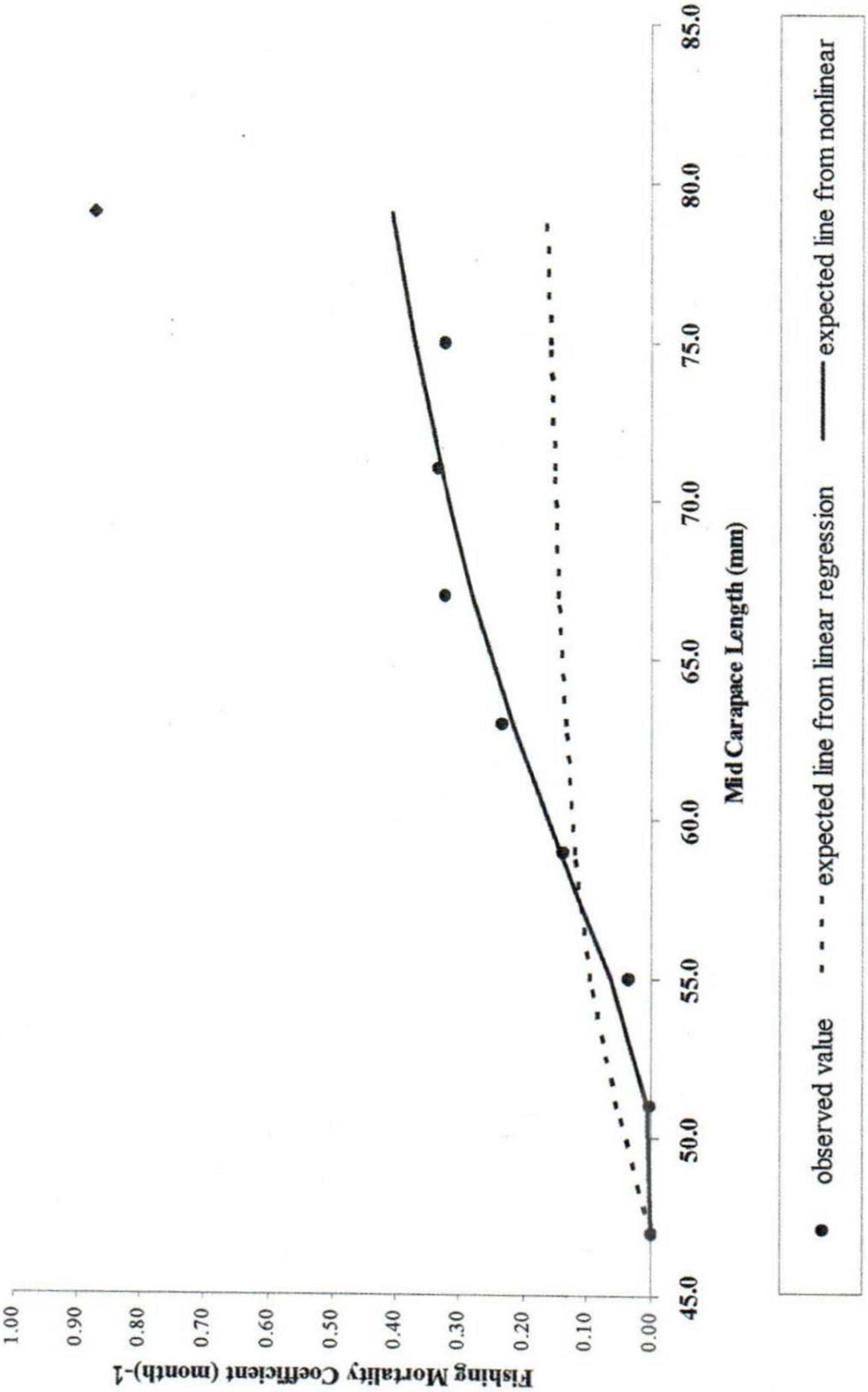

Figure 2 : The Relationship of Female *P. monodon*

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APPENDIX A

The basic equations and conditions of length-based catch curve of Sommani's Virtual Population Analysis (after Sommani, 1987)

Suppose that we divide the fish life span into intervals which **need not** to be equal in length. Let the i^{th} period begins from the fish at age t_i and end up at $t_i+\Delta t_i$ and mortality rate is set up to be constant. Under these conditions, the number of fish at the end of i^{th} period (N_{i+1}) described by "exponential decay model" is

$$N_{i+1} = N_i e^{-Z\Delta t} \qquad (1)$$

And the catch in number during such period (C_i) is described by :

$$C_i = \frac{F_i}{Z_i}(1-e^{-Z_i\Delta t})N_i \qquad (2)$$

where N_i = the number of fish at age t_i,
F_i = the instantaneous fishing mortality coefficient of the fish during i^{th} period,
Z_i = the instantaneous total mortality coefficient = F_i+M
M = the instantaneous natural mortality coefficient which assumed to be constant.

If the growth of the fish is under the condition of VBGF, hence, the VBGF is rearranged in term of time as :

$$t_i = t_o - \frac{1}{K}\ln\left[\frac{L_\infty - L_i}{L_\infty}\right] \qquad (3)$$

During Δt_i period, the fish will grow up from L_i to L_{i+1} sothat it can be shown the VBGF in term of Δt_i as

$$\Delta t_i = -\frac{1}{K}\ln\left[\frac{L_\infty - L_{i+1}}{L_\infty - L_i}\right] \qquad (4)$$

If we let $X_i = (L_\infty - L_{i+1})/(L_\infty - L_i)$, then the equation (4) should be rewritten as :

$$\Delta t = -\frac{1}{K}\ln X_i \qquad (5)$$

By substituting (5) in (1) and (2), we have

$$N_{i+1} = N_i X_i^{\frac{Z_i}{K}} \qquad (6)$$

And

$$C_i = -\frac{F_i}{Z_i}\left[1-X_i^{\frac{Z_i}{K}}\right]N_i \qquad (7)$$

respectively.

The expression $X_i^{Zi/K}$ is the survival rate of the fish during the i^{th} period (s_i) or $s_i = X_i^{(Fi+M)/K}$. Equation (7) can be summarized as :

$$C_i = E_i N_i \qquad \text{.....................................(8)}$$

where

$$E_i = \frac{F_i}{Z_i}\left[1-X_i^{\frac{z_i}{K}}\right] \qquad \text{.....................................(9)}$$

or exploitation rate of the fish during the i^{th} period

Considered in the next period, i+1, the catch in number of the fish during such period in term of the previous period is

$$C_{i+1} = E_{i+1} N_i X_i^{\frac{z_i}{K}} \qquad \text{.....................................(10)}$$

Let P_i is the catch ratio between the period i+1 and i (C_{i+1}/C_i), by equation (8) and (9) and (10), P_i can be described as follows:

$$P_i = \frac{E_{i+1} X_i^{\frac{z_i}{K}}}{E_i} \qquad \text{.....................................(11)}$$

and

$$E_{i+1} = P_i E_i X_i^{\frac{-z_i}{K}} \qquad \text{.....................................(12)}$$

If F_i is known, the right hand side can be calculated and F_{i+1} can be estimated by iterative method since the left hand side may be expressed in terms of F_{i+1}, M and X_{i+1} as :

$$E(E_{i+1}) = \frac{F_{i+1}}{F_{i+1}+M}\left[1-X_{i+1}^{\frac{(F_{i+1}+M)}{K}}\right] \qquad \text{.....................................(13)}$$

In the same condition, we can express the expected value of E_i as

$$E(E_i) = \frac{F_i}{F_i+M}\left[X_i^{\frac{-(F_i+M)}{K}} -1\right] \qquad \text{.....................................(14)}$$

By ignoring the subscript i and let j as the round of iteration, the method of iteration may be described as follow:

$$\Delta F_j = \frac{E_j - E(E_j)}{E'(E_j)} \qquad \text{..(15)}$$

Where $E'(E_j)$ is the first derivative of $E(E_j)$(equation 14) evaluated at $F=F_j$ as described by :

$$E'(E_j) = \frac{F}{F+M}\left[X^{\frac{-(F+M)}{K}} -1\right]\left(\frac{1}{F} - \frac{1}{F+M} - \frac{\ln X}{K\left[1-X^{\frac{(F+M)}{K}}\right]}\right) \qquad \text{.....................................(16)}$$

As the iteration is carried on, the value of $\Delta F_{(j)}$ will decreased continuously. When $\Delta F_{(j)}$ is approximately equal to zero or less than 10^{-8} as in this study, the estimate of F_i is obtained.

Practically, we usually constructed the table and easily estimated F at each length and N_i by Microsoft EXCEL under the concept of VPA as the following table:

Length[(1)]	$C_i^{(2)}$	$X_i^{(3)}$	$\Delta t_i^{(4)}$	$P_i^{(5)}$	E_{i+1}/P_i	$F_i^{(6)}$	Z_i	$S_i^{(7)}$	$E_i^{(8)}$	$N_i^{(9)}$

Remarks :

(1) Use lower limit length

(2) Catch in number either survey data or total landing ('exactly' total landing or 'raised' from sampling)

(3) $X_i = (L_\infty - L_{i+1})/(L_\infty - L_i)$. The plus group will not calculate

(4) $\Delta t_i = 1/K \ln X_i$

(5) $P_i = C_{i+1}/C_i$

(6) The number in parentheses is the input value which estimated from length-frequency data called "terminal F"

(7) $Si = e^{-Zi\Delta ti}$

(8) $E_i = F_i/Z_i(1-s_i)$ and the number in parentheses is $E = F/Z$

(9) $Ni = C_i/E_i$

<u>Step in calculation</u> :

1. Input the length and catch in number (Noted that we fixed M),
2. Calculate X_i, Δt_i and P_i,
3. Input terminal F, Z and E,
4. Calculate N_i of 'plus group',
5. Calculate E_{i+1}/P_i of the first backward length class using terminal F,
6. Iterate ΔF_j from equation (15) by Microsoft EXCEL. The iteration will stop when ΔF_j less than 10^{-8}. Then the estimated F will obtain and input back to the table,
7. Compute F_i, Z_i, S_i, E_i and N_i respectively,

8. Repeat step (6) and (7) until reach the smallest length class.

From this method, we estimate the number of the fish in each length class under the condition of VPA. Besides, the F_i in each length class will use to estimate the Sommani's catch curve which describe in the next Appendix.

APPENDIX B

The basic concepts and model derivation of Sommani's Catch Curve (after Sommani, 1988)

According to the fishing mortality coefficient of the fish will firstly increase as the length increase and then become asymptotically constant at the ultimate length. Assuming further that the rate of change of the F declines curvilinearly of the of the following form

$$dF/dL = \frac{\beta F}{(L_t - \gamma)^c} \quad \text{.....................................(1)}$$

Where dF/dL = the rate of change of F by length,

β,c = constant and

γ = the length at which the F equal to zero

At the first approximation, it will be assumed that 'c' is equal to 2. Then the equation (1) should be :

$$dF/dL = \frac{\beta F}{(L_t - \gamma)^2} \quad \text{.....................................(2)}$$

It is known that L_t will not greater than L_∞ according to the concept of growth, therefore, F will become constant at the L_∞. By integrating equation (2), the following function will be :

$$F = \alpha e^{\frac{-\beta}{(L_t - \gamma)}} \quad \text{.....................................(3)}$$

Where α = the actual upper limit of the F when the length of the fish become infinite

The equation (3) will define as "Sommani's Catch Curve" that quite similar to Johnson-Schumacher Function as expressed by Grosenbaugh (1965) except the sign in denominator of the exponent. The forms of the curve of equation (3) is the asymmetric sigmoid curve.

APPENDIX C

Method of Sommani's catch curve fitting

From Sommani's catch curve, let the subscript i is the i^{th} pair of observation sothat the equation becomes :

$$F_i = \alpha e^{\frac{-\beta}{(L_i - \gamma)}} \qquad \text{.....................................(1)}$$

By using the natural logarithmic transformation, equation (1) will be :

$$\ln F_i = \ln\alpha - \frac{\beta}{(L_i - \gamma)} \qquad \text{....................................(2)}$$

If γ is known, equation (2) is the straight line when lnF is plotted against the reciprocal of $(L_i - \gamma)$. In fact, this parameter is unknown and hence, the parameters, a, b and γ, must be estimated. The most simplest way is to vary the value of γ until the trend of scatter plot will be a straight line. Hereafter, the two left parameters can be estimated by least square analysis. If the input value of γ, say L_0, gives the minimum sum square error, or maximum R^2, this L_0 can be the good estimator of γ as well as the Y-intercept and the negative value of the slope will be the good estimator of a and b respectively. The equation (2) can be written in term of the estimators as follow :

$$F = ae^{\frac{-b}{(L_i - L_0)}} \qquad \text{......................................(3)}$$

Practically, the best input value of L_0 should be defined as its definition is the *'maximum lower limit of length class* ***before*** *the fish was caught in the Length Frequency Data'*. At this length class, it can be assumed that the F is zero. By using the L_0, it can be easily estimated the a and b components by the least square analysis.

All of the parameters, a, b and L_0, will be the 'input estimators' in the nonlinear regression analysis. The most popular method is Gauss-Newton (Ratkowsky, 1983). Nowadays, there are many statistical software packages that can analyze the nonlinear regression, SPSS for instance. The value of the three constants can readily read from the output as well as the R^2 and the standard error.