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Growth and Mortality of the Red-Spot Prawn (*Metapenaeopsis Barbata*) in the Northeastern Coast off Taiwan

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ABSTRACT

Seasonal growth parameters, mortalities and exploitation rate of red-spot prawn (*Metapenaeopsis barbata*) in the northeastern coast off Taiwan were examined using 12 monthly length-frequency data (February 1995 to February 1996) and analyzed with the ELEFAN methods. Parameters of the von Bertalanffy growth equation with seasonal fluctuations obtained are (1) K (growth coefficient) = 1.5 year^{-1}, L_∞ (asymptotic length) = 27.4 mm carapace length (CL), C (amplitude of seasonal growth oscillation) = 0.95, WP (winter point) = 0.25 of year, and Rn = 0.575 for females; and (2) K = 1.14 year^{-1}, L_∞ = 23 mm CL, C = 0.95, WP = 0.59, and Rn = 0.556 for males. The instantaneous rate of total mortality obtained through seasonalized length-converted catch curve for females and males are 4.80 and 4.10 year^{-1}, respectively. The instantaneous rate of natural mortality is 2.69 year^{-1} in females and 2.32 year^{-1} in males. The instantaneous rate of fishing mortality is 2.11 year^{-1} in females and 1.78 year^{-1} in males. The exploitation rate, E = 0.44 in females and 0.43 in males, implies that the stock is slight under-exploited.

***Key words**: Metapenaeopsis barbata, growth parameter, mortality, ELEFAN, Taiwan.*

INTRODUCTION

Estimates of population parameters such as growth and mortality are the first and fundamental step for dynamic pool model being one of the major tools for assessment and management of shrimp resource (Oh *et al.*, 1999). Length-frequency analysis may be currently the only method available for reliable estimation of growth parameters of shrimp, since hard body-parts are lost during molting, and tagging is not practicable (Baelde, 1994).

Although the growth of crustaceans is discontinuous during the molting period, the von Bertalanffy growth equation (VBGE) is still believed to be a reasonable approximation for Penaeidae (Parrack, 1979). However, because shrimp growth is strongly affected by temperature, suggestion has been made to incorporate seasonal fluctuation into the growth curve to produce a better description of shrimp growth (Pauly *et al.*, 1984). The VBGE incorporating seasonal variations presented by Pauly and Gaschutz (1979) is the most widely used model for decapod stocks (Oh *et al.* 1999).

When organisms cannot be aged individually, length-converted catch curve was frequently used to estimate the instantaneous rate of total mortality. Pauly *et al.* (1995) have shown that total mortality from non-seasonalized length-converted catch curve could be overestimated, but the instantaneous rate of total mortality produced from seasonalized length-converted catch curve will be equal or similar to age-structure catch curve.

Red-spot prawn is one of the most

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abundant and economically valuable species among the catch of shrimps off Taiwan (Wu, 1985). Studied on the distribution, reproduction, growth and seasonal variation of abundance for the red-spot prawn population have been conducted (Wu, 1984; Wu, 1985; Lee, 1986; Tzeng *et al.*, 1998). However, estimates of mortalities and exploitation rates for determining the status of the fishery are still absent. Thus, the objectives of this paper are to estimate the growth parameters, mortality and exploitation rate of red-spot prawn population in the northeastern coast off Taiwan based on length-frequency data using the ELEFAN methods.

MATERIALS AND METHODS

A total of 12 length-frequency data was collected monthly from a specific otter trawler operating in the northeastern coast off Taiwan (Fig. 1) between February 1995 and February 1996. For each specimen, sex was determined, and carapace length (CL) measured to the nearest 0.1 mm and total length (TL) to the nearest 1 mm. The body weight (WT) was also measured to the nearest 0.1 g to elucidate the relationship between WT and CL. The total sample size is 5,461 for females and 4,383 for males. The CL is defined as the length from the post-orbital notch of the carapace to the mid-posterior dorsal margin. The TL is defined as the length from the tip of rostrum to the tip of telson. The females and males carapace length data measured were grouped by interval of 1 mm, and then separately analyzed by the ELEFAN method incorporated in the FiSAT software (Gayanilo *et al.*, 1995).

The relationship between CL and WT is described by the equation $WT = a\ CL^b$, where b is the growth exponent and a is a constant. The regression of the log-transformed WT against log-transformed CL was conducted and then the back transformed power function of WT versus CL for females and males.

A seasonally oscillating version of the VBGE developed by Pauly and Gaschutz (1979) and later modified by Somers (1988) was used to describe the growth of red-spot prawn. It takes the form

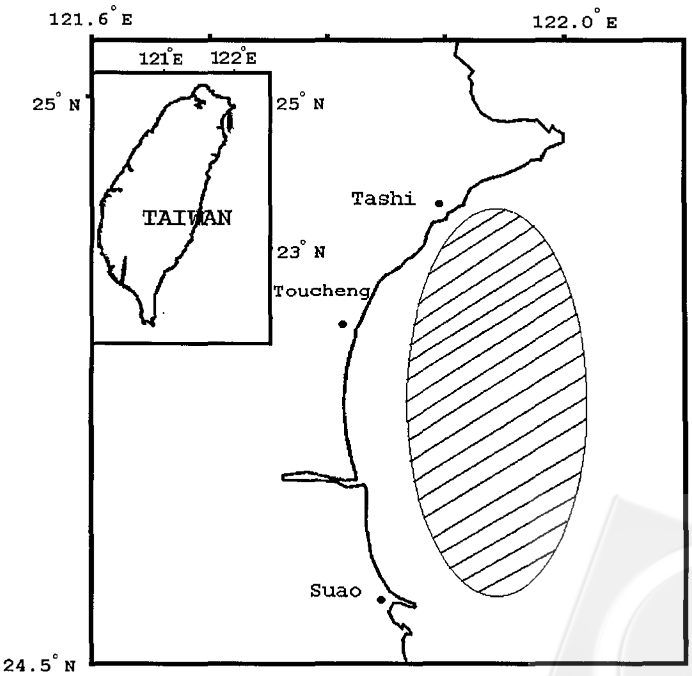

Fig. 1. Shadowed area shows the sampling area from the northeastern coast off Taiwan.

$$L_t = L_\infty(1-\exp(-K(t-t_0)$$
$$-(CK/2\pi)\sin 2\pi(t-t_s)$$
$$+(CK/2\pi)\sin 2\pi(t_0-t_s))$$

where L_∞ is the asymptotic length, K the growth coefficient, L_t the length at age t, C the amplitude of growth oscillations, t_0 the age of the prawn at zero length, and is the starting point of a sinusoidal growth oscillation. In our computation, WP (winter point) is substituted for t_s so that WP = t_s + 0.5. WP is the time when growth is slowest. Parameter t_0 is the hypothetical age at the length zero. The ELEFAN method uses a goodness-of-fit index (R_n) to judge the quality of a growth curve; the best growth curve has the highest R_n value.

Both growth performance indexes Φ and Φ' (Pauly and Munro, 1984) were computed to evaluate their reliability in estimates of growth parameters. The growth performance is separately reflected by

$$\Phi = \log K + 2/3 \log W_\infty \text{, and}$$
$$\Phi' = \log K + 2 \log L_\infty \text{,}$$

where L_∞ is the asymptotic carapace length expressed in mm, and W_∞ is the asymptotic weight expressed in g.

The length-converted catch curve with seasonality (Pauly, 1990) was used to estimate the instantaneous rate of total mortality Z. The right descending arm of this curve was fitted with a regression line. The regression equation has the form $\ln(N_i) = a + bt_i'$, where is the number of individuals caught in a given length class i in all samples, t_i' is the relative age of the length class i, and b with the sign changed gives the value of Z. The instantaneous rate of the natural mortality M was estimated through Pauly's (1980) empirical equation. The Pauly's empirical equation is as follow:

$$\log M = -0.0066 - 0.279 \log TL_\infty,$$
$$+ 0.6543 \log K + 0.4634 \log T$$

where T is the annual mean water temperature of the habitant for red-spot prawn expressed in ^{o}C, and TL_∞ is the asymptotic total length expressed in cm. The instantaneous rate of fishing mortality F was computed through F = Z - M, and the exploitation rate E was computed from E = F/Z.

RESULTS

The carapace lengths of females vary between 10.11 and 26.34 mm, while their weights range between 0.8 and 13.1 g. The carapace lengths of males range between 9.6 and 22.6 mm, while their weights vary between 0.6 and 8.7 g. The relationships between CL and WT for both sexes give the following relationship (Fig. 2):

Female: $WT = 1.1550*10^{-3}\,CL^{2.8638}$
Male: $WT = 1.3438*10^{-3}\,CL^{2.8406}$

The CL-TL relation is described by the equation TL = a + b CL. The total lengths of females vary between 47 and 122 mm, but those of males range between 48 and 119 mm. The carapace lengths of females vary between 10.23 and 26.22 mm, but those of males range between 9.70 and 22.10 mm. The results for both females and males are shown as (Fig. 3):

Female: TL = 7.5678 + 4.4194 CL
Male: TL = 5.0746 + 4.7635 CL

The values of R_n were estimated as 0.575 and 0.556 for females and males, respectively. The restructured length-frequency data and the seasonal growth curves fitted by ELEFAN I for both females and males are shown in Fig. 4. Estimates of seasonal growth parameters for females and males are as follow:

Female: L_∞ = 27.4 (mm), K = 1.5 (year^{-1}), C = 0.95, WP = 0.25
Male: L_∞ = 23 (mm), K = 1.14 (year^{-1}), C = 0.95, WP = 0.59

The value of t_0 is not determined because the ELEFAN I procedure is incapable of extracting to from length-frequency data. Parameter t_0 is only a location parameter and

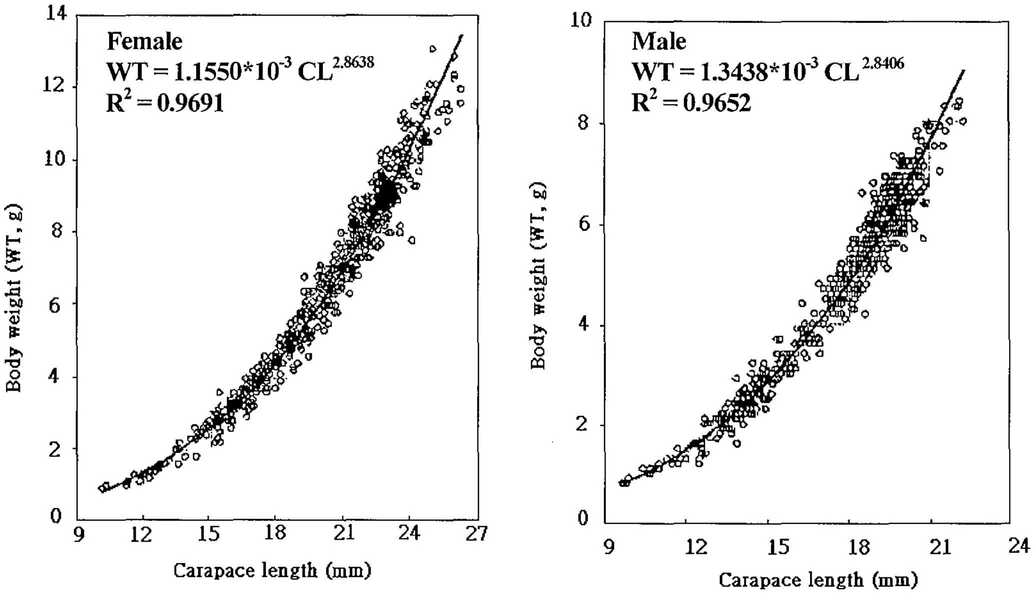

Fig. 2. Relationship between body weight (WT) and carapace length (CL) for females and males.

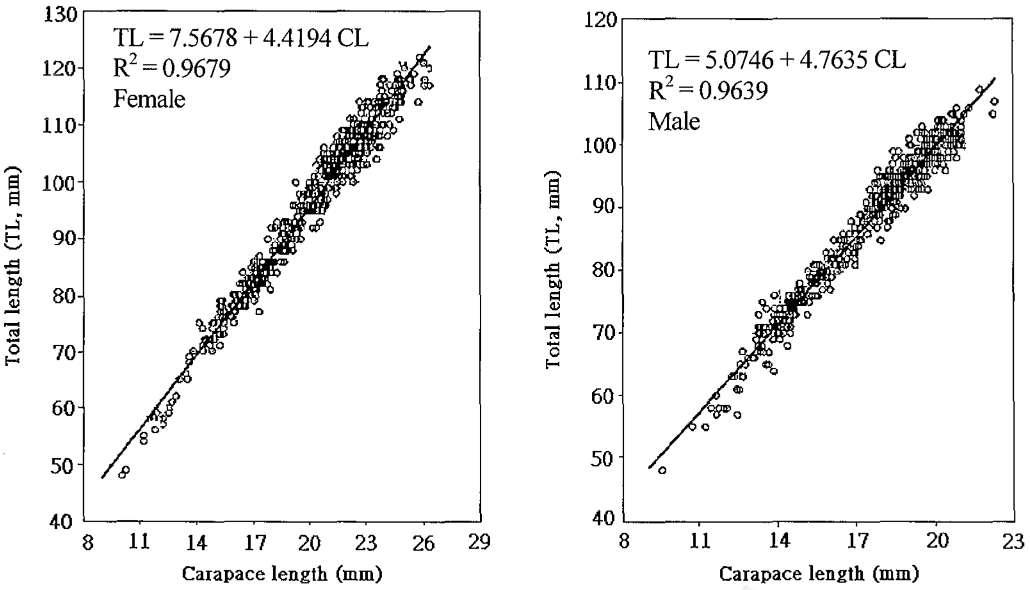

Fig. 3. Relationship between carapace length (CL) and total length (TL) for females and males.

its absence here does not compromise the accuracy of other computed parameters.

The asymptotic weight W_∞ calculated through the relationship between WT and CL obtained here is 15.14 (g) for females and 9.92 for males. The values of Φ were estimated as 0.96 and 0.72 for females and males, and Φ' were estimated as 3.05 and 2.78 for females and males, respectively.

The length-converted catch curve with

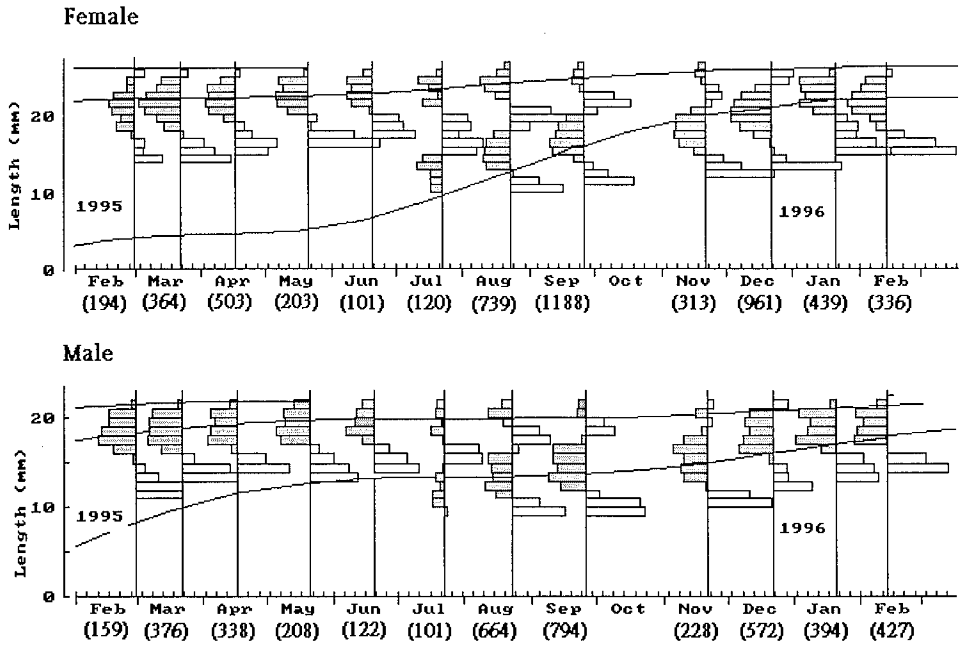

Fig. 4. Restructured length-frequency data and growth curve of red-spot prawn from the northeastern coast of Taiwan for females (above) and males (below). Sample sizes are in parentheses below months.

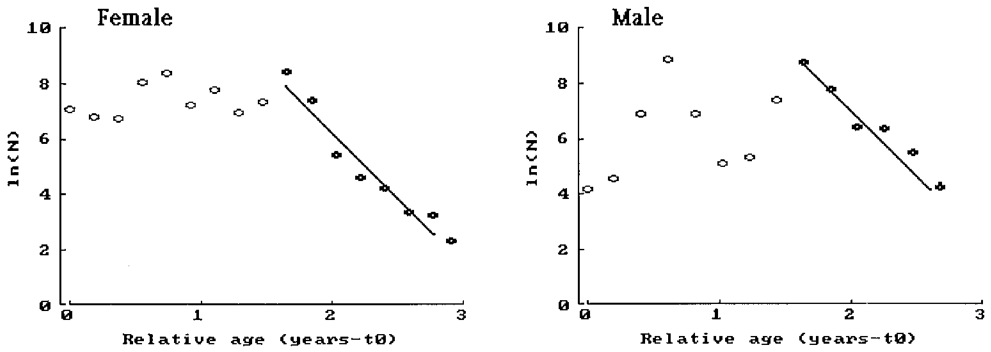

Fig. 5. Length-converted curve with seasonality of red-spot prawn from the northeastern coast of Taiwan for females and males. The total mortality is 4.80 year^{-1} in females and 4.10 year^{-1} in males.

seasonality gives the Z value of 4.80 (year^{-1}) in females but 4.10 (year^{-1}) in males (Fig. 5). The average habitant temperature of 23°C was used in the estimation of the instantaneous rate of natural mortality. The asymptotic total length (TL_{∞}) calculated through the relationship between TL and CL is 12.87 (cm) in females but 11.46 (cm) in males. Therefore, the value of M estimated from Pauly's equation is 2.69 (year^{-1}) in females and 2.32 (year^{-1}) in males. Therefore, the value of F is 2.11 (year^{-1}) in females and 1.78 (year^{-1}) in males. The exploited rate E is 0.44 in females and 0.43 in males.

DISCUSSION

In order to obtain more reliable estimates of population parameters, the suitability of the length-frequency data used is also an important consideration. Some criteria have been developed to determine this suitability. The length-frequency data should exhibit peaks with apparent shift in modal length over time (Wolf, 1989). The number of monthly samples and the sample size must be adequate. Hoenig *et al.* (1987) provides a scale of 0-5 on which the adequacy of samples could be judged. A total sample size of 1500 or more, collected over a period of six months is excellent. Our length-frequency data meet all these criteria. It displays clear modes that can be followed through time (Fig 4), and has a total sample size over 1500 individuals (5461 for females and 4383 for males) taken in a period of 12 consecutive months.

Growth seasonality is a well-known phenomenon for prawns (Pauly *et al.*, 1984). Garcia (1985) has indicated that the seasonal growth equation proposed by Pauly and Gaschutz (1979) can properly describe the seasonal growth of prawn. This equation contains an empirical constant C indicating the amplitude of growth oscillation. The tendency of the amplitude of seasonal growth oscillation to reach high values (0.95) indicates that red-spot prawn in the north-eastern coast of Taiwan experiences quite strong seasonality in growth. Pauly (1987) has suggested that growth oscillation is mainly due to temperature changes. The largest deviation of habitant temperature around the sampling area is about 9°C; this explained the high value of C.

Lee (1986) used the Akamine's method (Akamine, 1982) to estimate the growth parameters of red-spot prawn from the southern Taiwan Strait, but had not considered the effect of seasonal variation. Further, the number of length frequency used in Akamine's method is only one at each time, as Fournier *et al.* (1990) pointed out that more reliable estimates could be obtained if analysis is applied to several length-frequency data simultaneously. Therefore, the K values (0.11 $year^{-1}$ in females and 0.247 $year^{-1}$ in males) estimated by Lee (1986) may be unreliable. The K values have been calculated to be 1.5 in females and 1.14 in males in this study, and these values correspond to the best estimates of L_∞ (27.4 mm in females and 23 mm in males) for red-spot prawn in the northeastern coast of Taiwan, fall within the range of values estimated for various stocks of penaeid shrimp species by Pauly *et al.* (1984), i.e. between 0.39 and 1.6 per year. Therefore, we believed that the estimates of growth parameters are reliable.

The growth performance index is preferred for growth comparison rather than comparison of L_∞ and K individually, because these two parameters are correlated (Pauly and Munro, 1984). This index is more robust than either L_∞ or K individually as it takes into account the negative correlation between the two parameters, and fulfils the requirement for a simple single parameter for comparison of growth (Oh *et al.*, 1999). This growth performance index provides an indication of the reliability of estimates since it is suggested that these values of Φ' are similar for the same species and genera (Bellido *et al.*, 2000). Our estimates of growth parameters for red-spot prawn cannot be confirmed because no other growth study was performed in past. The Φ' value is 3.05 for females and 2.78 for males, indicating females of this species had higher growth rates than males. The value of Φ for each sex falls into the range of Φ values possible in Penaeidae (Pauly *et al.*, 1984), so we further believe that our estimates on growth parameters of red-spot prawn are reasonable.

Length-covered catch curve is feasible, assuming that the instantaneous rate of total mortality is constant from some length upwards. This assumption could be violated by migration out of fishing ground or avoidance of trawl by the larger shrimp. Prawns often migrate from inshore to offshore as they grow to certain size or life stage (Garcia and Le Reste, 1981). This suggests that the instantaneous rate of total mortality may have been overestimated. However, this error is not serious because the water depth outside of the sampling area increases sharply to over 200 m, and it is not easy to exist for this species. Another erroneous origin for estimation of total mortality for penaeid is due to growth oscillation. Pauly *et al.* (1995) has shown that when compared with age-structured catch curves, Z from length-converted catch curve without seasonality could be overestimated. Seasonalized length-converted catch curve produced Z-values equal or similar to age-structure catch curve (Etim and Sankare, 1998). The instantaneous rate of total mortality values estimated in this study are 4.80 ($year^{-1}$) in females and 4.10 ($year^{-1}$) in males fall within the range of values (2.46-7.07) estimated by Pauly *et al.* (1984) for several stocks and species of penaeid prawn, and also within the values (3.33-7.08) obtained for penaeid prawn species in Kuwait waters (Mathews *et al.*, 1987).

The estimation of natural mortality affects greatly the analysis of yield (Baelde, 1994). Pauly's (1980) empirical equation was used to estimate the natural mortality in this study, and gave the estimates of M are 2.69 and 2.32 for females and males, respectively. Although Pauly's formula is initially constructed for fish species, it has also given reasonable estimates for shrimps (Pauly *et al.*, 1984). The value for M of 2.68 ($year^{-1}$) in females and 2.23 ($year^{-1}$) in males are within the range 0.77-3.12 estimated for penaeid shrimp by Pauly *et al.* (1984). They are also within the range given by Garcia and Le Reste (1981). They stated that for the penaeid shrimp with a maximum life span of two years, the natural mortality should be within the range of 2 to 3. Moreover, the estimate of the M/K ratio locating between 1.0 and 2.5 was considered as more realistic (Mohamed, 1996). The calculated M/K values fall in this range (1.79 for females and 2.03 for males). We, therefore, considered that the estimates of M are reasonable in this study.

A stock is considered as optimal exploitation when fishing mortality equals natural mortality, or E = 0.5 (Gulland, 1971). Both exploitation rates estimated in this study (0.44 in females and 0.45 in males) show that this fishery is under-exploited. The Gulland's assumption of optimum E = 0.5 could only be applied when recruitment is independent of stock density (Francis, 1974). However, most stock-recruitment relationship in penaeid shrimps was considered that the recruitment is independent of the parental stock (Garcia and Le Reste, 1981), so the use of Gulland's assumption may be largely justified for shrimps. Therefore, although our analyses indicated that this red-spot prawn resource is under-exploited, reliable information on stock recruitment relationship and relative data are still required before it can be established that the fishery is at the optimum level of exploitation.

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台灣東北部沿岸產紅斑赤蝦(*Metapenaeopsis Barbata*)之成長參數及死亡率之估計

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(2005 年 5 月 31 日收件；2005 年 7 月 11 日修正；2005 年 8 月 20 日接受)

本研究係利用 1995 年 2 月至 1996 年 2 月間，連續 12 個月之月別體長資料，以 ELEFAN 法來估計台灣東北部沿岸產紅斑赤蝦(*Metapenaeopsis barbata*)之季節性成長參數、死亡率及開發率。應用雌雄蝦之頭胸甲長頻度分佈擬合季節性本托蘭裴成長方程式(von Bertalanffy growth equation)，其結果分別如下：(1) 雌蝦：成長參數 K = 1.5 ($year^{-1}$), 極限頭胸甲長 L_∞ = 27.4 mm, C = 0.95, WP = 0.25; (2) 雄蝦：K = 1.14 ($year^{-1}$), L_∞ = 23 mm, C = 0.95, WP = 0.59。利用季節化體長轉換漁獲體量曲線估計其全死亡率，雌雄結果分別為 4.80 ($year^{-1}$)和 4.10 ($year^{-1}$)。自然死亡率雌雄估計值分別為 2.69 ($year^{-1}$)和 2.32 ($year^{-1}$)。漁獲死亡率雌雄估計值分別為 2.11 ($year^{-1}$)和 1.78 ($year^{-1}$)。雌雄之開發率估計值分別為 0.44 和 0.43，顯示此紅斑赤蝦系群尚屬於低開發狀態。

關鍵詞：*Metapenaeopsis barbata*，成長參數，死亡率，ELEFAN，台灣。

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