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# Growth, Mortality and Recruitment of *Trachypenaeus curvirostris* in the Western Coast of Taiwan

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## ABSTRACT

Seasonal growth, mortalities and recruitment pattern of *Trachypenaeus curvirostris* in the western coast of Taiwan were examined using 6 monthly length-frequency data (February 1992 to July 1992) and analyzed with the ELEFAN methods. Parameters of the seasonalized von Bertalanffy growth equation obtained are (1) K (growth coefficient) = 1.20 year$^{-1}$, $L_\infty$ (asymptotic length) = 35.60 mm carapace length (CL), C (amplitude of seasonal growth oscillation) = 0.95, WP (winter point) = 0.05 of year for females; and (2) K = 0.96 year$^{-1}$, $L_\infty$ = 32.40 mm CL, C = 0.95, WP = 0.05 for males. Total mortality obtained through length-converted catch curve with seasonality for females and males are 3.62 and 3.11 year$^{-1}$, respectively. The natural mortality obtained from empirical equation of Pauly (1980) is 2.32 year$^{-1}$ for females and 2.04 year$^{-1}$ for males. Fishing mortality is 1.30 year$^{-1}$ for females and 1.07 year$^{-1}$ for males. The annual recruitment pattern obtained by back-projecting these length frequency samples onto an arbitrary one-year time axis showed that recruitment occurs in two pulses of approximate equal strength.

*Key words: Trachypenaeus curvirostris, Growth, Mortality, Recruitment, ELEFAN.*

## INTRODUCTION

Some biological parameters, such as growth parameters, mortalities, are essential to perform dynamic pool model (yield-per-recruit, Y/R), which has been one of major methods for assessment and management of shrimp stocks (Garcia, 1988). Shrimp growth is very difficult to estimate as its exoskeletons are lost during molting and thus the ageing of an individual is impossible based on traditional methods. Length-frequency analysis may be currently the only method available to obtain reliable estimates of growth and mortality parameters of shrimp (Baelde, 1994).

Because of asynchronous molting of individuals within a year class, von Bertalanffy growth equation (VBGE) is generally fitted to the mean length at estimated age of a year class (Fre'chette and Parsons, 1983; Enin *et al.*, 1996; Etim and Sankare, 1998; Oh *et al.*, 1999). Moreover, since the shrimp growth is strongly affected by water temperature (Pauly *et al.*, 1984), Pauly and Gaschutz (1979) modified the basic VBGE model to incorporate seasonal fluctuation to obtain a better description of shrimp growth. This revised VBGE model is the most widely used model on growth study for crustacean stocks (Etim and Sankare, 1998; Oh *et al.*, 1999).

Catch curve is one of major procedures used to estimate the total mortality. This method, however, is generally applied to organisms that have been aged. When organisms cannot be aged individually, we usually replace catch curve with length-converted catch curve to estimate the total mortality. Because the larger organisms need a longer time to grow through a length class than small ones, the organism growth in length is not linear (Pauly *et al.*, 1984). A

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correction for this effect of non-linearity must be conducted, otherwise the estimate of total mortality will be under-estimated (Pauly *et al.*, 1984). Furthermore, if the seasonal fluctuation in shrimp growth is not considered in length-converted catch curve analysis, the total mortality will be overestimated (Pauly *et al.*, 1995).

The western coast of Taiwan is an important fishing ground for shrimp fisheries. The growth and fishery biology of main shrimp species caught in Taiwan have been documented, e.g. *Metapenaeopsis barbata* (Tzeng and Yeh, 1995), *Penaeus japonicus* (Tzeng and Yeh, 1998), *Parapenaeopsis hardwickii* (Tzeng and Yeh, 2000), *Metapenaeopsis ensis* (personal communication), *Sergia lucens* (Huang, 2000). *Trachypenaeus curvirostris* is one of ten very abundant and major commercial species around Taiwan (Yu and Chen, 1986), but the information of its fishery biology is still not available. Thus, the objectives of this paper are to estimate the growth parameters, mortalities, and recruitment pattern of *Trachypenaeus curvirostris* in the western coast of Taiwan based on length-frequency data using ELEFAN methods.

## MATERIALS AND METHODS

The length-frequency data were collected monthly from a specific beam trawler operating in the western coast of Taiwan (Fig. 1) between February 1992 and July 1992. The cod end mesh size of the beam trawler is 18 mm. For each specimen, sex was recorded, and carapace length (CL) was measured to the nearest 0.1 mm. The body weight (WT) was also measured to the nearest 0.01 g. For some individuals, the total length (TL) was also measured to the nearest 1 mm. The total sample size is 1058 for females and 639 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 carapace length data measured were grouped by interval of 1 mm, and then analyzed by sex with 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 model of the VBGE developed by Pauly and Gaschutz (1979) and later modified by Somers (1988) was used to describe the shrimp growth. The seasonalized VBGE is

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

where $L_t$ is the length at time t, $L_\infty$ the asymptotic length and K is the growth coefficient, C is the amplitude of seasonal variation ranging between 0 and 1, $t_s$ is the year fraction when the growth rate is highest. The ELEFAN I program also determines a parameter denominated winter point (WP), which expresses the time fraction when the growth is slowest. The expression is $WP = t_s + 0.5$. Parameter $t_0$ is the hypothetical age at the length zero.

In order to estimate the growth parameters of *Trachypenaeus curvirostris*, we firstly used the Powell-Wetherall plot (Wetherall, 1986) as modified by Pauly (1986) to obtain an initial estimate of $L_\infty$. In this method the Beverton and Holt (1956) length-based Z-equation is rearranged to a linear regression model of the following form:

$$\bar{L} - L' = a + bL',$$

where $L'$ is the smallest legth of fully recruited shrimp and $L = [L_\infty + L']/[1+(Z/K)]$ is the mean length of all shrimps $\geq L'$ mm. We computed $L_\infty$ and Z/K from above equation thus: $L_\infty = a / b$, and $Z / K = -(1+b)/b$. With this initial estimate of $L_\infty$, the ELEFAN I procedure was used to fit the seasonalized VBGE to our length-frequency data.

Both growth performance indexes $\Phi$

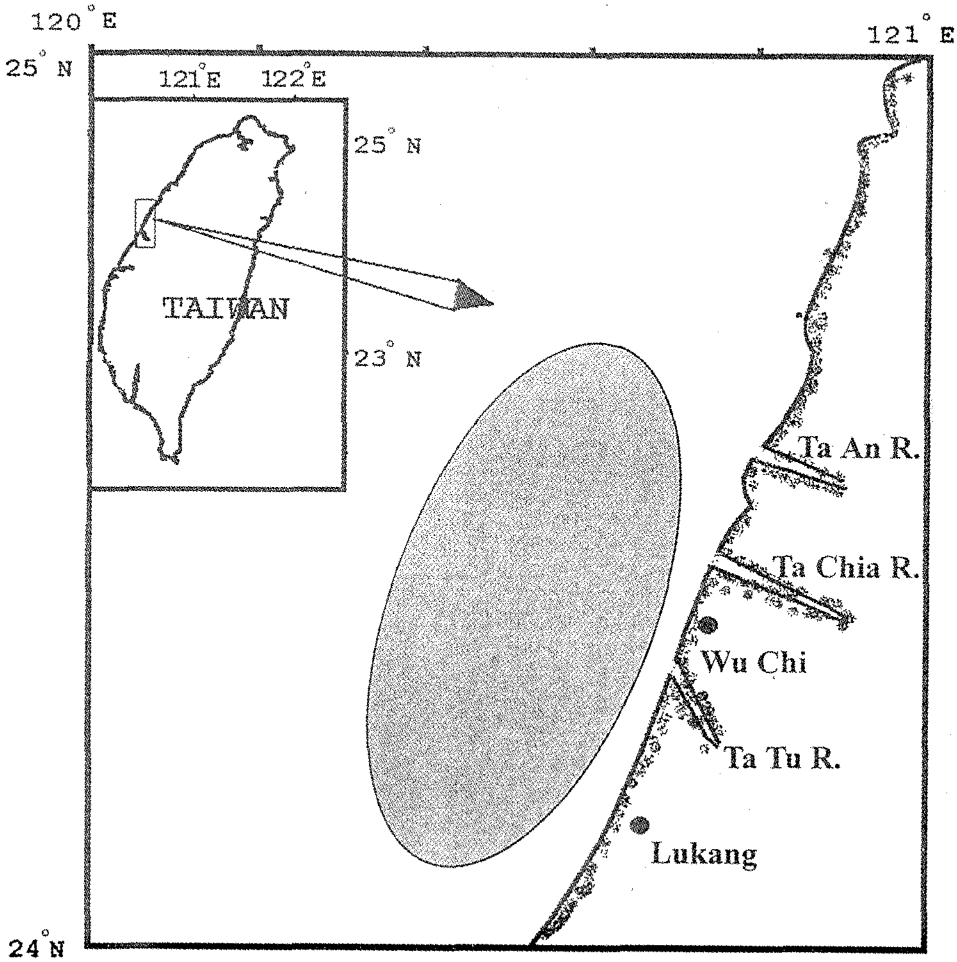


Fig. 1. Shadowed area shows the sampling area in the western coast of Taiwan.

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

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

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

The length-converted catch curve with seasonality (Pauly, 1990) was used to compute the total mortality Z. The right descending arm of this curve was fitted with a regression line. The regression equation has the form ln(N) = a + bt′, where N is the number of shrimp in pseudo-cohorts sliced by the growth curves, t′ is the relative age of shrimp in that pseudo-cohort, and b with the sign changed gives the value of Z.

The natural mortality coefficient M was estimated through method of Pauly (1980). The Pauly's empirical equation is as follow:

$$\log M = -0.006 - 0.27\log TL_\infty + 0.654\log K + 0.463\log T,$$

where T is the mean water temperature of the habitat for *Trachypenaeus curvirostris* expressed in ℃, and $TL_\infty$ is the asymptotic total length expressed in cm. The fishing mortality F was computed through F = Z - M.

## RESULT

The carapace lengths (CL) of females vary between 13.4 and 33.5 mm, while total lengths (TL) range between 60 and 122 mm. The carapace lengths of males range between 10.7 and 22.0 mm, while their total lengths vary between 51 and 89 mm. The relationship between CL and TL described in a linear form, TL = a + b CL, for both sexes were obtained as (Fig. 2):

Female: TL = 15.69 + 3.51 CL
Male: TL = 12.13 + 3.72 CL

A comparison of the slopes of regression lines for females and males by ANCOVA showed that there is a significant difference between females and males (P

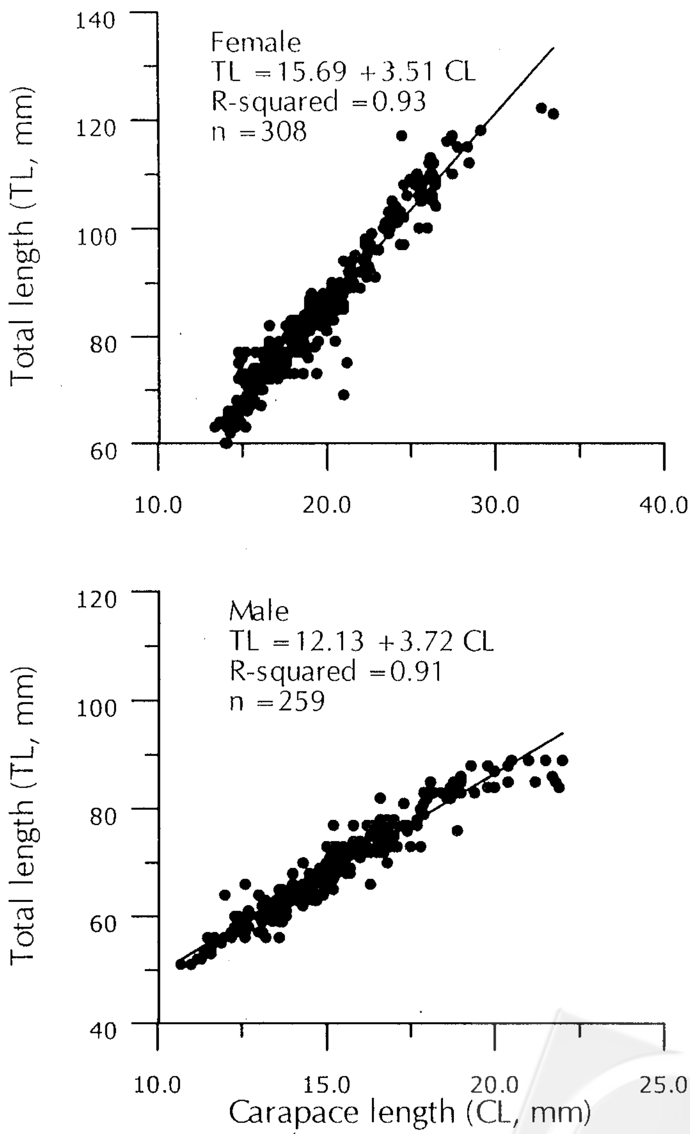


Fig. 2. Relationship between carapace length (CL) and total length (TL) for females (top) and males (down).

<0.05).

The carapace lengths of females vary between 10.8 and 31 mm, while their weights range between 1.01 and 17.94 g. The carapace lengths of males range between 10.6 and 26.8 mm, while their weights vary between 0.97 and 11.03 g. The relationships between CL and WT for both sexes give the following relationship (Fig. 3):

Female: $WT=1.48*10^{-3}\ CL^{2.76}$, $r^2=0.95$
Male: $WT=3.29*10^{-3}\ CL^{2.47}$, $r^2=0.88$

A comparison of the slopes of two regressions by ANCOVA showed that there is a significant difference between females and males (P<0.05).

The Powell-Wetherall procedure give an initial $L_\infty$ value of 34.38 mm and Z/K of 3.17 for females but an initial $L_\infty$ value of 32.11 mm and Z/K of 2.74 for males (Fig. 4).

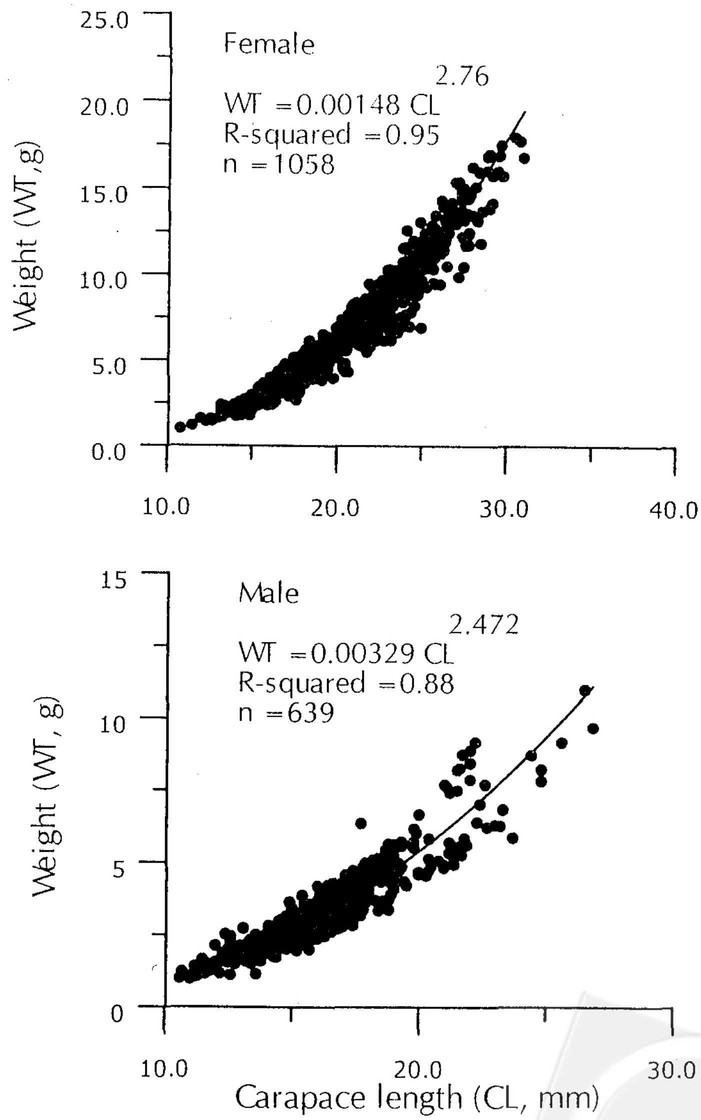


Fig. 3. Relationship between carapace length (CL) and weight (WL) for females (top) and males (down).

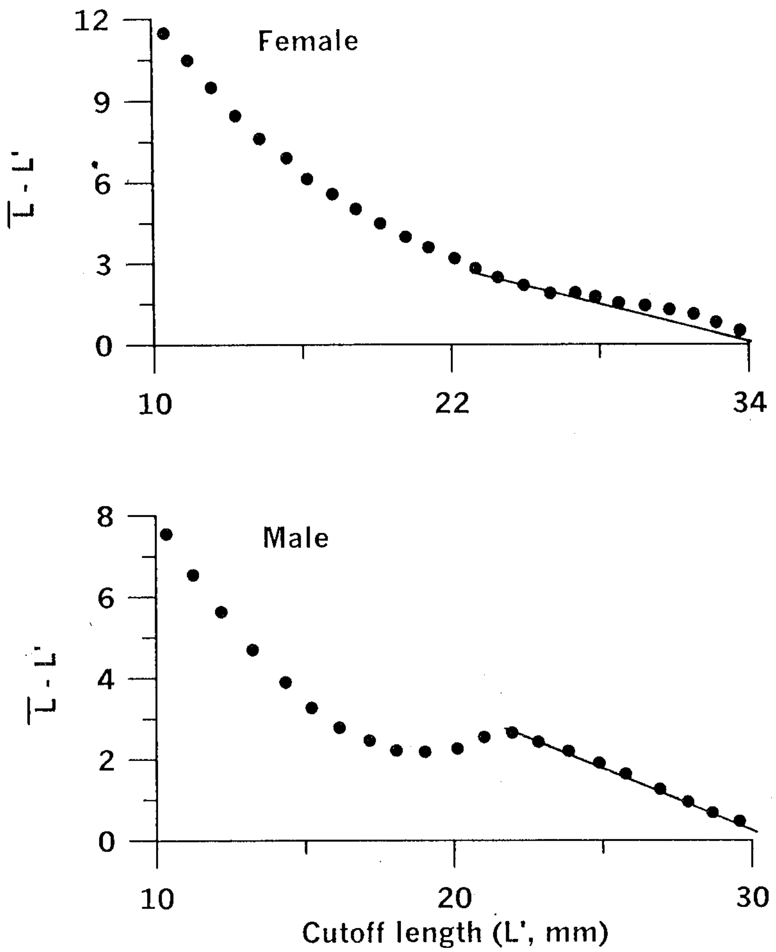


Fig. 4. Rowell-Wetherall plot for females (top) and males (down) *Trachypenaeus curvirostris*. The regression equation is Y = 8.23-0.239Xm r=-0.972, estimated $L_\infty$=34.38 mm and Z/K= 3.177 in females and Y=8.59-0.268X, r=-0.993, estimated $L_\infty$=32.11 mm and Z/K=2.737 in males.

These initial $L_\infty$ values were separately seeded into ELEFAN I to produce the optimized seasonal growth curve. The restructured length-frequency data and the seasonal growth curves fitted by ELEFAN I for both females and males are shown in Fig. 5. Seasonal growth parameters for females and males were estimated as follow:

Female: $L_\infty$ = 35.60 (mm),
K = 1.20 ($year^{-1}$), C = 0.95, WP = 0.05
Male: $L_\infty$ = 32.40 (mm),
K= 0.96 ($year^{-1}$), C = 0.95, WP = 0.05

The value of $t_0$ is not determined because the ELEFAN I procedure is incapable of extracting $t_0$ from length-frequency data. Parameter $t_0$ is only a location parameter and its absence here does not compromise the accuracy of other computed parameters.

The asymptotic weight $W_\infty$ calculated through the relationship between WT and CL obtained here is 28.52 (g) for females and 17.71 (g) for males. The values of $\Phi$ were estimated as 1.04 and 0.81 for females and males, and $\Phi'$ were estimated as 3.18 and 3.00 for females and males, respectively.

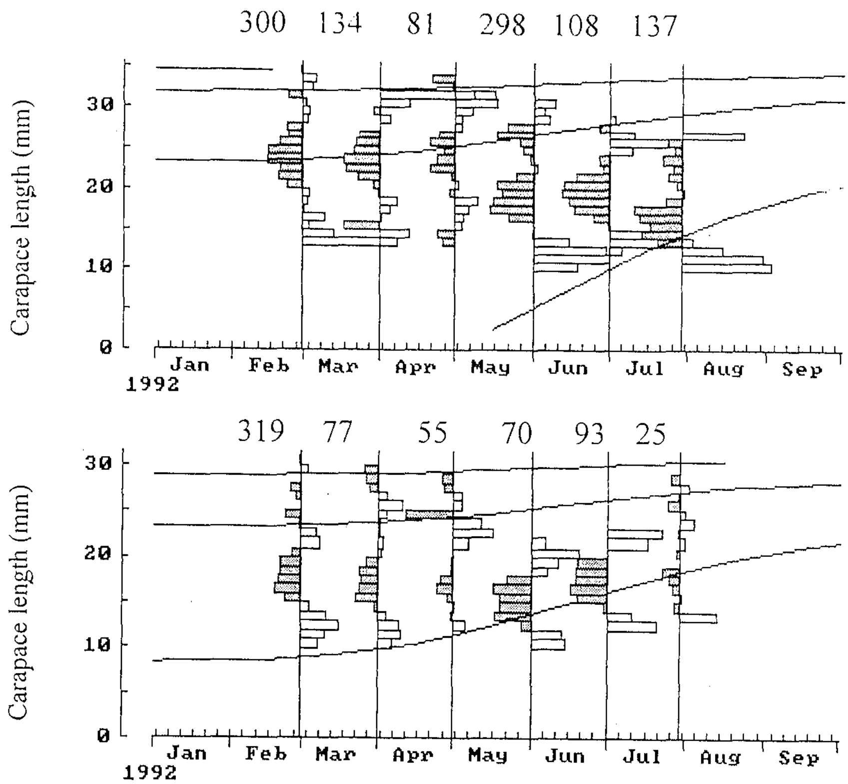


Fig. 5. Restructured length-frequency data and seasonal growth curves for females (top) and males (down). Numbers indicate sample size.

The length-converted catch curve with seasonality gives the Z value of 3.62 ($year^{-1}$) for females and 3.11 ($year^{-1}$) for males (Fig. 6). The monthly ambient temperature of *Trachypenaeus curvirostris* in the western coast of Taiwan ranged from 19 ℃ to 28 ℃ (NCOR, 2000). The average annual ambient temperature of 23 ℃ was taken and used in the estimation of natural mortality. The asymptotic total length ($TL_\infty$) calculated through the relationship between TL and CL obtained here is 14.1 (cm) for females and 13.3 (cm) for males. Therefore, the value of M estimated from Pauly's equation is 2.32 ($year^{-1}$) for females and 2.04 ($year^{-1}$) for males. The fishing mortality F is 1.30 ($year^{-1}$) for females and 1.07 ($year^{-1}$) for males.

The recruitment pattern of *Trachypenaeus curvirostris* was established by projecting the length-frequency data backward onto the time axis down to zero length, using the seasonalized VBGE and the estimated seasonal growth parameters (Pauly *et al.*, 1984). The ELEFAN II program automatically fits the recruitment pattern with one or two normal distributions. Because the value of $t_0$ used in the calculation is zero, the exact time of recruitment cannot be determined. The recruitment of *Trachypenaeus curvirostris* occurs in two pulses of approximate equal strength (Fig. 7).

## DISCUSSION

Several methods can be used to analyze length-frequency data to estimate growth parameters and mortalities. However, more reliable estimates could be obtained if analysis is applied to several length-frequency data sets simultaneously (Fournier *et al.*, 1990). Four procedures often used with the ability to analyze multiple length-frequency data sets

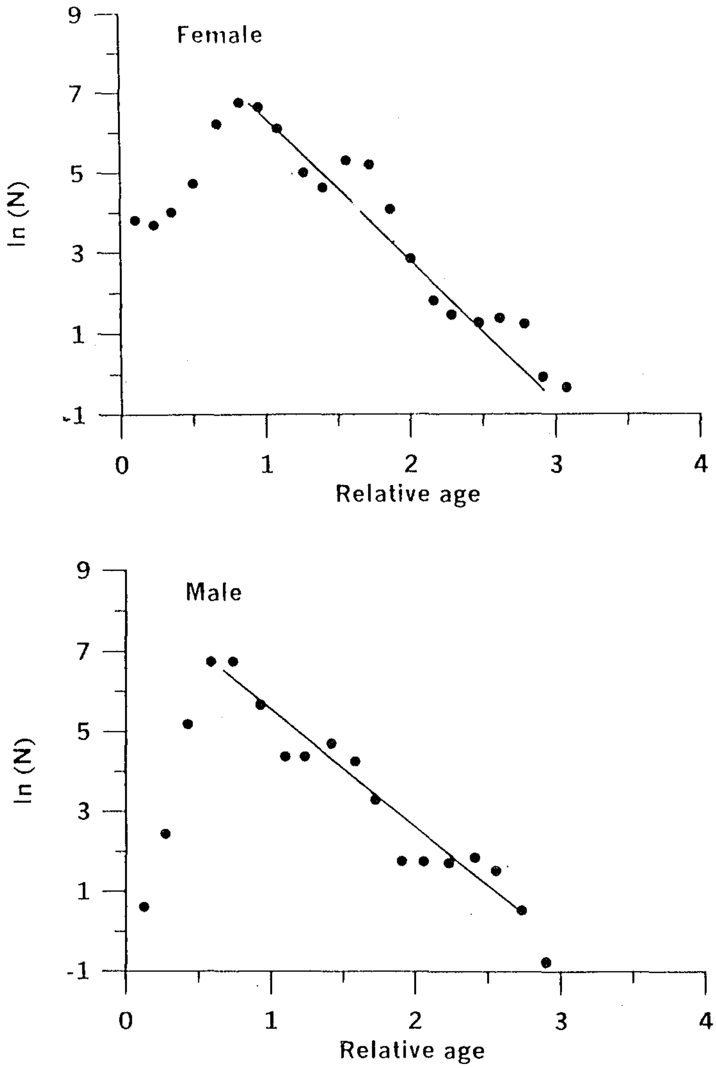


Fig. 6. Length-converted catch curves with seasonality for females (top) and males (down). The slope of right descending arm of the curve with size changed gives an estimate of Z with seasonality. The Z value is 3.62 $year^{-1}$ in females but 3.11 $year^{-1}$ in males.

synchronously are ELEFAN (Pauly *et al.*, 1984), MULTIFAN (Fournier *et al.*, 1990), Shepherd's length composition analysis (SRLCA, Shepherd, 1987), and projection matrix method (PROJMAT, Rosenberg *et al* ., 1986). Furthermore, when the characteristic of seasonal growth for species examined needs to be considered in growth analysis, only ELEFAN or MULTIFAN can be used to obtain seasonal growth parameters. Although the MULTIFAN may provide unbiased and more precise estimates (Terceiro *et al.*, 1992), the ELEFAN, however, requires less user input and assumption (Pauly *et al.*, 1984).

The MULTIFAN program is designed to analyze length-frequency data generated by single annual recruitment. However, this assumption is usually violated for shrimps, because shrimp recruitment generally occurs in two pulses in one year, e.g., *Trachypenaeus fulvus* (Pauly *et al.*, 1984), *Parapenaeopsis hardwickii* (Tzeng and Yeh, 2000), *Penaeus japonicus* (Tzeng and

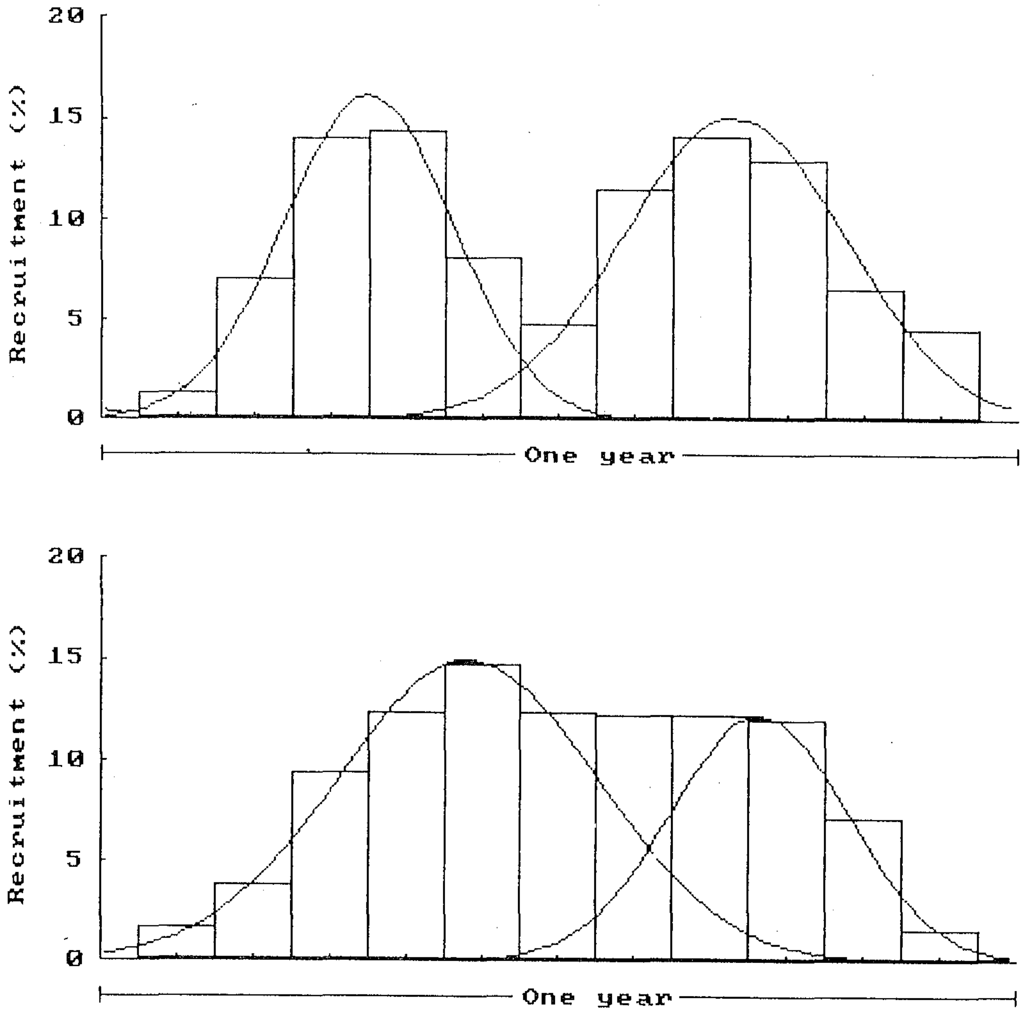


Fig. 7. Recruitment patterns for females (top) and males (down).

Yeh, 1998), *Haloporoiddes sibogae* (Baelde, 1994). Therefore, as suggested by updates on MULTIFAN software, the time period between two length samples was doubled to account for six monthly recruitment pulses and carried out the MULTIFAN analysis, and then the final K estimate was double to obtain annual value (Siddeek and Johnson, 1997). Although the modes of two recruitments may be apparent, the time period between two recruitment pulses may be not six months. Therefore, we could not use the MULTIFAN method to estimate the growth parameters for some shrimp species unless the assumption of six monthly recruitment pulses has strong justification. In ELEFAN, there is no need to make such a priori assumption about recruitment, and it produced comparable estimates to the MULTIFAN method (Siddeek and Johnson, 1997). Therefore, the estimates obtained from the ELEFAN are also reliable even though the annual recruitment pulse is one or two (Pauly *et al.*, 1984).

The suitability of length-frequency data used is an important consideration in the analysis of length data. Some criteria have been suggested to assess this suitability. The number of monthly samples and the total number of specimens must be adequate. Based on three assumptions that (1) the samples cover a wide range of lengths, (2) gear selection is accounted for, and (3) the sizes of monthly samples are more or less equal if the total sample is accumulated over more than one month, Hoenig *et al.* (1987) provides a method for assessing whether the adequacy of length-frequency data for analyzing the growth and mortality. If the number of sample accumulated over a period of 6 months and total sample size is over 500 or 1000, the length-frequency data is regarded as good or very good for such analysis, respectively.

Because (1) the total lengths ranges from 60.7 to 133.1 (mm) for females and from 52 to 94 (mm) for males obtained through the relationship between CL and TL here that contain the whole range of length (Yu and Chen, 1986); (2) the very small mesh size (18 mm) was used, and several authors have reported that there is hardly any mesh size selection for shrimp due to their shape (Garcia and Le Reste, 1981); and (3) a total sample size of 1058 for females and 639 for males taken in a period of 6 consecutive months, we, therefore, believe that the length frequency data sets obtained in this study meet above three assumptions, and are a very good (females) or good (males) length composition data for estimating growth parameters and mortalities. Wolf (1989) suggested that the presence of modal groups should be perceptible in length-frequency data, with apparent shifts in modal length over time. These features were also observed in the length-frequency data used in this study (Fig. 5).

Although some criteria for examining the suitability of the length-frequency data to estimate the population parameters were met, there are only six monthly length-frequency data used in this study that may lose some information of length distribution not obtained here, and thus will decrease the reliability of estimates. Because the life span ($\approx 3 / K$) of this species exceeds one year, the larger individuals will reflect more or less those information lost. This error, therefore, may be not serious. However, a more complete and long-term length-frequency data is still essential to obtain more reliable estimates of population parameters.

The high value of C (0.95 for both sexes) indicates that *Trachypenaeus curvirostris* has quite strong seasonality in growth. Pauly (1987) suggested that growth oscillation is mainly due to temperature changes. The largest deviation of habitant temperature around the sampling area is about 9 ℃; this explained the high values of C (0.95). An estimated winter point (WP, the period of the year with the slowest growth) at 0.05 for both sexes, suggests that growth is poorest in January, corresponding to the coldest month in this waters. Thus, water temperature is likely to affect growth of the shrimp.

The growth performance index is preferred for growth comparison rather than comparison of $L_\infty$ and K individually, because these two parameters are correlated (Pauly and Munro, 1984). This index is more robust than either $L_\infty$ 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 $\Phi'$ are similar for the same species and genera (Bellido *et al.*, 2000). Our estimates of growth parameters for *Trachypenaeus curvirostris* cannot be confirmed because no other growth study was performed in past. The $\Phi'$ value is 3.18 for females and 3.00 for males, indicating females of this species had higher growth rates than males. The value of $\Phi$ for each sex falls into the range of $\Phi$ values possible in Penaeidae (Pauly *et al.*, 1984), so we believe that our estimates on growth parameters of *Trachypenaeus curvirostris* are reasonable.

Length-converted catch curve for estimating Z value is premised on the assumption of steady-state age composition that implies constant recruitment and mortality with age and time. However, these conditions are barely satisfied. Thus Z estimated through this procedure is often prejudiced. Such an error could be very strong in short-lived organisms (Pauly, 1990), e.g., shrimps. Pauly *et al.* (1995) have shown that when compared with age-structured catch curves, Z from non-seasonalized length-converted catch curve could be overestimated. Seasonalized length-converted catch curve produced Z-values equal or similar to age-structure catch curve (Etim and Sankare, 1998). Age-structured catch curve is unbiased because growth in age has no seasonality.

In order to evaluate the effect of the monthly samples in estimation of total mortality, the jackknife technique was applied. Each of the 6 samples for both sexes was sequentially omitted with substitution. For each sex, 6 groups of 5 samples were generated, thus providing 6 estimates of total mortality. The results show that the 6 estimates of total mortality are the same with the one estimated from 6 samples for both sexes. Therefore, within these contexts, our value of Z is accurate and reliable.

The Pauly's empirical formula for estimating M is based on data for various finfish species, but this method can be useful for the crustaceans as well (Pauly *et al.*, 1984; Smita and Devaraj, 1990). 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 (1.88 for females and 2.07 for males) suggesting that the estimates of M are reasonable in this study.

Although projecting the length-frequency data backward onto the time axis down to zero length with adult growth parameters is questionable, it will not introduce large errors in determining whether there are one or two recruitment pulses (Siddeek and Johnson, 1997). However, using ELEFAN method to estimate the recruitment pattern is sensitive to the choice of the length-frequency distribution, and minor errors in growth parameters estimates could lead to a major shift in the peak of the recruitment pattern along the time axis (Etim and Sankare, 1988; Tzeng and Yeh, 2000), so a good representing of the population length composition is also essential for constructing the recruitment pattern using ELEFAN method.

The ELEFAN seems to be a much more flexible and robust analytical procedure than any hitherto applied to the study of growth and mortality in shrimp populations, but it is not always objective. Therefore, successful application of ELEFAN analysis for growth and mortality estimates presupposes and must depend on a good understanding of the biology of this species examined. Nevertheless, if such knowledge is not available, ELEFAN method could be used to determine the population parameters of the species studied on a provisional basis (Pauly *et al.*, 1984). Conclusions obtained would then need to be confirmed by biological study.

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# 台灣西部沿岸產彎角鷹爪對蝦(*Trachypenaeus curvirostris*)之成長、死亡及加入型態研究

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本研究利用1992年2至7月間，連續6個月之月別體長頻度資料以ELEFAN法，來估計台灣西部沿岸產彎角鷹爪對蝦(*Trachypenaeus curvirostris*)之季節性成長參數、死亡率及加入型態。應用雌雄體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：極限頭胸甲長$L_\infty$ = 35.60 mm，成長參數K = 1.2 (year$^{-1}$), C = 0.95 and WP = 0.05；(2)雄蝦：$L_\infty$ = 32.40 mm，K = 0.96 (year$^{-1}$), C = 0.95 and WP = 0.05。利用季節化體長轉換漁獲量曲線估計其全死亡係數Z，雌雄結果分別為3.62 (year$^{-1}$)和3.11 (year$^{-1}$)。利用Pauly (1980)之經驗式，估計自然死亡係數M，雌雄分別為2.32 (year$^{-1}$)及2.04 (year$^{-1}$)；漁獲死亡係數F利用Z = F + M之關係式估求，其雌雄值分別為1.30 (year$^{-1}$)及1.07 (year$^{-1}$)。加入型態分析結果顯示，彎角鷹爪對蝦每年具有兩個強度約略相等之加入群。

關鍵詞：*Trachypenaeus curvirostris*，成長，死亡，加入，ELEFAN

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