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Population Dynamics of the African River Prawn, *Macrobrachium vollenhovenii*, in Dawhenya Impoundment

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Abstract

Studies were conducted on the growth and mortality parameters, recruitment pattern, probability of capture, yield-per recruit, and present rate of exploitation of the African river prawn, *Macrobrachium vollenhovenii* from Dawhenya impoundment, Ghana. Estimation of the von Bertalanffy growth parameters gave; L_∞ = 14.2 cm, K = 1.0 yr^{-1}, and t_o = -0.195 yr^{-1} with the growth performance index, Φ' of 2.303. From the linearised length-converted catch curve, total mortality, Z was 5.36 yr^{-1}. Natural mortality, M calculated from Pauly's empirical formula was 2.20 yr^{-1} and fishing mortality, F calculated from Z - M was 3.16 yr^{-1}. From the mortality estimations, the present rate of exploitation, E calculated from F/Z was 0.59 indicating that, the species is on the verge of being over-exploited in the impoundment. Using the estimated value of the growth coefficient, K, the longevity was found to be about 3 yrs. Estimations from the probability of capture routines gave the length-at-first capture, L_c as 3.07 cm while the size distribution of the catches suggest two recruitment pulses in a year. It is therefore recommended that, the property right-based system for fisheries management should be implemented so that fishermen can cooperate in the management of the *Macrobrachium* fishery.

Keywords: Growth, mortality, exploitation, recruitment.

Dawhenya Göletinde Afrika Nehir Karidesinin, *Macrobrachium vollenhovenii*, Populasyon Dinamikleri

Özet

Gana'da Dawhenya göletinden Afrika nehri karidesinin, *Macrobrachium vollenhovenii*, büyüme ve ölüm parametreleri, stoka katılım modeli, avlanma olasılığı, stoka katılan birey başına ürün, mevcut sömürme oranı üzerinde çalışmalar yapılmıştır. von Bertalanffy büyüme parametrelerinde elde edilen tahminler şu sonuçları vermiştir: L_∞ = 14.2 cm, k = 1.0 $yıl^{-1}$, ve t_o = -0,195 $yıl^{-1}$ büyüme performans endeksiyle, Φ' of 2,303. "Boy kompozisyonu üzerinden tahmin" yöntemiyle toplam ölüm, "z" 5,36 $yıl^{-1}$ olarak hesaplanmıştır. Pauly'nin ampirik formülüyle hesaplanmış doğal ölüm m, 2,20 $yıl^{-1}$ olarak, z - m ile hesaplanan avcılık ölümü F 3,16 $yıl^{-1}$ olarak hesaplanmıştır. Ölüm tahminlerine dayanarak mevcut sömürme oranı E, F/Z ile hesaplanarak 0,59 bulunmuştur. Bu sonuç, göletteki bu türün aşırı sömürülmenin eşiğinde olduğunu işaret etmektedir. Tahmini büyüme katsayısı değeri kullanılarak, "k", yaşam süresi yaklaşık 3 yıl olarak bulunmuştur. Avlanma rutini olasılığından elde edilen tahminler, ilk avlanmada boyunu, L_c 3,07 cm olarak verirken avların dağılım büyüklükleri ise stoka katılım açısından bir yılda iki eğilim olduğunu öne sürmektedir. Bu yüzden balıkçılık işletmesi için mülkiyet hakkı esasına dayanan sistemin uygulanması gerektiği, bu şekilde balıkçıların *Macrobrachium* balıkçılığının yönetiminde işbirliği yapabileceği önerilmektedir.

Anahtar Kelimeler: age composition, sex ratio, size, weight.

Introduction

Freshwater prawns are decapod crustaceans belonging to the Palaemonidae family. They are distributed throughout the tropics and subtropics on all continents except Europe (Holthuis, 1980). The freshwater prawn, *Macrobrachium vollenhovenii* (Herklots, 1857) supports artisanal fisheries in many developing countries especially in Africa (Nwosu and Wolfi, 2006). It is a welcome substitute when fish becomes scarce in the market. However, the growth and mortality parameters of this species that contribute immensely to the economy of many developing countries are not well known (Powell, 1983) except the investigations of (Marioghae, 1982; Gabche and Hockey, 1995; Bello-Olusoji and Somers, 1997; Etim and Sankare, 1998; Nwosu and Wolfi, 2006) the paucity of information on its growth and mortality in Ghana therefore prompted this study to determine its population parameters, with a view of evolving management strategies for its sustainable exploitation.

Materials and Methods

The study was conducted at the Dawhenya impoundment, 5°04'-6°00' N, 0°10'-0°05' E. Monthly samples of *M. vollenhovenii* were obtained from all the four existing fish landing sites of the Dawhenya impoundment using artisanal traps designed by local fishermen for a period of 12 months (August 2006 and July 2007). Traps were set at dusk and retrieved at dawn the following day since this species is noted to be nocturnal and samples collected for laboratory analysis. Soak time was estimated as the number of hours between the date and time of trap placement and the date and time of trap collection. Traps were conical in shape about 160 cm x 80 cm x 50 cm (base diameter, top diameter and height respectively) with the mouth (entrance) located at the top. The decision on soak time and sampling sites were made by the local fishermen with expertise in prawn fishing. Trap saturation, observed as a reduction in catch rate with increasing catch was not likely to occur since the soak time was only about 10 hours.

Total lengths of 200 individual prawns were measured monthly for a period of 12 months and were later grouped into length frequency data of constant class intervals of 1.0 cm beginning with a minimum of 2.5 cm to a maximum of 14.5 cm. The sample size for the length frequency was 2,400. Out of this number, 2,361 prawns were later randomly selected for length and weight measurements for the regression analysis. A sample size of 1,500 or more collected over a period of at least six months is termed adequate by Pauly (1990). The length frequency data was obtained by measuring the total length of each specimen (from tip of rostrum to tip of telson) to the nearest 0.1 cm using vernier calipers while the body weight measured to the nearest 0.01 g using a Mettler Toledo balance after mopping off water from the surface of the specimen. The length-weight equation; $W = a L^b$ as described by Ricker (1975) was used to establish the length-weight relationship of the species measured, where W is the weight (g), L is the total length (cm) and *a* and *b* are constants.

The analysis of the population parameter estimates were done using the routines in the FAO-ICLARM Stock Assessment Tools, FiSAT (Gayanilo *et al.*, 1995). The estimates of the von Bertalanffy growth parameters, the asymptotic length (L_∞) and the growth coefficient (K), were obtained using the ELEFAN I routine of FiSAT which allows the estimation of growth parameters without knowing the age of the individuals (Pauly and David, 1981). Pauly's empirical equation for the theoretical age at length zero (*to*) was used to obtain this parameter as:

$Log_{10} (-to) = -0.392 – 0.275 Log_{10} L_\infty - 1.038 Log_{10} K$ (Pauly, 1979).

The estimates of L_∞ and K were used to compute the growth performance index, Φ' of the species (Munro and Pauly, 1983; Pauly and Munro, 1984; Moreau *et al.*, 1986).

Thus, $\Phi' = Log_{10} K + 2 Log_{10} L_\infty$ and longevity (t_{max}) was estimated using the equation t_{max} = approximately 3/K (Pauly, 1980a).

Estimates of total mortality (Z) were derived from the linearised length – converted catch curve (Pauly, 1990), a component of ELEFAN 1 by fitting a regression line through the natural logarithm (ln) of the number (N) of prawns in various length groups divided by the time (dt) needed for an average individual prawn to grow through the length class, against their relative age, t (i.e. ln (N/dt) = a + bt). Z was estimated from the slope, b (with sign changed) of the descending right arm of the plot (Sparre and Venema, 1992). The regression line was fitted excluding the initial ascending data points as well as the right most point. Natural mortality (M) was derived through the empirical equation of Pauly (1980b) using a mean annual surface habitat temperature of 27.9°C. Thus,

$$Log_{10} M = -0.0066 – 0.279 Log_{10} L_\infty + 0.6543 Log_{10} K + 0.463 Log_{10} T.$$

The fishing mortality rate, F was then calculated by the difference between (Z) and (M) from the equation; F = Z – M and the rate of exploitation (E) was calculated by the quotient between fishing and total mortality:

E = F/Z (Pauly, 1984).

Estimates of length-at-first capture (L_{50}) were derived from probabilities of capture generated from the catch curves which consist of incompletely recruited prawns. This method consists of backward extrapolation of the left descending side of the catch curve to include prawns that ought to have been caught had not been it for the effect of incomplete selection and/recruitment. The annual recruitment pattern was produced from ELEFAN II routine of FiSAT (Moreau and Cuende, 1991), through reverse projection of the restructured data onto the time axis of available length frequency data by means of growth parameters.

From the analysis, E_{max} (exploitation rate giving maximum relative yield-per-recruit), $E_{0.1}$ (exploitation rate at which the marginal increase in relative yield-per-recruit is 10% of its value at E = 0), and $E_{0.5}$ (exploitation rate corresponding to 50% of the unexploited relative biomass-per-recruit) were also estimated from the modified form of Beverton and Holt (1964) relative yield-per-recruit (Y'/R) analysis by Pauly and Soriano (1986).

Results

The von Bertalanffy growth model for *M. vollenhovenii* in the Dawhenya impoundment is described as: $L_t = 14.2\ (1\text{-}e^{-1(t+0.195)})$ The length frequency distribution output from ELEFAN 1 of FiSAT is shown for *M. vollenhovenii* (Figure 1). The growth parameters were $L_\infty = 14.2$ cm, $K = 1.0$ yr^{-1} and $t_o = -0.195$ years. From these results the growth performance index Φ' was 2.303, while the longevity t_{max} was 3 years. The instantaneous total mortality, Z = 5.36 yr^{-1}, natural mortality, M = 2.20 yr^{-1}, and fishing mortality, F = 3.16 yr^{-1} (Figure 2). The rate of exploitation, E = 0.59 while the values of M/K ratio was 2.2. The length-at-first capture, $L_c = 3.07$ cm was obtained from the probability of capture (Figure 3) while the size distribution of the catches suggest two recruitment pulses of almost equal strength in a year (Figure 4). The selection gives option of FiSAT was used in the analysis of relative yield per recruit and biomass per recruit analysis (Figure 5) and produced values of $E_{10} = 0.415$, $E_{50} = 0.213$ and $E_{max} = 0.525$.

Discussion

The parameters that describe growth in length (L_∞= 14.2 cm and K = 1.0 yr^{-1}) of *M. vollenhovenii* in this study were different from those observed by other workers. Gabche and Hockey (1995) recorded L_∞ of 16.4 cm and K of 3.19 yr^{-1} while Etim and Sankare (1998) had values of L∞ to be 18.0 cm and K to be 0.81 yr^{-1}. Nwosu and Wolfi (2006) on the other hand, separated the species into sexes and obtained L∞ of 21.4 cm and 19.8 cm, K values of 1.24 yr^{-1} and 1.25 yr^{-1} for males and females respectively. Since the average size of adult *M. vollenhovenii* in this study was smaller than that from areas with high rainfall, its culture could be more successful in the forest belt of the country where the rainfall pattern is high than in the coastal savanna zone where the study was carried out. Isaac (1990) demonstrated that growth parameters estimated from ELEFAN 1 routine could be biased as a result of individual growth variability, seasonal oscillations in growth, the restructuring procedure, size-dependent selection, variable

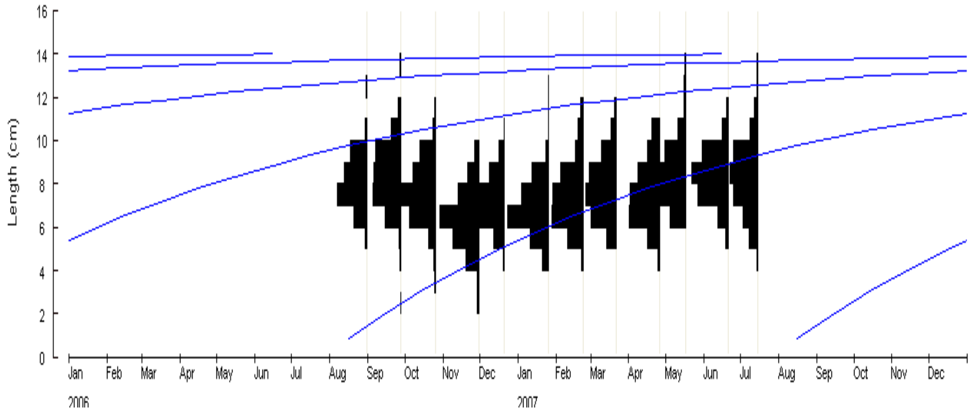

Figure 1. Length-frequency distribution output from FiSAT with superimposed growth curve for *M. vollenhovenii* from Dawhenya impoundment. $L_\infty = 14.2$ cm (total length), $K = 1.0$ yr^{-1} and $R_n = 0.170$.

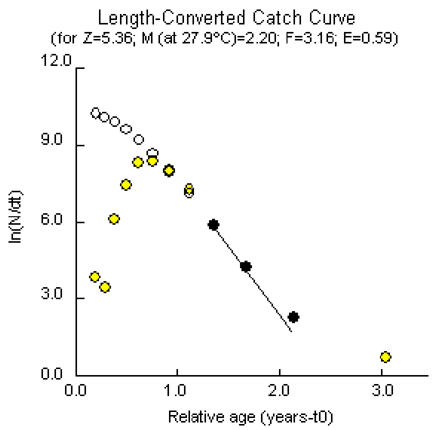

Figure 2. Length-converted catch curve for *M. vollenhovenii* from the Dawhenya impoundment. Solid dots are those used in calculating the parameters of the straight line, the slope of which (with sign changed) is an estimate of Z. Open dots represent fish not fully selected by the gear used in the fishery and/or not used in mortality estimation.

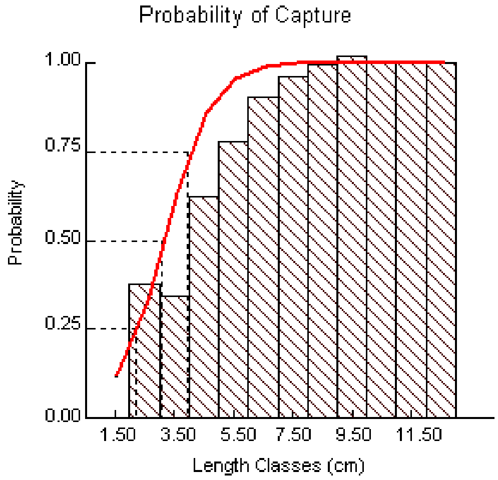

Figure 3. Probability of capture of *M. vollenhovenii* from the Dawhenya lmpoundment estimated from the ascending arm of the catch curve. The length-at-first capture, L_c = 3.07 cm obtained from this procedure was an input data for the computation of relative yield per-recruit.

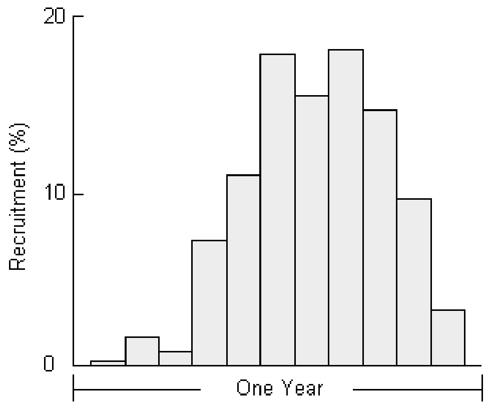

Figure 4. Recruitment pattern of *M. vollenhovenii* from Dawhenya impoundment showing two recruitment pulses of almost equal strengths within a year.

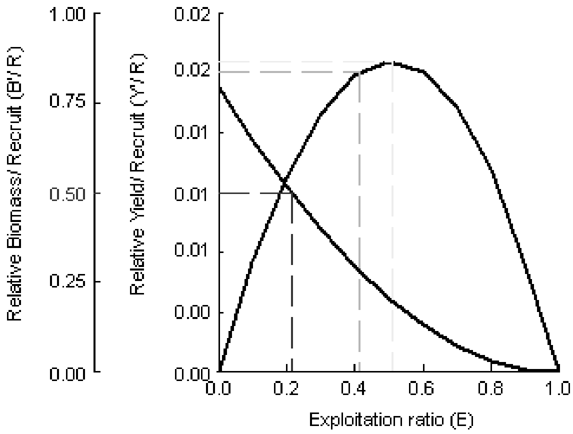

Figure 5. Relative yield-per-recruit and biomass-per-recruit curves for *M. vollenhovenii* from Dawhenya impoundment using the selection ogive option (E_{10} = 0.415, E_{50} = 0.213, E_{max} = 0.525).

recruitment period and large size-class interval. However, the validity of this routine rests on the following assumptions: that the sample(s) used represents the population investigated; that the growth pattern in the population is the same from year to year; that the von Bertalanffy Growth Function (VBGF) describes the average growth of the investigated stock; that all fishes in the (set of) sample(s) have the same length at the same age, and that, therefore, differences in length can be attributed to differences in age. The first assumption above is a sampling problem since the decision on soak time and sampling sites of this study were made by the local fishermen with expertise in prawn fishing. However, the last of these assumptions does not strictly apply, since it is known that fishes have the same age may have different lengths. However, simulations show, that this assumption, which is essential to the operation of the routine, does not generate a marked bias (Dwiponggo *et al*., 1986).

Estimation of growth and mortality is fundamental in fisheries because stock assessment and management rely on these population parameters. Length-frequency-based methods become important when aging techniques are either not possible or very expensive (Wang and Ellis, 2005). According to Pauly (1991), the growth performance index, Φ' is the basis for comparison of growth parameters assuming that the species grows according to the von Bertalanffy model. Also, related species present similar values of Φ' and each *taxa* may have a particular distribution of values different from other *taxa* (Pauly and Munro, 1984). The results of this study (2.30) fall within acceptable ranges since other workers such as Gabche and Hockey (1995) and Etim and Sankare (1998), who obtained Φ' values of 2.93 and 2.47 for *M. vollenhovenii*, respectively, whereas Nwosu and Wolfi (2006) recorded 2.75 and 2.67 for males and females, respectively. This therefore suggests that the particular distribution of Φ' values of *M. vollenhovenii* in African fresh and brackish waters is within the range of 2.29 to 2.94 with the species recording low Φ' values in water bodies in the low rainfall savanna plains and high Φ' values in high rainfall forest zones.

Pauly *et al*. (1984) first demonstrated the applicability of ELEFAN routines of FiSAT to shrimp/prawn length-frequency data. Also, Spare and Venema (1992) showed that the growth of a cohort of crustaceans conforms to the von Bertalanffy growth function and therefore justifying the use of length-frequency analysis tools of FiSAT for shrimps/prawns. The initial ascending points of the catch curve in this study may result from the fishing gear selectivity, which would let the smallest individuals to escape, or from the absence of individuals in that particular age classes in the study area (Ricker, 1975). The total mortality, Z, natural mortality, M and fishing mortality, F obtained in this study were 5.36 yr^{-1}, 2.2 yr^{-1} and 3.16 yr^{-1} respectively. While Gabche and Hockey (1995) obtained Z of 3.406 yr^{-1}, M of 3.40 $yr^{-1}$and F of 0.26 yr^{-1}. Etim and Sankare on the other hand obtained Z to be 3.69 yr^{-1}, M of 1.97 yr^{-1} and F of 1.72 yr^{-1}. However, Nwosu and Wolfi (2006) who separated the species into sexes recorded Z of 3.93 yr^{-1} and 6.85 yr^{-1}, M of 2.21 yr^{-1} and 2.27 yr^{-1}, F of 1.72 yr^{-1} and 4.58 yr^{-1} for males and females respectively. The high total mortality rate recorded in this study represents a sum of natural mortality, fishing mortality and probably emigration because emigration sometimes appears as a seeming mortality, though it may be compensated by immigration (Laevastu and Favorite, 1988). Most of the natural mortality could be attributed to the predation factor (Laevastu and Favorite, 1988). Many authors' question is the use of natural mortality rates due to their expression as a single value, despite intensity changes throughout the different phases of the life cycle (Vetter, 1988; Pascual and Iribane, 1993). However, they still represent an important tool in fishery studies (Caddy and Defeo, 2003; Khan and Helser, 2005). According to Beverton and Holt (1957), the reliability of the estimated natural mortality, M is ascertained by using the M/K ratio which is within the ranges of 1.12 to 2.5 for most fishes. The M/K ratio of 2.2 obtained in the present study was within this range and therefore suggests that the natural mortality estimated for this species was reliable. Information about the magnitude of natural mortality is essential for effective management of exploited fish populations. Unfortunately, natural mortality is difficult to estimate directly because natural deaths are rarely observed (Quinn and Deriso, 1999). In addition, it is difficult to separate the effects of natural mortality, fishing mortality, and recruitment on abundance, making the estimation of any single factor problematic (Hilborn and Walters, 1992; Quinn and Deriso, 1999). According to Ricker (1975), estimating M from a regression equation relating Z and fishing effort should be more generally applicable than using a catch curve, because the approach can be used with exploited populations. However, the disadvantages of the regression approach include its long-term nature and the difficulty of estimating fishing effort and obtaining sufficient contrast in levels of Z (Hightower *et al*., 2001). Methods that relate M to life history parameters such as maximum age or growth rate have been widely used because they require minimal data (Vetter, 1988). Further more, life history attributes such as the size and age at sexual maturity provide the basis for key biological reference points required for the development of rational fisheries management regimes (Grandcort *et al*., 2003). However, this approach provides no information about how M might vary seasonally or among ages or years (Pascual and Iribarne, 1993).

From the probability of capture curve, the length-at-first capture (L_c) was 3.07 cm indicating that the prawns were caught at smaller sizes before they had the chance to grow large enough to contribute substantially to stock biomass, which indicates growth over-fishing. Hence a fisheries regulation of minimum escape gaps (mesh sizes) of artisanal traps should be enforced in the *Macrobrachium* fishery of the Dawhenya impoundment to ensure that small size prawns can escape from the traps when caught.

Using the estimated value of the average growth coefficient K, the longevity was found to be 3 yrs (36 months). This confirms the findings of Garcia (1988) who suggested that tropical prawns are generally fast-growing and short-lived, with maximum life spans of 2 to 3 years. Nwosu and Wolfi (2006) obtained longevity of 29 months (males) and 28.8 months (females) while Gabche and Hockey (1995) and Etim and Sankare (1998) estimated longevity of 11 months and 39.6 months respectively for the same species. The present rate of exploitation, E obtained was 0.59, implying that the species is on the verge of being over-exploited in the Dawhenya impoundment since E was slightly greater than 0.50 (Gulland, 1971; Pauly and Munro, 1984).

From the relative yield-per-recruit analysis, the computed exploitation rate E = 0.59 is slightly above the predicted maximum values of $E_{max} = 0.525$ (i.e. $E > E_{max}$). Thus, confirming the slightly high fishing pressure on the species in the Dawhenya impoundment. Therefore, the property right-based system for fisheries management should be implemented so that fishermen can cooperate in the management of the *Macrobrachium* fishery. Also, since there is little information on this species in Ghana, further biological investigations, including catch-effort data, full range of size strata in the population, and studies concerning possible migration patterns of *M. vollenhovenii* should be conducted.

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