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Population dynamics of the freshwater clam *Galatea paradoxa* from the Volta River, Ghana

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ABSTRACT

Key-words: *recruitment, mortality, growth parameters, Volta River, Bivalvia*

Population parameters such as asymptotic (L_∞), growth coefficient (K), mortality rates (Z, F and M), exploitation level (E) and recruitment pattern of the freshwater clam *Galatea paradoxa* were estimated using length-frequency data from the Volta River estuary, Ghana. The L_∞ for *G. paradoxa* at the Volta estuary was 105.7 mm, the growth coefficient (K) and the growth performance index (Ǿ) ranged between 0.14–0.18 year^{-1} and 3.108–3.192, respectively. Total mortality (Z) was 0.65–0.82 year^{-1}, while natural mortality (M) and fishing mortality (F) were 0.35–0.44 year^{-1} and 0.21–0.47 year^{-1}, respectively, with an exploitation level of 0.32–0.57. The recruitment pattern suggested that *G. paradoxa* has year-round recruitment with a single pulse over an extended period (October–March) in the Volta River. The Volta River stock of *G. paradoxa* is overfished and requires immediate action to conserve it. This can be achieved by implementing a minimum landing size restriction and intensifying the culture of smaller clams which is a traditional activity at the estuary.

RÉSUMÉ

La dynamique des populations de palourdes d'eau douce *Galatea paradoxa* de la rivière Volta, Ghana

Mots-clés : *recrutement, mortalité, paramètres de croissance, Rivière Volta, Bivalve*

Les paramètres de population tels que ($L\infty$) asymptotique, le coefficient de croissance (K), les taux de mortalité (Z, F et M), le niveau d'exploitation (E) et le modèle de recrutement des palourdes d'eau douce *Galatea paradoxa* ont été estimés à l'aide des données de fréquences de longueur dans l'estuaire du fleuve Volta, au Ghana. Le $L\infty$ pour *G. paradoxa* dans l'estuaire de la Volta était de 105,7 mm, le coefficient de croissance (K) et l'indice de performance de croissance (Ǿ) variaient entre 0,14 à 0,18 an^{-1} et de 3,108 à 3,192, respectivement. La mortalité totale (Z) était de 0,65 à 0,82 an^{-1}, tandis que la mortalité naturelle (M) et la mortalité par pêche (F) étaient de 0,35 à 0,44 an^{-1} et de 0,21 à 0,47 an^{-1}, respectivement, avec un niveau d'exploitation de 0,32 à 0,57. Le schéma de recrutement suppose que *G. paradoxa* a du recrutement tout au long de l'année avec un maximum sur une longue période (octobre–mars) dans le bassin de la Volta. Le stock de *G. paradoxa* de la rivière Volta est surexploité et exige une action immédiate pour le conserver. Ceci peut être réalisé en mettant en œuvre une restriction de taille minimale de débarquement et en intensifiant la culture de petites palourdes qui est une activité traditionnelle dans l'estuaire.

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INTRODUCTION

The freshwater clam *Galatea paradoxa* (Born, 1778) is a bivalve mollusc belonging to the superfamily Tellinoidea and family Donacidae (Purchon, 1963). It is endemic to the West African sub-region with a range that extends from the Gulf of Guinea to the Congo (Moses, 1990). *Galatea Paradoxa* is the basis of an artisanal clam fishery at the Volta River estuary providing employment and an affordable protein source to the riparian human communities and beyond (Amador, 1997). Furthermore the clam shell has a number of important uses notably as a source of calcium in poultry feed and in lime manufacturing.

The population dynamics of bivalves are studied with the objective of sustainable management and conservation (Urban, 1998; Nassar, 1999). Growth rate in bivalves is not constant throughout their life-span, it is faster at the larval stage and steadily declines as the animal approaches the asymptotic length (L_∞) (Moura *et al.*, 2009). Since individual growth is a non-linear process, the comparison of growth among different organisms or populations is difficult due to the problem of correlation between the growth coefficient (K) and L_∞. To overcome this problem, the overall growth performance index, phi-prime (Ǿ) (Pauly, 1979; Munro and Pauly, 1983) is often used to compare growth between different populations of a species.

Recruitment patterns in bivalve populations are either a single annual event as in most temperate bivalves occurring within a short period of the year when conditions are favourable; *e.g.*, *Mytilus edulis* in mid July (Petraitis, 1991) or over an extended period from late summer to late winter or spring; *e.g.*, *Macomona liliana* (Roper *et al.*, 1992). In other species such as *Solemya* sp., recruitment is continuous year-round (Rainer and Wadley, 1991). Recruitment patterns are greatly influenced by climatic conditions as observed in the Wadden Sea, where higher recruitment of *Cerastoderma edule*, *Mytilus edulis*, *Macoma balthica* and *Mya arenaria* in the summer after severe winters is a common phenomenon (Strasser *et al.*, 2001).

Mortality in bivalve populations consists of two parts, natural mortality (M) and fishing mortality (F). In unexploited populations total mortality (Z) is equal to natural mortality (M). Once exploitation starts mortality due to fishing is introduced which in most instances assumes an important role as the exploitation level increases. In order to ensure sustainability in any fishery, it is recommended that mortality due to fishing should not exceed 50% of total mortality *i.e.* $F = M$ (Gulland, 1965). However, it has been difficult maintaining this level of exploitation even under regulated conditions. Exploitation has always gone beyond optimal or sustainable levels leading to drastic reduction in numbers or in some cases extinction of species. For example in the *Polymesoda solida* fishery of Colombia, fishing mortality accounts for 72% of total mortality (Rueda and Urban, 1998). Similarly, in the *Modiolus metcalfei* fishery of the Philippines, fishing mortality accounts for 73% of total mortality (Tumanda Jr. *et al.*, 1997).

Length-weight relationships usually describe a mathematical relationship between length and weight, such that one may be converted to the other. It also measures the deviation from the expected weight for a specified length of an individual or a group of individuals as indication of condition and gonad development (Le Cren, 1951). It has been found that the length-weight relationship of most organisms can adequately be described by the formula: $W = \alpha L^\beta$, where W = weight, L = length, α is a constant and β an exponent usually lying between 2.5 and 4.0 (Martin, 1949). An ideal organism maintains the same shape throughout life such that growth is uniform for all body parts and $\beta = 3$. This type of growth is described as isometric, a condition only occasionally observed (Allen, 1938). In the vast majority of instances where length-weight relationships have been calculated, it has been found that $\beta \neq 3$, in that case growth is referred to as allometric where certain parts of the body grow faster than others (Gaspar *et al.*, 2002).

For the sustainable management of mollusc resources, knowledge of various population parameters and exploitation level (E) of the population is required. There are many tools for assessing exploitation levels and the population dynamics of a stock, however, the FAO-ICLARM stock assessment tools (FiSAT) has been most frequently used for estimating population parameters of finfish and shellfish (Vakily, 1992; Mancera and Mendo, 1996; Al-Barwani *et al.*, 2007) because it needs only length-frequency data. Despite its commercial importance there is limited information on the population dynamics of *G. paradoxa* in the Volta

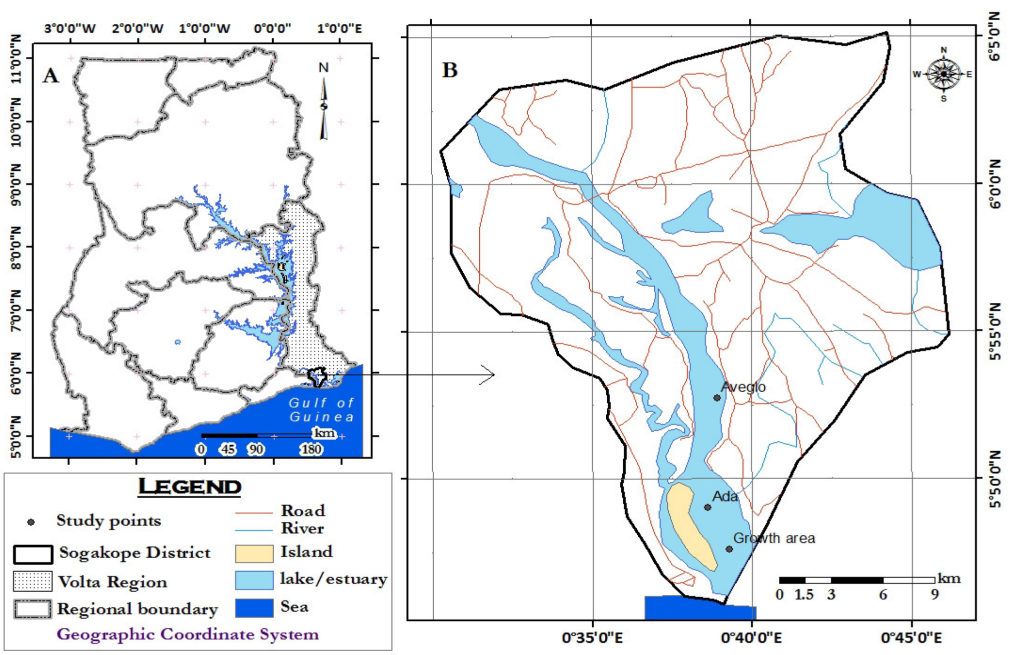

Figure 1
Map showing the clam sampling locations at Ada and Aveglo at the Volta estuary, Ghana.

River. This information is crucial for estimating sustainable exploitation rates as well as the potential of the species for aquaculture production. This study was aimed at estimating the population parameters and exploitation level of *G. paradoxa* in the Volta River.

MATERIALS AND METHODS

> STUDY AREA

The study was conducted at the estuary of the Volta River, south-eastern Ghana (Figure 1). The Volta River estuary lies within the coastal savannah zone with an annual rainfall of 750–1250 mm (Dickson and Benneh, 1977). The estuary is about 1.2 km wide at the mouth, however, due to the formation of a sandbar, the river enters the sea through a narrow opening. Two dams have been built on the Volta River at Akosombo (100 km) and further downstream at Kpong, 75 km from the river's mouth. These dams in addition to a sandbar at the mouth of the river influence the estuary's seawater and freshwater dynamics. Sampling was carried out at two sites, Ada (Latitude 05° 49′ 10″ N and 0° 38′ 38″ E) and Aveglo (5° 52′ 54″ N, 0° 38′ 55″ E) (Figure 1).

> CLAM SAMPLING

Clam samples were collected monthly from March 2008 to February 2010 at Ada and Aveglo at the Volta estuary from clam fishers. In order to obtain a sample covering the range of sizes in the population and eliminate any bias due to the preference of fishers for larger clams (clams less than 20 mm are not picked by fishers), 2 grab samples (grab size equivalent to 0.1 m^2) were collected monthly from each site. The sediments were washed over a 1 mm sieve and any clam recovered kept separately for length-frequency distribution of juvenile clams.

Samples were transported in insulated boxes with ample river water which was refreshed every 12 h to the wet laboratory for processing within 24 h.

Samples from the fishers catch in addition to the grab samples were processed for estimation of population parameters by the analysis of the length-frequency distribution of the monthly samples. The shell length (maximum anterior-posterior dimension) of each specimen was measured with a pair of digital callipers (Hangzhou United Bridge Tools, Hangzhou, Zhejiang, China) (0.01 mm), total wet weight (shell + flesh) was recorded with a Sartorius PT1200 balance (DWS, Elk Groove, IL, USA) (0.1 g) after blotting the shell with absorbent paper to remove excess water and allowing the shell to air-dry at room temperature.

> *RECRUITMENT PATTERN*

The recruitment pattern of the stock was determined from the length-frequency distribution of the grab samples by backward projection onto the length axis of the length-frequency data of Ada and Aveglo as described in FiSAT. The routine reconstructs the recruitment pulse from a time series of the length-frequency data to determine the number of pulses per year and the relative strength of each pulse. The input parameters are L_∞, K and t_0. Normal distribution of the recruitment pattern (%) was determined by NORMSEP (Pauly and Caddy, 1985) in FiSAT II.

> *ESTIMATION OF MORTALITY RATES*

Total mortality (Z) of the population was estimated from the length-frequency distribution by the length converted catch curve method (Pauly, 1984). Natural mortality (M) was estimated using the empirical relationship of Pauly (1980):

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

where M is the natural mortality, L_∞ the asymptotic length, K refers to the growth coefficient of the von Bertalanffy growth function (VBGF) and T is the mean annual habitat temperature, which was (28.6 °C) at the Volta estuary over the study period. With Z and M estimated, fishing mortality (F) was obtained from the relationship: $F = Z - M$, where Z is the total mortality, F is the fishing mortality and M is the natural mortality. The exploitation level (E) was obtained by the relationship of Gulland (1965): $E = F/Z = F/(F + M)$. The growth performance index (Ǿ) (Pauly, 1984) of *G. paradoxa* from Ada and Aveglo was estimated using the L_∞ and K estimates and the equation: Ǿ $= 2 \log_{10} L_\infty + \log_{10} K$.

> *LENGTH-WEIGHT RELATIONSHIPS*

To establish the relationship between shell length and total weight, the commonly used relationship: $W = \alpha L^\beta$ was applied (Ricker, 1975) where W is total weight (g), L is shell length (mm), α is the intercept and β is the slope (growth coefficient). The parameters α and β were estimated by least squares linear regression, using logarithmic data: $\log_{10} W = \log_{10} \alpha + \beta \log_{10} L$. The coefficient of determination (R^2) was used as an indicator of the quality of the linear regression. A sample of 60 individuals were selected randomly from fisher's catch and processed for shell-free dry weight. A sterile stainless steel knife was used to open the shell and a scalpel blade carefully used to remove the flesh of each individual. The flesh of each sample was weighed on a Sartorius BP 210S micro balance (DWS, Elk Groove, IL, USA) to the nearest 0.0001 g (shell-free wet weight). The wet flesh was oven-dried to a constant weight at 60 °C for 48 h and weighed to the nearest 0.0001 g for shell-free dry weight. The regression coefficients for successive monthly samples from Ada and Aveglo were generated and the shell-free dry weight cycle for a 40 mm standard animal outlined.

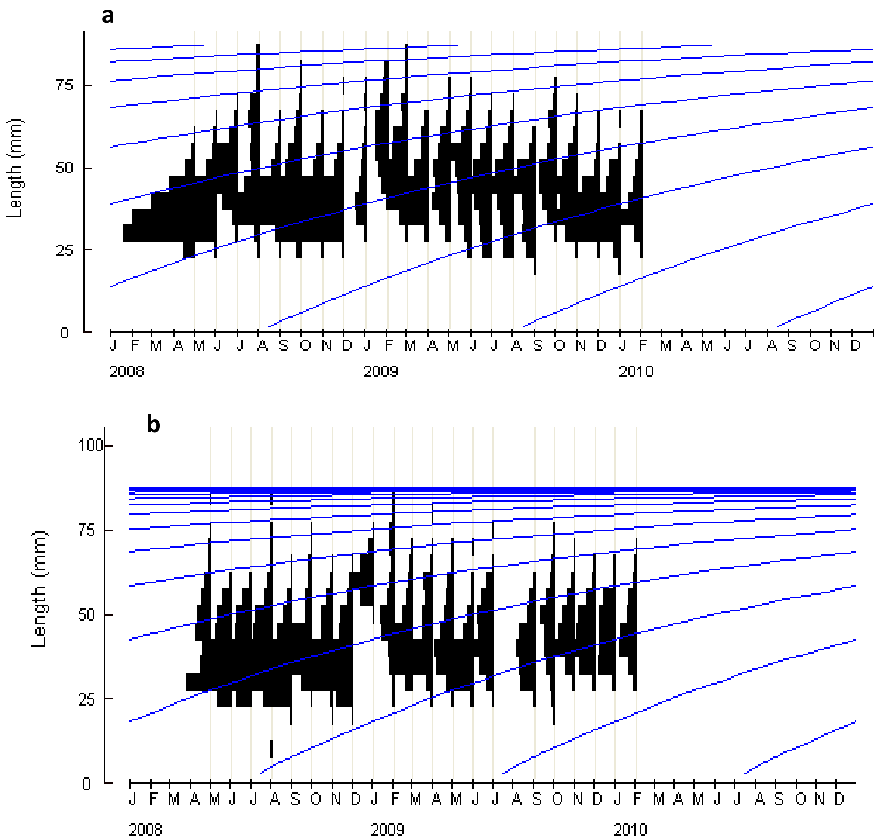

Figure 2
Length-frequency distributions of G. paradoxa *from two sites at the Volta estuary with growth curves superimposed (a) Ada and (b) Aveglo.*

RESULTS

The environmental variables monitored at the estuary were similar for the two sites (Ada and Aveglo) and varied within a narrow range except conductivity and to lesser extent salinity which was higher at high tide. Temperature was relatively constant throughout the study period and varied narrowly between 27.3 and 29.6 °C with a mean of 28.6 ± 0.8 °C (n = 24). Conductivity was fairly constant and similar at low tide with a mean of 57.9 $\mu S \cdot cm^{-1}$ at Ada and Aveglo. However, at high tide conductivity was higher (mean of 583.4 $\mu S \cdot cm^{-1}$) at Ada. The maximum conductivity recorded at Ada was 2879 $\mu S \cdot cm^{-1}$. Similarly, salinity was constant at 0.03 (psu) at low tide for the two sites during the study period. However, at high tide values as high as 1.5 psu were recorded at Ada. The clam beds at Ada are thus exposed to different conductivity and salinity regimes depending on tide.

> *GROWTH PARAMETERS*

The asymptotic length (L_∞) and growth coefficient (K) estimate for Ada was 105.7 mm and 0.14 year^{-1} while that for Aveglo was 84.4 mm and 0.18 year^{-1}. From the reverse von Bertalanffy Growth Function (VBGF), t_0 for Ada and and Aveglo were –0.125 and –0.119 respectively. Figure 2 presents the length frequency distribution by FiSAT II of *G. paradoxa* from Ada (Figure 2a) and Aveglo (Figure 2b) with growth curves superimposed. Because of fishing bias, individuals less than 20 mm were uncommon in the length-frequency distribution from

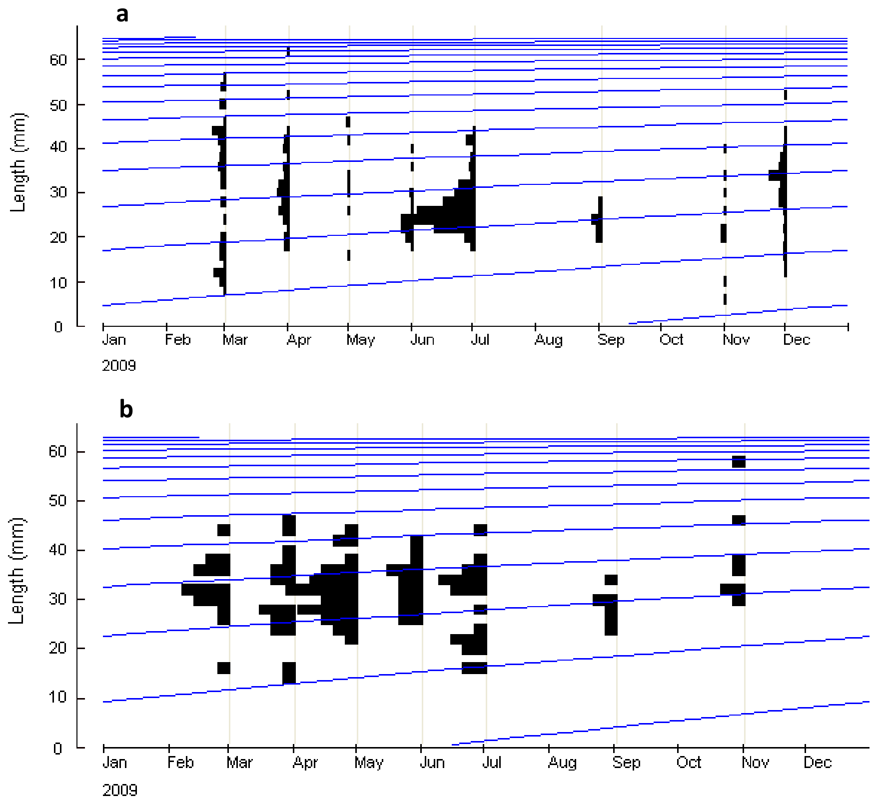

Figure 3
Length-frequecy distributions of smaller G. paradoxa *from grab samples taken at Ada (a) and Aveglo (b) at the Volta estuary with growth curves superimposed.*

the fishers catch (Figure 2). One could observe the movement of cohorts in the monthly samples from Ada and Aveglo as well as other notable shifts however, these were limited to a shell length range of 26–70 mm. There was no difference between Ada and Aveglo with regards to the length-frequency distribution. The Bhattacharya method allowed the separation of eight cohorts.

Figure 3 presents the length-frequency distribution of grab samples taken at Ada and Aveglo from March to December 2009. In all, 530 clams covering a range of sizes between 5–60 mm were retrieved from 30 grab samples from Ada and Aveglo. The clam fishers catch is biased towards larger clams as smaller clams (<20 mm) are not landed. The smallest clams (5 mm) were found in grab samples between November and March at Ada (Figure 3a).

> RECRUITMENT PATTERN

The recruitment pattern (%) generated by FiSAT for *G. paradoxa* at Ada and Aveglo was continuous throughout the year with a single peak. At Ada (Figure 4a) there was a single pulse with a peak between July and September. Similarly, recruitment at Aveglo (Figure 4b) had a single pulse with a peak between July and August.

> MORTALITY

The length converted catch curve analysis generated a total mortality value (*Z*) of 0.82 year^{-1} for *G. paradoxa* (Figure 5). Natural mortality (*M*) was 0.35 year^{-1} and fishing mortality was

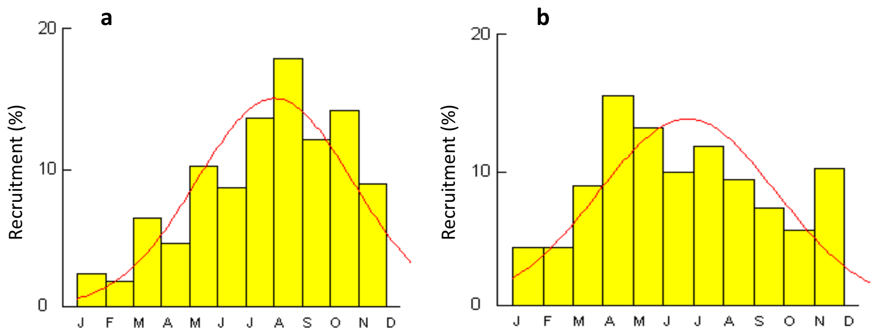

Figure 4
Recruitement pattern of G. paradoxa *obtained by backward projection, along a trajectory defined by the VBGF, of the restructred length-frequency data onto a one-year timescale. The months on the x-axis were located exactly by providing the location parameter (t_0) for Ada (–0.125) and Aveglo (–0.19).*

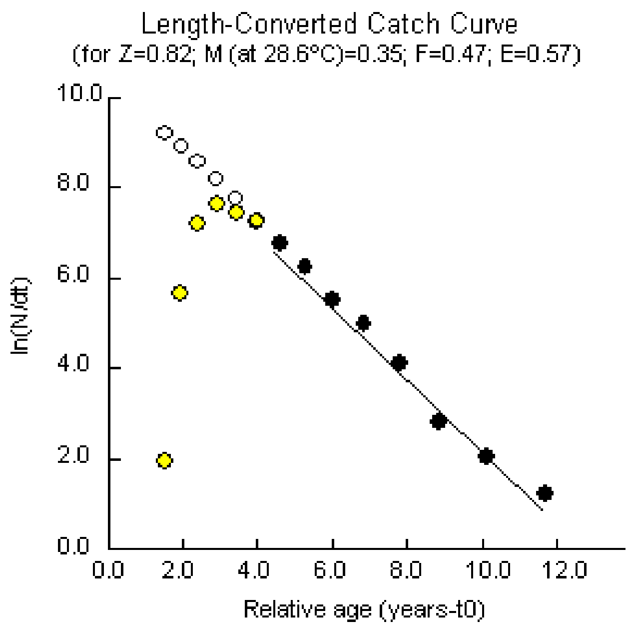

Figure 5
Length-converted catch curve of G. paradoxa *from the Volta estuary based on pooled monthly length-frequency data (grey dots). Darkened data points: used for regression to generate mortality indices, grey data points: excluded from regression. White dots: portion of regression dots excluded from regression equation.*

0.47 year^{-1} for Ada. The exploitation level (*E*) of *G. paradoxa* was 0.57 (Table I). For Aveglo the parameters were $Z = 0.65$ year^{-1}, $M = 0.44$ year^{-1}, $F = 0.21$ year^{-1} and $E = 0.32$.

Table I gives a summary of the population parameters at the two sites.

> LENGTH-WEIGHT RELATIONSHIP

The length of clams ranged from 6.8 to 102.0 mm and total wet weight from 0.1 to 186.2 g. Growth in *G. paradoxa* was allometric as the exponent β of the total wet weight *versus* shell length regression was <3.0 for a greater part of the study period. Figure 6 presents the shell-free dry weight cycle of a 40 mm standard animal from Ada and Aveglo. The pattern of the shell-free dry weight cycle was similar for clams from Ada and Aveglo.

Table I
Summary of population parameters of G. paradoxa *in the Volta River, Ghana.*

Population parameters	Ada	Aveglo
Asymptotic length ($L\infty$) in mm	105.7	84.4
Growth coefficient, K (year^{-1})	0. 14	0.18
Total mortality, Z (year^{-1})	0.82	0.65
Fishing mortality, F (year^{-1})	0.47	0.21
Natural mortality, Z (year^{-1})	0.35	0.44
Exploitation level (*E*)	0.57	0.32
Length range (mm)	6.8–102.0	9.0–82.8
Weight range (g)	0.1–186.0	0.2–182.0
Sample number (*N*)	4905	5149

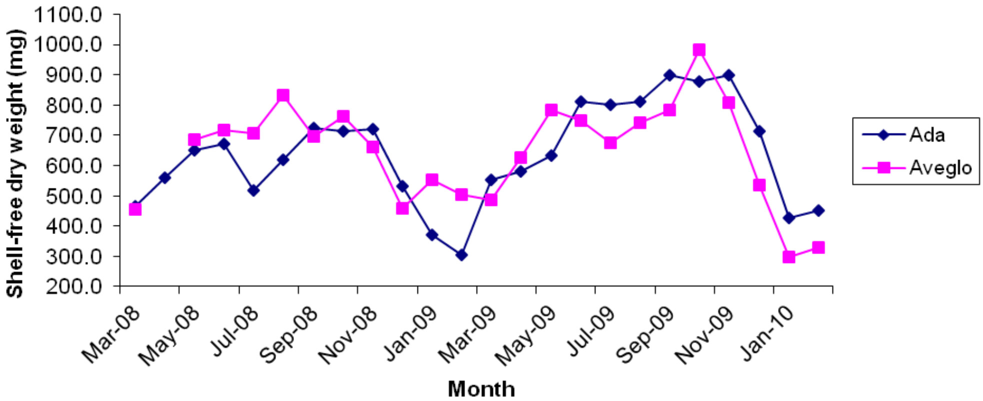

Figure 6
Shell-free dry weight cycle of a 40 mm standard animal from Ada and Aveglo from March 2008 to February 2010.

At Ada, there was a gradual build up of tissue from the start of the study in March 2008 to a peak in September 2008, afterwards there was a steady decline to a minimum value of 300 mg in February 2009. The cycle was repeated in 2009, rising steadily from the minimum value of 300 mg in February to a maximal value of 900 mg in September 2009 and thereafter declining sharply to 400 mg in January 2010. There was a slight drop in tissue weight between June–July in 2008.

Samples from Aveglo showed a similar trend, increasing steadily from March 2008 to a maximum value of 800 mg in August 2008 and falling sharply to a minimum value of 450 mg in December 2008. Similarly, tissue weight increased from the minimum value in December 2008 to about 800 mg in May 2009, declined briefly in June–July and then rose to a maximum value of 1000 mg in October 2009 before falling sharply to a minimum level of 300 mg in January 2010.

DISCUSSION

> *POPULATION PARAMETERS*

The effective management and conservation of any fishery resource requires considerable knowledge of population parameters such as the recruitment pattern, mortalities and exploitation level of the stock (Gaspar *et al.*, 2004; Abohweyere and Falaye, 2008). The asymptotic length (L_∞) is a major parameter used in evaluating the status of a population. The L_∞ for *G. paradoxa* at the Volta estuary (105.7 mm) was very close to the 107.4 mm found by Vakily (1992) who re-analysed data collected by Kwei (1965) at Tefle on the Volta River just after the construction of the Akosombo dam (Table II). Similarly, it was close to the 102 mm reported by

Table II
Growth and related parameters of the G. paradoxa stocks in West Africa.

Location	$L\infty$	K	Ǿ	Source
Volta river (Akosombo, Ghana) 6° 16′ N	145.1*	0.75	4.198	Vakily (1992), Kwei (1965)
Volta river (Tefle, Ghana) 5° 59′ N	107.4*	0.71	3.912	Vakily (1992), Kwei (1965)
Cross river (Nigeria) 5° 11′ N	93.0	0.36	3.493	Moses (1990)
Cross river (Nigeria) 5° 11′ N	111.0	0.30	3.568	King *et al.* (1992)
Cross river (Nigeria) 5° 11′ N	98.9	0.83	3.909	Etim and Brey (1994)
Nun river (Nigeria)	102.0	0.25	3.415	King (2000)
Volta estuary, Ada, Ghana	105.7	0.14	3.192	This study
Volta estuary, Aveglo, Ghana	84.4	0.18	3.108	This study

* These values were originally given as shell height and were converted by Etim and Brey (1994).

King (2000) on the stock of *G. paradoxa* in the Nun River, Nigeria. It was, however, lower than the 145.1 mm obtained by Vakily (1992) from the re-analysed data collected by Kwei (1965) at an upstream station (Akosombo) on the Volta River and the 111.0 mm obtained by King *et al.* (1992) on the Cross River stock of *G. paradoxa*. The L_∞ estimate in this study was higher than that of Moses (1990) and Etim and Brey (1994) for *G. paradoxa* stocks in the Cross River in Nigeria (Table II). The growth coefficient (K) estimate of 0.14–0.18 year^{-1} in this study was the lowest ever recorded in studies of the population dynamics of *G. paradoxa* (Table II).

The growth performance index (Ǿ) allows inter and intra specific comparison of growth performance in bivalve species of different stocks (Abohweyere and Falaye, 2008). The Ǿ values of 3.192 and 3.108 obtained for *G. paradoxa* at Ada and Aveglo, respectively, were the lowest recorded for any population of *G. paradoxa*. They were also reduced compared to the 4.198 and 3.912 obtained by Vakily (1992) who re-analysed the data of Kwei (1965) on the stock of *G. paradoxa* from Akosombo and Tefle on the Volta River just after the construction of the Akosombo dam. They were also lower than that reported from studies conducted (Moses, 1990; King *et al.*, 1992; Etim and Brey, 1994; King, 2000) on the stock of *G. paradoxa* in the Nun and Cross Rivers of Nigeria (Table II).

The low growth rate and growth performance recorded in this study could be attributed to the negative effects of habitat modification as a result of damming the Volta River. Damming has affected the nutrient dynamics and flow regime of the Volta River, resulting in the formation of a sand bar at the estuary and the growth of aquatic weeds on the clam beds (Attipoe and Amoah, 1989). The data of Kwei (1965) and (Vakily, 1992) were collected just after the completion of the dam at Akosombo with little or no effects of its impact on the physical and chemical characteristics of the river and thus, on the clams' habitat. According to King (2000), the reported maximum sizes and ages of *G. paradoxa* are highly variable attributes within its geographic distribution. The different populations of *G. paradoxa* therefore, display disparities in growth and longevity owing to differences in environmental factors such as substratum type, food supply, population density and physico-chemical factors of the habitat (King, 2000).

The slight differences in L_∞, K and Ǿ between Ada and Aveglo could be attributed to the observed habitat characteristics of the two sites. Ada is shallow with depths between 0.60–2.0 m, there are patches with dense aquatic weeds and the sediment is mainly fine sand with patches of mud while Aveglo, on the other hand, is deeper with depths between 4.0–6.0 m and the sediment is predominantly coarse sand to gravelly. The shallowness of Ada allows sunlight to penetrate to the bottom of the water column thus, increasing the benthic primary productivity of the area compared to Aveglo which is deeper. These habitat differences could possibly explain the better growth performance observed at Ada. Despite these minor differences the lifespan of *G. paradoxa* in the Volta River (8–12 years) is within that of its marine venerid relatives.

> RECRUITMENT

Recruitment has been described as a continuous phenomenon for tropical species because of the relatively stable and elevated water temperatures allowing year round breeding (Qasim, 1973; Weber, 1976). The recruitment pattern suggests that *G. paradoxa* exhibits year-round recruitment with a single pulse over an extended period (October–March) in the Volta River. Although, the movement of cohorts were observed in the monthly length-frequency distribution of samples from the fishermen catch it only gives information about recruitment into the fishery after the clams were almost 2-years old. Clam fishers do not harvest clams less than 20 mm therefore the recruitment pattern was best determined from grab samples which captured smaller clams. The smallest clams (5 mm) were detected in grab samples between November and March. Aligning this observation with the growth curves on the length-frequency distribution of grab samples (Figure 3) suggests that recruitment in *G. paradoxa* occurs between October and March.

Other studies on *G. paradoxa* did not report on its recruitment pattern; however, studies elsewhere on tropical bivalves are in agreement with this finding. Al-Barwani *et al.* (2007) reported a continuous year-round recruitment pattern with a major peak between July-August for *Perna viridis* in the coastal waters of Malacca, Malaysia. *Modiolus metcalfei* from Panguil Bay, Southern Philippines, has a unimodal recruitment pattern with the peak of recruitment between May–July (Tumanda Jr. *et al.*, 1997). Similarly, Mancera and Mendo (1996) reported that the recruitment pattern of *Crassostrea rhizophorae* from the Cienaga Grande de Santa Marta, Colombia, was continuous with a single peak in October–November.

> MORTALITY RATES

Mortality rates at the two sites were slightly different with Ada having a higher total mortality (0.82 $year^{-1}$) compared with Aveglo (0.65 $year^{-1}$) Table I. The difference could be attributed to the higher fishing mortality at Ada (0.47 $year^{-1}$) compared with 0.21 $year^{-1}$ at Aveglo. Clams at Ada are, therefore, highly exploited (0.57) compared with Aveglo (0.32). This result is supported by what actually happens in the fishery. Ada is shallow (0.60–2.0 m) and therefore attracts a high number (three times) of fishers both manual and Hookah divers than Aveglo. This is in agreement with the findings of Moses (1990) who studied the stock of *G. paradoxa* in the Cross River, Nigeria. The mortality values obtained in this study are in agreement with the findings of Moses (1990), who studied the stock of *G. paradoxa* in the Cross River, Nigeria. The estimated mortality coefficients of his study were: total mortality 0.82 $year^{-1}$; fishing mortality 0.50 $year^{-1}$; and natural mortality 0.32 $year^{-1}$. The exploitation level was 0.61 and Moses (1990) concluded that the stock was overfished and required immediate imposition of landing size restriction (<60 mm) and the culture of young clams to prevent the collapse of the fishery. King (2000) obtained similar estimates for the stock of *G. paradoxa* in the Nun River, Nigeria. The estimated coefficients were 0.80, 0.50 and 0.30 $year^{-1}$ for total mortality, fishing mortality and natural mortality, respectively. The conclusion was that the stock was overfished owing to the high exploitation level of 0.62. Etim and Brey (1994) however, obtained higher mortality values for the stock of *G. paradoxa* in the Cross River compared with Moses (1990). The estimated total fishing and natural mortality coefficients were 2.03, 1.10 and 0.93 $year^{-1}$, respectively. The exploitation level was 0.45 which is close to the optimum exploitation level of 0.50. According to Gulland (1965), the yield is optimised when $F = M$; thus when E is equal to 0.5. The stock of *G. paradoxa* in the Volta River is overfished as the stocks in the Nigerian rivers and requires the imposition of minimum landing size restrictions in order to salvage the fishery.

> LENGTH-WEIGHT RELATIONSHIPS

Periodic length-weight data (Rueda and Urban, 1998) and linear regression analysis on log-transformed data for a standard animal has been used to study the reproductive cycle of bivalves. An abrupt decrease in weight between successive months may indicate a spawning event while an increase over a longer period could be interpreted as the developing phase before the spawning season. The shell-free dry weight cycle of a 40 mm standard *G. paradoxa* showed a trend of building gonad tissue prior to the start of spawning activity which occurs between July and October in the Volta estuary. The slight drop in tissue weight during June-July indicates the start of spawning in the clam with August–September being the peak of spawning in *G. paradoxa*. Growth in *G. paradoxa* is allometric as the exponent of the regression equation was <3 ($\beta \neq 3$) for almost the entire study period. This is in agreement with the vast majority of instances where β, in the length-weight relationships has been found to be not equal to 3 (Gaspar *et al.*, 2002).

In conclusion, the growth rate and performance appears to be declining as a result of habitat modification owing to the negative effects of damming the river. The Volta River stock of *G. paradoxa* is overfished and requires immediate action to conserve this important and valuable fishery. This can be achieved by implementing a minimum landing size restriction and intensifying the culture of smaller clams.

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REFERENCES

Abohweyere P.O. and Falaye E.A., 2008. Population parameters of *Macrobrachium vollenhovenii* in the Lagos-Lekki lagoon system, Nigeria. *Journal of Fisheries International*, *3*, 27–33.

Al-Barwani S.M., Arshad A., Nurul Amin S.M., Japar S.B., Siraj S.S. and Yap C.K., 2007. Population dynamics of the green mussel *Perna viridis* from the high spat-fall coastal water of Malacca, Peninsular Malaysia. *Fish. Res.*, 147–152.

Allen K.R., 1938. Some observations on the biology of the trout (*Salmo trutta*) in Windermere. *J. Anim. Ecol. 7*, 333–349.

Amador M.K., 1997. A review of the Volta Clam, *Egeria radiata* fishery in the Lower Volta, BSc thesis, Kwame Nkrumah University of Science and Technology, Ghana.

Attipoe F.Y.K. and Amoah C., 1989. Ecological and economic problems associated with the Volta Dam: the case of the Egeria and Macrobrachium fisheries of the lower Volta, Paper presented at the Ghana National Seminar on Inland Fisheries and Aquaculture, 1989, 20 p.

Dickson B.K. and Benneh G., 1977. A new geography of Ghana. Longman Group Ltd., London, 173 p.

Etim L. and Brey T., 1994. Growth, productivity, and significance for fishery of the bivalve *Egeria radiata* (Donacidae) in the Cross River, Nigeria. *Archive of Fishery and Marine Research*, *42*, 63–75.

Gaspar M.B., Pereira A.M., Vasconecelos P. and Monteiro C.C., 2004. Age and growth of *Chamelea gallina* from the Algarve coast (Southern Portugal): influence of seawater temperature and gametogenic cycle on growth rate. *J. Mollus. Stud.*, *70*, 371–377.

Gaspar M.B., Santos M.N., Vasconcelos P. and Monteiro C.C., 2002. Shell morphometric relationships of the most common bivalve species (Mollusca: Bivalvia) of the Algarve coast (southern Portugal). *Hydrobiologia*, *477*, 73–80.

Gulland J.A., 1965. Estimation of mortality rates, Annex to Arctic Fisheries Working Group Report ICES C.M./1965/D:3 (Mimeo), Reprinted as: Cushing P.H. (ed.), Key Papers on Fish Populations, IRL Press, Oxford, 231–241.

King R.P., 2000. Poulation structure, growth performance and mortality rates of the freshwater clam *Galatea paradoxa* (Born, 1778) in Nun River, Nigeria. *Archive of Fishery and Marine Research*, *48*, 21–30.

King R.P., Egwali E.C. and Nkanta N.A., 1992. Population dynamics of the freshwater clam *Galatea paradoxa* (Donacidae) in the cross River, Nigeria. *Fishbyte, 9*, 34–36.

Kwei E.A., 1965. The spawning and growth of the Volta oyster *Egeria radiata* (L.). *Ghana Journal of Science*, *5*, 150–160.

Le Cren E.D., 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *J. Anim. Ecol.*, 20, 201–219.

Mancera E. and Mendo J., 1996. Population dynamics of the oyster *Crassostrea rhizophorae* from the Cienaga Grande de Santa Marta, Colombia. *Fish. Res.*, 26, 139–148.

Martin W.R., 1949. The mechanics of environmental control of body form in fishes. *University Toronto Student Biology*, *58 (Publ. Ont. Fish. Res. Lab. 70)*, 1–91.

Moses S.B., 1990. Growth, biomass, mortality, production and potential yield of the West African clam, *Egeria radiata*(Lamarck) (Lamellibranchia, Donacidae) in the Cross River system, Nigeria. *Hydrobiolobia*, *196*, 1–15.

Moura P., Gaspar M.B. and Monteiro C.C., 2009. Age determination and growth rate of a *Callista chione* population from the southwestern coast of Portugal. *Aquat. Biol.*, *5*, 97–106.

Munro J.L. and Pauly D., 1983. A simple method for comparing the growth of fishes and invertebrates. *Fishbyte*, *1*, 5–6.

Nassar A.K.V., 1999. Length-weight relationships of tuna batifish from the Lakshadweep Island, India. *Naga, ICLARM Quarterly*, *22*, 42–44.

Pauly D., 1979. Gill size and temperature as governing factors in fish growth: a generalization of von Bertalanffy's growth formula. *Ber. Inst. Meereskd Christian-Albrechts University, Kiel*, *63*, 1–156.

Pauly D., 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *J. Cons. Int. Explor. Mer.*, *39*, 175–192.

Pauly D., 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. *ICLARM Contrib.*, *143*, 325.

Pauly D. and Caddy J.F., 1985. A modification of Bhattacharya's method for the analysis of mixtures of normal distributions, FAO Fisheries Circular, FAO, Rome, 781, 16 p.

Petraitis P.S., 1991. Recruitment of the mussel *Mytilus edulis* L. on sheltered and exposed shores in Maine, USA. *J. Exp. Mar. Biol. Ecol.*, *147*, 65–80.

Purchon R.D., 1963. A note on the biology of *Egeria radiata* Lam. (Bivalvia, Donacidae). *Proceedings of the Malacological Society of London, 35,* 251–271.

Qasim S.Z., 1973. Some implications of the problem of age and growth in Marine fishes from Indian waters. *Indian J. Fish*, *20*, 351–371.

Rainer S.F. and Wadley V.A., 1991. Abundance, growth and production of the bivalve *Solemya* sp., a food source for juvenile rock lobsters in a seagrass community in Western Australia. *J. Mar. Biol. Ecol.*, 152, 201–233.

Ricker W.E., 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.*, 191, 382.

Roper D.S., Pridmore R.D. and Thrush S.F., 1992. Recruitment to the macrobenthos of *Macomona liliana* (Bivalvia: Tellinidae) in Manukau Harbour, New Zealand. *N. Z. J. Mar. Freshwater Res.*, *26*, 385–392.

Rueda M. and Urban H.-J., 1998. Population dynamics and fishery of the freshwater clam *Polymesoda solida* (Corbiculidae) in Cienaga Poza Verde, Salamanca Island, Colombian Carribbean. *Fish. Res.*, *39*, 75–86.

Strasser M., Hertlein A. and Reise K., 2001. Differential recruitment of bivalve species in the northern Wadden Sea after the severe winter of 1995/96 and of subsequent milder winters. *Helgoland Marine Research*, *55*, 182–189.

Tumanda Jr. M.I., Yap H.T., McManus L.T., Ingles J.A. and Lopez M.G., 1997. Growth, mortality and recruitment of the brown mussel, *Modiolus metcalfei* (Bivalvia: Mytilacea), in panguil Bay, Southern Philippines. *Aquaculture*, *154*, 233–245.

Urban H.-J., 1998. Description and management of the clam fishery (*Gari solida*, Psammobiidae) from Bahia Independencia, Peru (14 °S). *Fish. Res.*, *35*, 199–207.

Vakily J.M., 1992. Determination and comparison of growth in bivalves, with emphasis on the tropics and Thailand, ICLARM Technical Report, 36, 125 p.

Weber W., 1976. The influence of hydrographic factors on the spawning time of tropical fish. *In*: Tiews K. (ed.), Fisheries Resources and their Management in Southeast Asia, 269–281.