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Age Determination and Growth Rate of the Freshwater Clam *Galatea Paradoxa* (Born 1778) from the Volta River Estuary, Ghana

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Abstract The age and growth of the freshwater clam *Galatea paradoxa* from the Volta River estuary, Ghana was estimated during a two-year study using surface growth rings, length-frequency distributions and tagging recapture experiment. Mean lengths at ages 1 to 8 years were 19.4, 28.4, 37.1, 44.1, 49.5, 55.5, 65.6 and 73.1 mm, respectively. The von Bertalanffy growth curves obtained by three the methods were: $L_t = 80.4(1\text{-}e^{-0.17t})$, $L_t = 105.7(1\text{-}e^{-0.14t})$ and $L_t = 104.5(1\text{-}e^{-0.16t})$ for surface rings, length-frequency distributions and tagging recapture respectively. All the age determination methods were successful in estimating the age of *G. paradoxa* indicating that surface ring counting is an appropriate and reasonably accurate method for simple and rapid age estimation in this species. The estimated growth curves obtained from surface rings, length-frequency distributions and the tagging-recapture experiment revealed that the methods provided similar estimates of growth rates.

Keywords: *surface rings, tagging-recapture, length-frequency distributions, growth curves*

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1. Introduction

The determination of the age and growth rate of bivalves is fundamental for studies on population dynamics [1,2]. Growth rate in bivalves is influenced by several factors including habitat type, environmental variables as well as geographical latitude [3,4]. While some freshwater bivalves are short-lived with their ages ranging from a few months to a maximum of four years in *Pisidium* [5], others such as *Margaritifera* are long-lived with specimens over 100 years old being reported [6].

Geographical latitude has a profound effect on the growth rate and age of bivalves [4]. For example bivalves occupying warmer waters tend to have faster growth rates compared with populations in cooler waters, e.g. *Callista chione* in the Mediterranean [7] had a growth rate of 0.24 year^{-1} compared with a similar population in the Atlantic ocean with growth rates between 0.15 and 0.18 year^{-1}[4]. Temperate bivalves grow more rapidly in spring and summer with a decreased rate or no growth in autumn and winter [2,4]. Among arctic bivalves, *Arctica islandica* does not grow during the cold winter for 6 – 8 months. Instead, growth is restricted to periods when temperature ranges between 0° and 16°C in the spring and summer [8]. *Arctica islandica* is slow growing and long-lived, the maximum recorded age is close to 500 years, and individuals over 100 years old are abundant in the North Atlantic [9,10].

The type of habitat inhabited by a bivalve tends to influence its growth rate hence the maximum age attainable. Several authors have documented the effects of wave action on growth rates [11,12]. The effect of wave action may be species-specific, as an increase in wave exposure may lead to either an increased [13], or decreased growth rate [14,15]. [16] found that *Perna perna* populations on a wave exposed shore had a faster growth rate (0.64 year^{-1}) compared with similar populations on a sheltered shore (0.31 year^{-1}). Longevity, however, was lower in the exposed population (2.59 years) than the sheltered population (6.72 years) as growth rate and longevity are inversely related [17,18,19].

A number of methods have been used to estimate the age and growth rate of bivalve populations, including counting the annual growth rings visible on the shell surface or in the microstructure of polished and etched shells [20], length-frequency distribution analysis [21,22] and tagging and recapture experiments [23,24]. Each of these methods has its advantages and disadvantages. While certain techniques may be more appropriate for one species than another, the best approach is to employ a range of methods in order to provide a more robust estimate than using one method alone [25].

The freshwater clam *Galatea paradoxa* (Born 1778) is a bivalve mollusc belonging to the Order, Veneroidea, Superfamily, Tellinoidea and Family, Donacidae [26]. It is endemic to the West African sub-region with a range that extends from the Gulf of Guinea to the Congo [27]. *G. paradoxa* is the basis of an artisanal clam fishery at the Volta River estuary providing a source of employment and an affordable protein source to riparian human communities and beyond [28]. Furthermore, the clam shell has a number of important uses notably as a source of calcium in poultry feed and in lime manufacturing. Despite its commercial importance there is limited information on the population dynamics of *G. paradoxa*. This information is crucial for estimating sustainable exploitation levels and possible aquaculture development. The objective of this study was to determine the age and growth rate of a population of *G. paradoxa* in the Volta River, Ghana, using three methods; shell surface rings, length frequency distributions and tagging and recapture experiments.

2. Materials and Methods

2.1. Study Area

The study was conducted at Ada and Aveglo in the estuary of the Volta River, south-eastern Ghana (Figure 1).

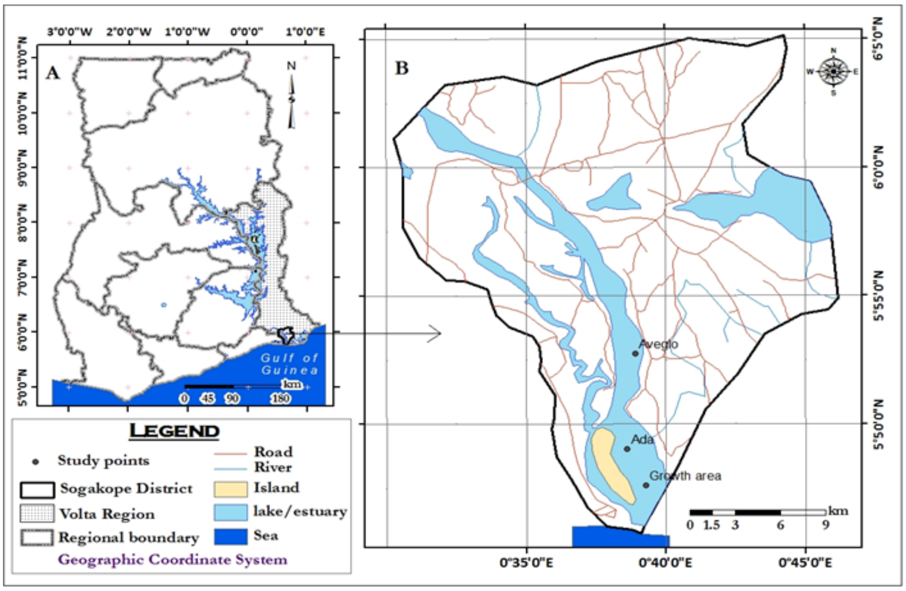

Figure 1. Map of Ghana (A) showing the Sogakope District (B) sampling areas (Ada and Aveglo) and Growth area site of a growth trial in [29] in the Volta estuary

The Volta River estuary lies within the coastal savannah zone with an annual rainfall of 750–1,250mm [30]. The estuary is about 1.2km wide at the mouth, but owing 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 (100km) and further downstream at Kpong (75km) from the mouth of the river. The dams, in addition to a sandbar at the mouth of the river, influence the seawater and freshwater dynamics of the estuary. Ada (5° 49′ 10″ N, 0° 38′ 38″ E), was located 10 km from the mouth of the river and represents the seaward (0.03 and 1.5 psu) limit of *G. paradoxa* distribution in the Volta River. The area is generally shallow with depths between 0.60 and 2.0m. There are patches of dense aquatic weeds (such as *Ceratophyllum sp*.) owing to the shallowness of the area. The sediment at Ada consists mainly of fine sand with patches of mud. Aveglo (5° 52′ 54″ N, 0° 38′55″ E), was situated 15 km from the mouth of the river. It is predominantly freshwater (0.03 psu) and deeper with depths between 4.0 - 6.0m. The sediment is coarse sand to gravel. Temperature at the two sites was relatively constant throughout the study period and varied narrowly between 27.3 and 29.6°C with a mean and standard deviation of 28.6 ± 0.8°C.

2.2. Clam Sampling

Clam samples were collected from clam fishers monthly between March 2008 and February 2010. 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 20mm are not picked by fishers), two grab samples (grab size equivalent to $0.1m^2$) were collected monthly from each site. Samples were transported in insulated boxes with ample river water which was refreshed every 12 hours to the wet laboratory within 24 hours. 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) (0.01mm). A stainless steel knife was used to open the shell and a scalpel blade carefully used to remove the flesh of each clam from the shell. The shells were air-dried, and subsequently used in age determination. Age and growth rate was determined by three methods: counting of shell surface rings, length frequency distributions and tagging-recapture experiments.

2.3. Surface Rings

Four hundred and eighty samples collected between March and December 2008 were aged by counting of surface rings. About fifty individuals of varied sizes were aged monthly and the age-length data generated over the period pooled in the computation of the age-length range, mean length-at-age and standard deviations (Table 1). Shell surface rings were not distinct for the shells to be aged immediately after sampling, however, after air drying at room temperature for a period (at least a week) the rings were discrete for aging. Size-classes of clams with shell lengths corresponding to the ages of the cohorts were identified and used as a guide in the ageing process.

2.4. Length-Frequency Distributions

Cohort analysis follows the progression of a group from the time it is recruited into the fishery until it disappears. The Bhattacharya method [31] available in the fish-stock assessment tool FISAT II [32] is commonly used because it needs only length-frequency data. A total of 4,905 and 5,149 samples were analysed from Ada and Aveglo, respectively. The shell length data obtained from the two sampling sites was grouped into shell length classes at 2mm intervals [33] and subsequently analysed using routines in FISAT II. Preliminary estimates of L_∞ and Z/k were obtained through the Powell-Wetherall plot [34,35,36].The final asymptotic length (L_∞) and the growth coefficient (k) were estimated by fixing the initial L_∞ from the Powell-Wetherall plot into the Shepherd method [37] in FiSAT II to estimate the asymptotic length (L_∞) and growth coefficient (k) of the von Bertalanffy Growth Function (VBGF) [38]: $L_t = L_\infty (1-e^{-k(t-t_0)})$, where L_∞ is the asymptotic length (mm), k is the growth coefficient (year^{-1}), t is the age (year) and t_0 is the theoretical age of the animal at a length equal to zero. The (t_0) was estimated by inverse VBGF: $t_0 = t + 1/k*\text{Ln}(1-L_t/L_\infty)$.

2.5. Tagging-Recapture Experiment

A tagging-recapture experiment was conducted at Ada from June 2008 to May 2009 to monitor the growth of individual clams at the Volta estuary and to validate the age and growth rate estimates from surface rings and the length-frequency distributions. An additional sample of 600 individuals was collected from the clam fishers at the start of the experiment in June 2008. Clams were categorised into three size classes corresponding to the three dominant size classes in the population; small (20 - 30 mm), medium (31 - 40 mm) and large (> 40 mm). Nine wooden boxes (50 × 40 × 15 cm) werefilled with the sandy sediment found at the point of occurrence of the clams. Fifty clams (density in the boxes corresponded to minimum density obtained from the natural clam beds at the estuary) were randomly selected, individually marked by etching a specific number on one side of the shell and assigned to one of the boxes. Each size class was replicated three times. The boxes were gently lowered to the bottom of the river. The shell length was taken at the start of the experiment and every two months thereafter. The data from this experiment was treated as growth increment data and analysed by the Munro routine [39] in FiSAT II to estimate the L_∞ which was then seeded in the Gulland and Holt plot [40] to compute k.

3. Results

3.1. Surface Rings

Table 1 presents data on the mean shell lengths and standard deviations (SD) obtained for each annual age class based on the analysis of shell surface rings. The length estimate for a one year old *G. paradoxa* was 19.4 ± 4.5mm while those for the second and third year individuals were 28.4 ± 7.3 and 37.1 ± 5.9 mm, respectively (Table 1).

Table 1. Mean length-at-age and the respective standard deviations (mm) along with maximum and minimum length of *G. paradoxa* obtained from shell surface rings

Age (years)	N	Mean length ± SD (mm)	Size (mm)	
			Minimum	Maximum
1	14	19.4 ± 4.5	16.2	22.6
2	108	28.4 ± 7.3	23.3	33.6
3	94	37.1 ± 5.9	33.0	41.3
4	60	44.1 ± 7.6	41.2	49.4
5	51	49.3 ± 3.9	46.6	53.3
6	30	55.5 ± 5.3	51.5	58.0
7	18	65.6 ± 6.0	61.0	67.7
8	5	73.3 ± 1.8	69.9	73.4

N = sample size

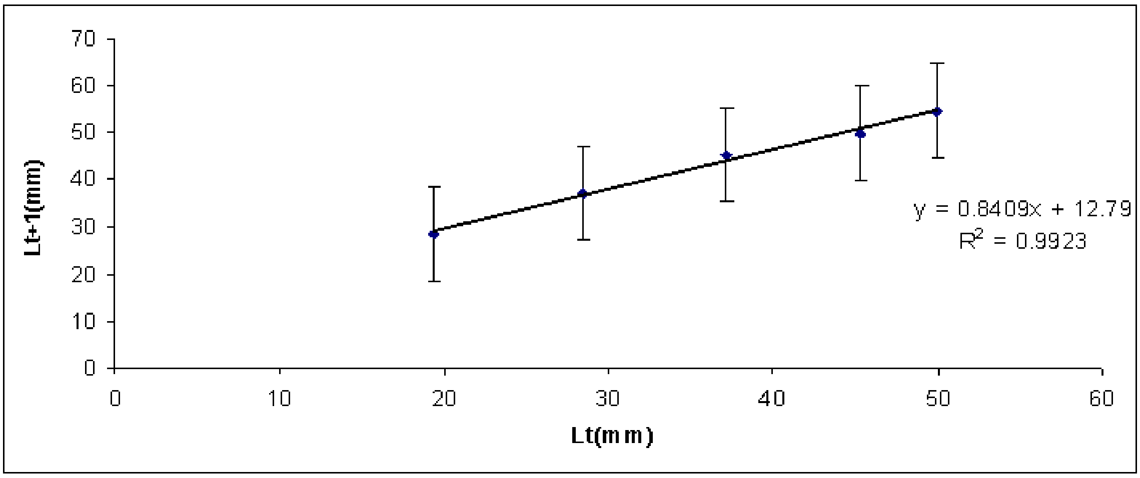

Figure 2. Ford –Walford Plot, using the mean length and standard deviation of *G. paradoxa* individuals (L_{t+1}) against L_t

The length-at-age data generated from surface rings (Table 1) was re-arranged to the form $L_{t+1} = a + bL_t$ where L_{t+1} and L_t pertain to lengths separated by a constant time interval (1 year), and a and b are constants of the Ford-Walford plot [41]. The seventh and eighth year old clams were not properly aged due to their low numbers in the population as well as the difficulty in discriminating between the rings at their shell margins. Consequently, the Ford-Walford plot (Figure 2) was based on the age-length data of the first six years. From the Ford-Walford equation of y = 0.841x + 12.79, where a = 12.79 and b = 0.841, the asymptotic length (L_∞) was calculated as [a / (1-b)] and the growth coefficient (k) = -$\log_e$b. The estimated asymptotic length (L_∞) and growth coefficient (k) were 80.44 mm and 0.17 year^{-1}, respectively.

Figure 3 is a plot of shell length against the age of individual clams determined from the counting of surface rings. From the regression equation y = 23.46Ln (x) +12.3 and that of a Ford-Walford plot (Figure 2), the length of a 1-year-old clam from surface rings ranged between 12.3 - 12.8mm.

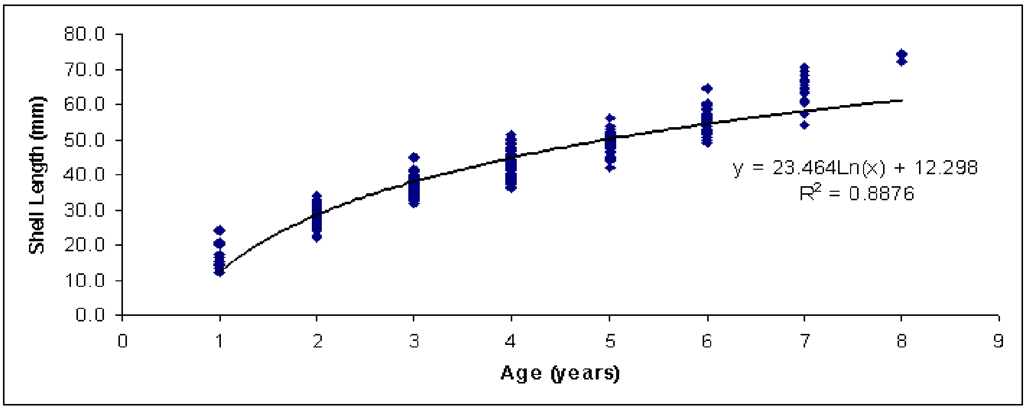

Figure 3. Plot of shell length against age of individual clams determined from the counting of shell surface rings

3.2. Length Frequency Distributions

The Bhattacharya's method allowed the separation of eight cohorts. The mean length at age values and standard deviations for the first, second and sixth years were 15.8 ± 3.0, 26.4 ± 4.5 and 55.1 ± 8.1mm, respectively (Table 2). The L_∞ and k estimate for Ada was 105.7 mm and 0.14year^{-1} while that for Aveglo was 84.4 mm and 0.18year^{-1}.

The largest live specimen found at the estuary during the study period was 102 mm. Therefore, the L_∞ and k estimate of 105.7 mm and 0.14year^{-1}from Ada provided a more realistic estimate compared with 84.4 mm 0.18year^{-1} from Aveglo. From the reverse VBGF, t_0 for Ada and Aveglo were -0.125 and -0.119, respectively, allowing growth curves to be computed and superimposed on the length-frequency data displayed in Figure 4.

3.3. Tagging-Recapture Experiment

Growth in length was about 1-2 mm per month between January and June for individuals during the tagging experiment. This, however, slowed down to about 1mm per month between September and December during the spawning season and the period when the clams were spent. The Munro plot generated an initial L_∞ estimate of 69.1mm which when seeded into the Gulland and Holt plot, gave a k estimate of 0.46year^{-1}. The estimated L_∞ of 69.1mm by the Munro plot was lower than the largest specimen (102mm) observed at the estuary hence the k value (0.46year^{-1}) was overestimated. A more realistic estimate of L_∞ and k was provided by plotting the starting lengths against the end lengths of individuals in the tagging-recapture experiment at the Volta estuary from June 2008 to May 2009 (Figure 5). Generally, growth was faster between March and June at a rate of 0.21 year^{-1} and slower between August and January at a rate of 0.16 year^{-1}. The estimated L_∞ and k were 104.5mm and 0.16year^{-1} from the equation of the linear regression in Figure 4.

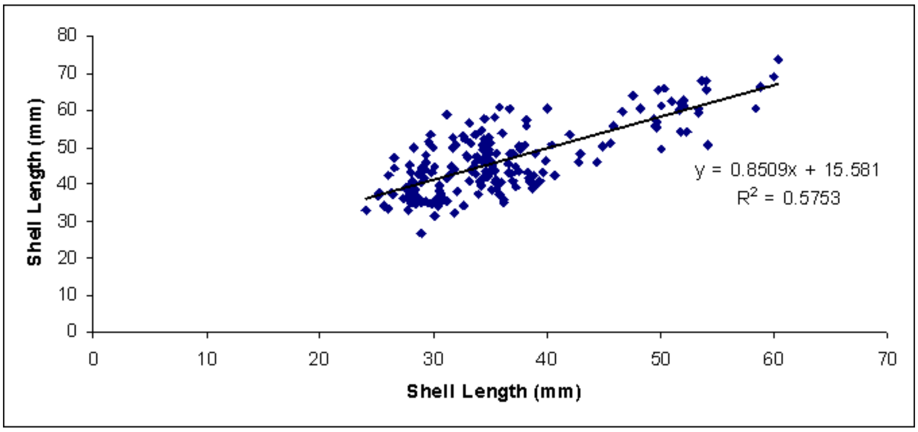

Figure 4. Plot of starting length against end length of individual clams in the tagging experiment at the Volta estuary from June 2008 to May 2009. Included is the regression equation used to calculate L_∞ and k

A comparison of the age-at-length data derived from the regression coefficients from the Ford-Walford plot based on surface rings (Figure 2) and the tagging-recapture experiment (Figure 4) show that the length of 1-year-old *G. paradoxa* ranges between 12.3 - 15.6 mm.

3.4. Von Bertalanffy Growth Curves

The age-length estimates obtained from the three methods were fitted to the VBGF in order to describe the growth of *G. paradoxa* as shown below.

1. Surface rings: $L_t = 80.4(1-e^{-0.17t})$
2. Length-frequency distributions: $L_t = 105.7(1-e^{-0.14t})$
3. Tagging recapture: $L_t = 104.5(1-e^{-0.16t})$

Data on the corresponding age-length estimates for the three methods is presented in Table 2.

The age-at-length data from the three methods were subjected to one-way analysis of variance followed by Tukey's multiple comparison test to ascertain any differences between methods ($p < 0.05$). From Table 2, there was no difference in the age-at-length data for the three methods from ages 1 to 4 ($p > 0.05$). However, for ages 5 to 7 the mean length-at-age estimates obtained from the tagging experiment were higher ($p < 0.02$) than the other methods (Table 2). Additionally, the L_∞ was lower for surface rings due to the lack of older clams. The graphical representation of the growth equations are shown in Figure 5.

The growth rate estimate (k) from the tagging-recapture experiment ($k = 0.16year^{-1}$) was similar to that from the length-frequency distributions ($k = 0.14year^{-1}$) and surface rings ($k = 0.17year^{-1}$). The asymptotic length L_∞ was lower when the VBGF parameters were estimated using data from surface rings (80.4mm) than from length-frequency distributions (105.7mm) and the tagging-recapture experiments (104.5mm).

Table 2 Mean length-at-age and standard deviations (mm) of *G. paradoxa* obtained from surface rings, length-frequency distributions and tagging-recapture experiment

Age(years)	Method		
	Surface rings	Length-frequency	Tagging-recapture
1	19.4 ± 4.5^a	15.8 ± 3.9^a	15.4 ± 1.6^a
2	28.4 ± 7.3^a	26.4 ± 4.5^a	28.6 ± 2.1^a
3	37.1 ± 5.9^a	35.1 ± 7.6^a	39.8 ± 2.9^a
4	44.1 ± 7.6^a	43.6 ± 6.7^a	49.4 ± 3.5^a
5	49.3 ± 3.9^a	49.9 ± 7.8^a	57.5 ± 3.3^b
6	55.5 ± 5.3^a	55.1 ± 8.1^a	64.5 ± 4.4^b
7	65.6 ± 6.0^{ab}	61.3 ± 6.5^a	70.4 ± 2.8^b
8	73.3 ± 1.8^a	69.1 ± 7.5^a	75.5 ± 1.5^a
L_∞	80.4	105.7	104.5

[a,b] Mean values in the same row with different superscripts are significantly different ($p < 0.05$)

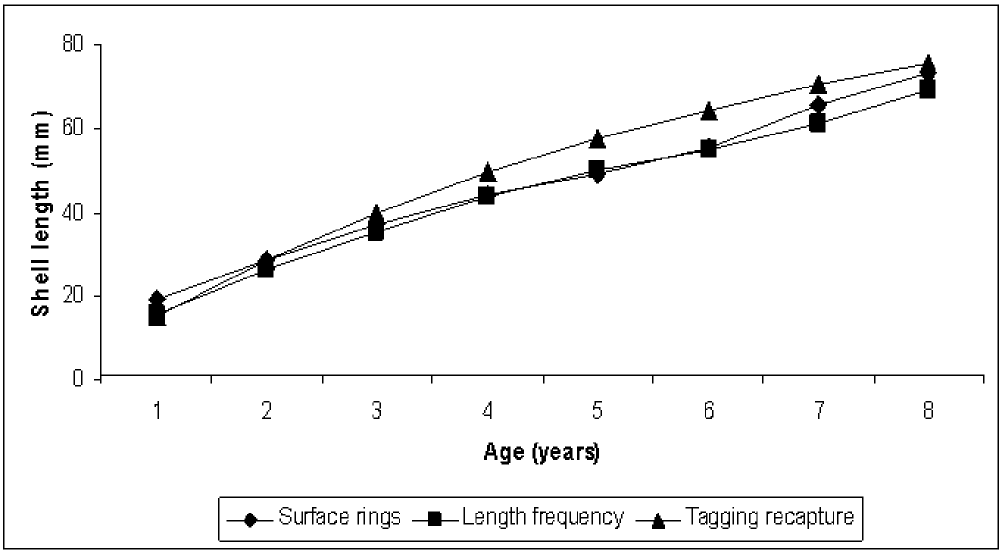

Figure 5. von Bertalanffy growth curves fitted using the three methods: surface rings, tagging-recapture and length frequency distributions

4. Discussion

The results showed that all the three methods could be successfully used to estimate the age of specimens of *G. paradoxa*. The examination of surface rings requires the drying of the shells for a period (at least a week at room temperature) for the rings to be clearly distinct for aging. A larger sample covering various sizes ensured that the mean and standard deviation was representative of the different age classes in the population. The most recently deposited surface rings in older specimens were difficult to discriminate due to their closeness as a result of reduced shell growth. The low numbers of older clams encountered in this study made it difficult properly age seven and eight year old clams. This method is however, relatively simple and independent of shell colouration or shape. The establishment of representative size-classes as a confirmation in allotting clams to their respective age classes was instrumental in minimising error due to the misidentification of disturbance rings.

A comparison of the age-length estimates obtained from the three methods showed that the estimated ages were similar for the three methods (Table 2 and Figure 5). This indicates that, surface ring counting is an appropriate and reasonably accurate method for simple and rapid age estimation of *G. paradoxa*. This is in agreement with the finding of [4] who reported that age estimates from the counting of surface rings was appropriate for *Callista chione* up to 10 years old. For older specimens, age was more accurately estimated from the analysis of growth lines in the cross section of shells. The estimated growth curves obtained from surface rings, length-frequency distributions and the tagging-recapture experiment revealed that the methods provided similar estimates of growth rates until the fourth year of life (50mm). Afterwards the age-length estimates were slightly higher ($p < 0.02$) in the tagging-recapture experiment than the other methods (Table 2).

G. paradoxa is a tropical bivalve that lives in an environment with a relatively constant temperature [27]. Spawning in *G. paradoxa* is a single annual event occurring over an extended period between June-July and October [42] which coincide with the rainy/flooding season in southern Ghana. The spawning activity combined with a higher suspended particulate matter in the flood water, low food availability and reduced growth rate might possibly cause the deposition of annual rings at this time [51]. This observation is in agreement with the findings of [43] who observed that *Chione cortezi*, *C. fluctifraga* and *C. californiensis* at the Colorado River mouth grew more slowly when large amounts of freshwater reached the Gulf of California. The deposition of annual rings as a result of spawning activity has been observed in other studies [44,45].

The age-length estimates obtained in this study are in contrast to the findings of [46] who estimated the ages of a population of *G. paradoxa* from the Nun River, Nigeria by counting surface rings. The ages estimated from his study had year 1 to 7 corresponding to mean shell lengths of 53, 64, 72, 79, 83, 89 and 91 mm, respectively. The samples for King's study were obtained from fishermen's catch which is biased towards larger clams and excluded clams less than 40 mm in length. The age estimates were therefore based on the smallest length class in the commercial catch and not on the entire population hence, his starting length corresponded to clams that were 4-5 years old as found in this study (Table 2). By assigning the starting length of 53 mm to a 5-year old clam, as shown in Table 2, the age-length estimates of [46] map directly onto that derived in this study. In order to avoid this bias, samples from fishermen catch were augmented with grab samples which captured the smallest clams not normally harvested by fishermen. The age-shell length estimates in this study are therefore more robust compared to previous studies that were solely based on samples from commercial catch [24,27,46]. The L_∞ for *G. paradoxa* at the Volta estuary (105.7 mm) is very close to the 107.4 mm found by [48] who re-analysed data collected by [47] at Tefle on the Volta River just after the construction of the Akosombo dam. Similarly, it is close to the 102 mm reported by [46] on the stock of *G. paradoxa* in the Nun River, Nigeria. It is, however, lower than the 145.1 mm obtained by [48] from the re-analysed data collected by [47] at an upstream station (Akosombo) on the Volta River and the 111.0 mm obtained by [46] on the Cross River stock of *G. paradoxa*. The L_∞ estimate in this study is higher than that of [24,27] for *G. paradoxa* stocks in the Cross River, Nigeria. The growth coefficient (k) estimate of 0.14 - 0.18 in this study is the lowest ever recorded in studies on *G. paradoxa*. The low growth rate 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 [49]. The data of [47] and [48] 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 [46], 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 substrate type, food supply, population density and physico-chemical factors of the habitat [46]. It is therefore imperative that in ageing any population of *G. paradoxa*, a combination of methods are applied to validate the age estimates as well as the accuracy of the methods. The differences in L_∞ and k between Ada and Aveglo could be attributed to habitat characteristics, Ada is shallow while Aveglo is deeper (refer to study area). 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 with Aveglo which is deeper. These habitat differences could explain the better growth performance observed at Ada compared with Aveglo. Variations in growth patterns owing to site characteristics as observed in this study had a significant effect on the growth curves thus, on the validity of the age determining method applied. The slightly higher length estimates from the tagging recapture experiment especially for ages 5-7 could be attributed to the site characteristics at Ada where the study was conducted. In comparison, the length estimates from the other methods were based on samples collected from the two sites and therefore, reflect more accurately the growth pattern of *G. paradoxa* at the Volta estuary. Despite these differences the lifespan of *G. paradoxa* in the Volta River (8-12 years) is comparable with its marine venerid relatives.

Artisanal clam fishing plays an important role in the socioeconomic life of inhabitants of the Volta estuary. Commercial extinction of *G. paradoxa* is imminent in the estuary as a result of habitat alteration and overfishing. There is the need to put in place a sustainable harvesting strategy that targets medium to large size clams against the current situation where the catch is dominated by smaller clams. In order to prevent the extinction of the clam and to ensure that the communities continue to benefit from the fishery, it is recommended that a minimum landing size of 50 mm which corresponds to the mean size of a 4 year old clam should be imposed. The minimum size restriction should be done in consultation with the chiefs and traditional authorities in the communities who have managed the fishery to date. The marketing of clams below the minimum landing size should be abolished and enforced by the traditional authorities. Secondly, the farming of smaller size clams which is a traditional activity at the estuary should be encouraged so that fishers who harvest undersize clams can seed them on their culture plots.

The suitability of *G. paradoxa* as a potential aquaculture species has been demonstrated by growth trials in the

Volta estuary [49,50] and this study shows that the species has an annual growth rate of ≈ 10 mm. It is a species that could easily be integrated into the local tilapia cage culture, since they do not require external feed and can clean the environment of excess phytoplankton or suspended particulate matter through filter feeding. Integration into the existing fish farming systems will augment the income of fish farmers, especially pen culturists in the Volta River as it will utilize the same space and water resources. Large tracts of suitable areas exist in the previous range of the species (up to 100 km) from the mouth of the river. Moreover, the communities around the estuary are already practicing a form of culture which relies on juveniles from the fishery.

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