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Growth, productivity, and significance for fishery of the bivalve *Egeria radiata* (Donacidae) in the Cross River, Nigeria*

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Abstract

The population dynamics of the clam *Egeria radiata* inhabiting the Cross River, Nigeria were investigated. From tagging-recapture data, a Von Bertalanffy growth function with L_∞ = 98.9 mm and K = 0.828 y^{-1} was established. Total mortality Z was calculated to be 2.03 y^{-1}. Natural mortality M and fishery mortality F were estimated to be 1.10 y^{-1} and 0.93 y^{-1}, respectively, corresponding to an exploitation rate of 0.45. Total annual yield by artisanal fishermen was estimated to be 600 tons wet mass.

Kurzfassung

Wachstum, Produktivität und fischereiliche Bedeutung der Muschel *Egeria radiata* (Donacidae) im Cross River, Nigeria.

Das Wachstum von *Egeria radiata* im Cross River konnte mit einer von Bertalanffy Funktion (L_∞ = 98,9 mm, K = 0.828 y^{-1}) beschrieben werden. Die Gesamtsterblichkeit in der Population betrug Z = 2.03 y^{-1}, zusammengesetzt aus der natürlichen Sterblichkeit von M = 1.10 y^{-1} und der fischereilichen Sterblichkeit von F = 0.93 y^{-1}. Dies entsprach einer Ausbeutungsrate von 0,45. Der jährliche Ertrag der lokalen Fischerei wurde auf 600 Tonnen Feuchtgewicht geschätzt.

Resumen

Crecimiento, productividad y importancia pesquera de la almeja *Egeria radiata* (Donacidae) en el Rio Cross, Nigeria.

La dinámica poblacional de la almeja *Egeria radiata* que habita el Rio Cross en Nigeria fue investigada. Se estableció, usando datos de marcado y recaptura una función de crecimiento Von Bertalanffy de L_∞ = 98.9 mm y K = 0.828 y^{-1}. La mortalidad total Z fue calculada siendo éste de 2.03 y^{-1}. La mortalidad natural M y la mortalidad por pesca F fueron estimados siendo de 1.10 y^{-1} and 0.93 y^{-1}, respectivamente, correspondiendo a una tasa de explotación de 0.45. El rendimiento anual total por pesca artesanal fue estimado en 600 toneladas de peso humido.

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Introduction

The freshwater clam *Egeria radiata* Lamarck (*Galatea paradoxa* (Born)), the only freshwater species of the Donacidae family, is endemic to the West African subregion. It is an infaunal suspension feeder living in soft bottoms of various rivers. Little is known about reproduction and recruitment, although the larvae are assumed to develop in the mantle cavity of the adult females (Purchon 1968). A detailed description of its anatomy and biology is given by Purchon (1964).

In several large rivers including the Volta (Ghana), Sanaga (Cameroon) and Cross (Nigeria) *E. radiata* supports thriving artisanal fisheries. Despite this, little work has been carried out to investigate the population dynamics of *E. radiata*. Vakily (1992) analyzed growth in the Volta River population based on the size-at-age data presented by Kwei (1965). In the Cross River population, Moses (1990) estimated growth from visible shifts of modal peaks in subsequent size-frequency distributions, and King *et al.* (1992) used growth marks on shell surfaces to establish a growth curve.

This paper investigates growth, mortality and productivity of *E. radiata* in the Cross river based on growth-increment (tagging-recapture) data and size-frequency distributions. The aim is to evaluate the significance of this species for the local fishery.

Methods

Rainfall is the major climatic factor affecting the hydrology of the Cross River system. At the sampling site, Itu, Nigeria (Fig.1), the average water depth varies between 4 m (dry season) and 14 m (rainy season), and water temperature varies between 22 °C and 30 °C (Etim and Enyenihi 1991 and references therein). *E. radiata* occurs in a hydrodynamically relatively homogeneous section of the Cross River which stretches about 25 km to the north and 25 km to the south of Itu, and which is hydronamically relatively homogeneous (Etim and Enyenihi 1991). Artisanal fishermen collect *E. radiata* by diving in the whole area, but landing of catch is concentrated at Itu.

All clams used in this investigation were bought from local fishermen at Itu. Monthly samples of 10 - 20 specimens were bought between February 1987 and September 1989 for the analysis of size-mass relationships. Eight large samples (68 - 1303 specimens each) consisting of the whole catch of one or several fishermen were bought between May 1990 and January 1991 to establish size-frequency distributions.

The length (maximum anterio-posterior distance) of each specimen was measured with callipers, and total wet mass, shell free wet mass and shell free dry mass (oven dried at 60 °C for 72 h) were determined. Size-mass relations were established by linear regression of the lg-transformed data.

To determine growth, live specimens of *E. radiata* were collected, measured and marked with a number on the smooth surface of the periostracum. They were returned to the river bottom and re-collected about three months later. A first batch of 320 specimens was marked on March 6th 1990, a second batch of 208 specimens four days later. 16 specimens from the first batch and 8 specimens from the second batch could be re-collected on June 4th (91 days and 87 days later, respectively), *i.e.* 24 size-increment data pairs were available for growth analysis.

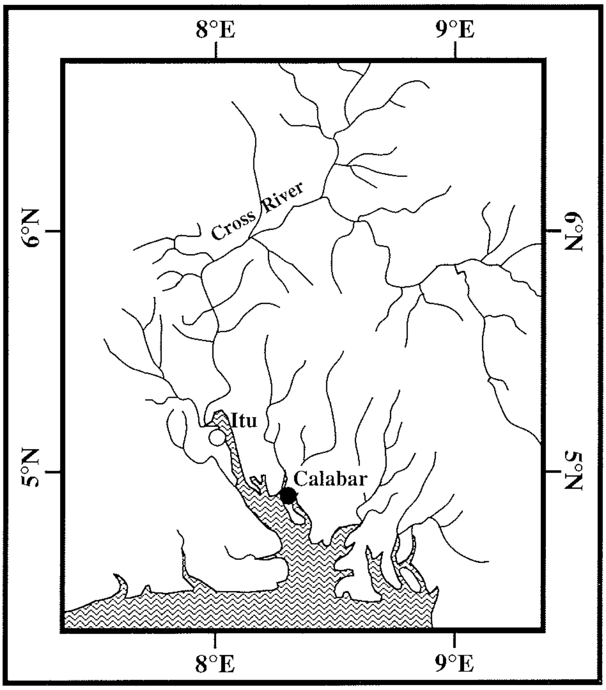

Figure 1: Map of the Cross River and Cross River delta, south-eastern Nigeria. Circle (Itu) indicates sampling area.

We used the Von Bertalanffy growth model (Von Bertalanffy 1938) to describe individual growth, since it results in a straight forward approach for estimating mortality (see below):

$$L_t = L_\infty \cdot [1 - e^{-K \cdot (t - t_0)}]$$

The parameters L_∞ and K of this function were estimated by an iterative non-linear least-square method (SIMPLEX algorithm, Press et al. 1986) which was applied to the re-arranged growth function:

$$L_2 = L_1 + (L_\infty - L_1) \cdot [1 - e^{-K \cdot (t_2 - t_1)}]$$

For t_0 no estimate can be obtained from growth increment data. Overall growth performance was estimated by the index Φ' (Munro and Pauly 1983, Pauly and Munro 1984):

$$\Phi' = \lg(K) + 2 \cdot \lg(L_\infty)$$

Total mortality rate Z was estimated by a size-converted catch curve (Pauly 1984), assuming exponential mortality. This curve was calculated from the size-frequency distribution of the eight pooled large samples (monthly samples previously converted from number per size class to percentage per size class) and the Von Bertalanffy growth function by the ELEFAN (Electronic Length Frequency Analysis) program of D. Pauly and co-workers (see Brey *et al.* 1988, Gayanilo *et al.* 1989):

$$(N_i/\Delta t_i) = N_0' \cdot e^{-Z \cdot ti}$$

N_i is the number of animals in size class i, Δt_i is the time required to grow through this size class and t_i is the relative age of the mid-size of class i. If the plot of $\ln(N_i/\Delta t_i)$ versus t_i shows a straight descending relationship of the fully exploited age groups to age, the exponential model is valid and total mortality Z can be computed by the linear regression:

$$\ln(N_i/\Delta t_i) = a + b \cdot t_i; \quad Z = -b$$

A subsequent correction for non-linearity of the growth model is made by the iterative solution of:

$$\ln(N_i/[1- e^{(-Zi \cdot \Delta ti)}]) = a - Z_i \cdot \Delta t_i$$

Natural mortality rate M was estimated on an empirical basis. In unexploited populations M equals Z. Allen (1971) showed that in a steady state population the somatic P/B ratio is equal to Z, if mortality can be described by the single negative exponential model, and if individual growth follows a Von Bertalanffy function. Hence natural mortality of *E. radiata* can be estimated from empirical relations between certain population parameters such as maximum age (A_{Max}) and annual P/B ratio in unexploited benthic invertebrate populations. A_{Max} of *E. radiata* was estimated from age at maximum size based on our data and the data of Vakily (1992) from the Volta River. From total mortality Z and natural mortality M we computed fishing mortality F (F = Z - M) and exploitation rate E (E = F/Z). A selection curve giving the probability of capture P_i per size class i was computed by a procedure outlined by Pauly (1984) and Gayanilo *et al.* (1989). Yield per recruit was computed by the Beverton and Holt (1964) model, from which a predicted value for optimum exploitation rate was also obtained.

Results

E. radiata exhibits distinct annual oscillations in shell free dry mass with peak values between April and July and minimum values in October/November (Fig.2). The length-mass relations for specimens pooled from all months are given in Table 1.

Length frequency distributions of *E. radiata* (Fig.3) did not show a clear pattern of peaks which could be tracked during time to determine growth.

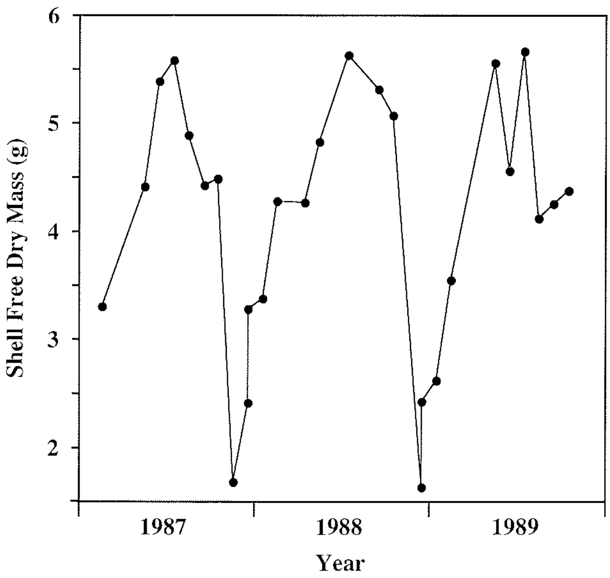

Figure 2: Seasonal variation of shell free dry mass in *E. radiata* between February 1987 and September 1989. Each data point represents the mean mass of 10 to 20 individuals between 70.0 mm and 73.0 mm length.

Table 1: Length-mass relations in *Egeria radiata* for pooled data from all sampling dates. lg(mg Mass) = a + b · lg(mm Length).

Dependent Variable	Intercept a	Slope b	Number of Data Pairs	r^2
Total Wet Mass	0.4560	2.3619	500	0.897
Shell Free Wet Mass	-0.8653	2.7337	500	0.859
Shell Free Dry Mass	-1.0274	2.4996	500	0.740

The best fit to the size-increment data obtained from the tagging-recapture experiment was provided by Von Bertalanffy growth curve parameters L_∞ = 98.85 mm and K = 0.828 y-1 (N = 24, Residual Sum of Squares (RSS) = 162.5, index of goodness of fit (1-RSS/TSS) = 0.960), see Fig.4.

Total mortality was estimated to Z = 2.03 y^{-1} from the size-converted catch curve (Fig. 5). Maximum age was estimated to be about 4 years (Vakily 1992: 3.3 and 3.6 y, our data: L_{Max} = 98.0 mm -> A_{Max} = 5.7 y), and natural mortality rate M was computed to be 1.10 y^{-1} (mean of

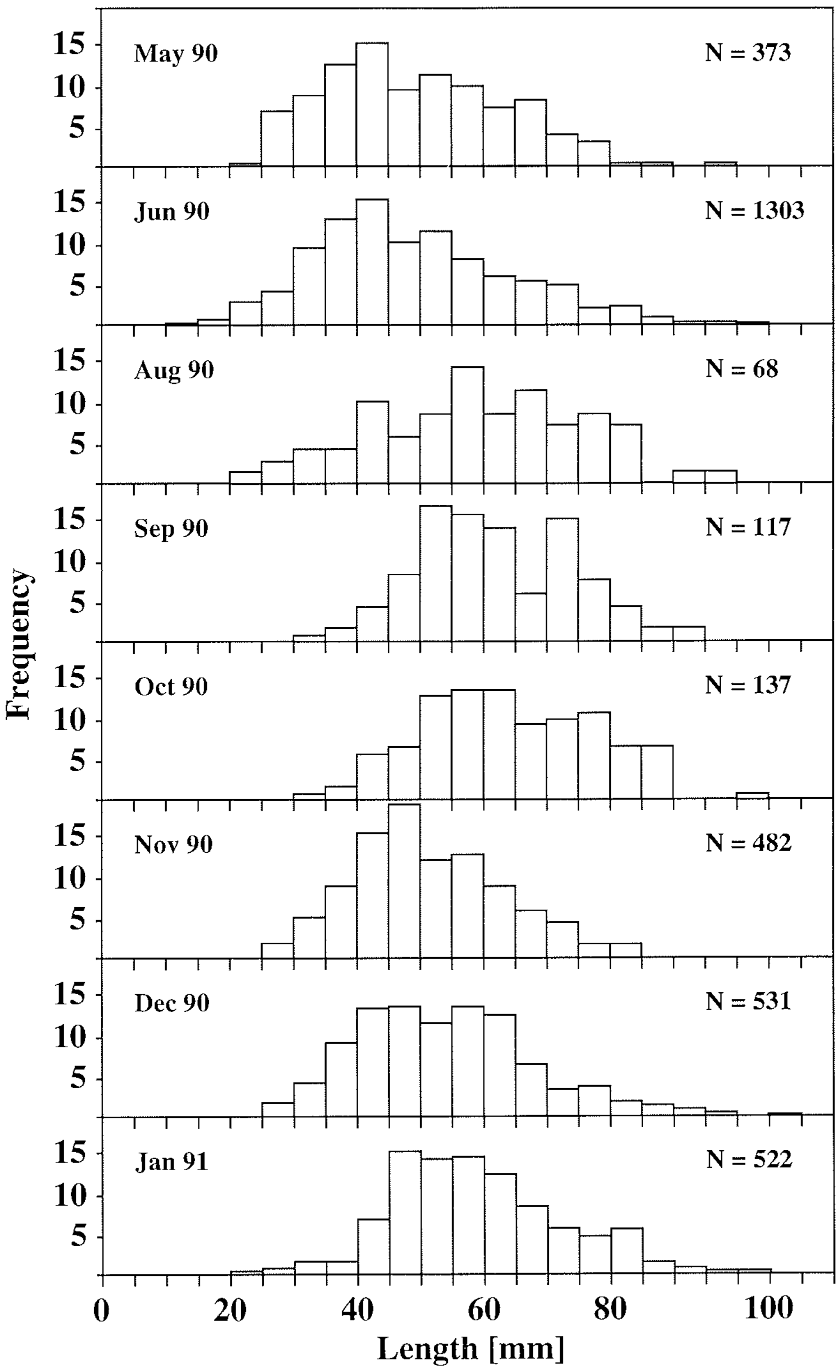

Figure 3: Length-frequency distribution of *E. radiata* in the eight samples.

1.003, 1.081 and 1.208) by the three different empirical relations (Table 2). F was computed to be 0.93 y^{-1} and exploitation rate E to be 0.45. Fig.6 shows the selection curve for the fishermen's sampling method. Specimens ≤ 15 mm are not caught at all, whereas specimens ≥ 50 mm are fully available to the fishery. Mean length at first capture is computed to be 35 mm. Computations of yield per recruit are shown in Fig. 7. The optimum exploitation rate is predicted to be at 0.59 per year.

Table 2: Empirical relationships between maximum age (A_{Max}) and annual P/B ratio in benthic invertebrate populations. P/B equals Z in unexploited populations.

Nos.1 and 2: $lg(P/B) = a + b \cdot lg(A_{Max})$

No. 3: $lg(P/B) = a + b \cdot A_{Max}$

1) Bivalves only

Author	Intercept a	Slope b	Number of Data	r^2
1 Brey (unpubl.)[1)]	0.682	-1.130	219	0.767
2 Hoenig (1983)	0.625	-0.982	134	0.820
3 Warwick (1980)	0.538	-0.112	85	0.567

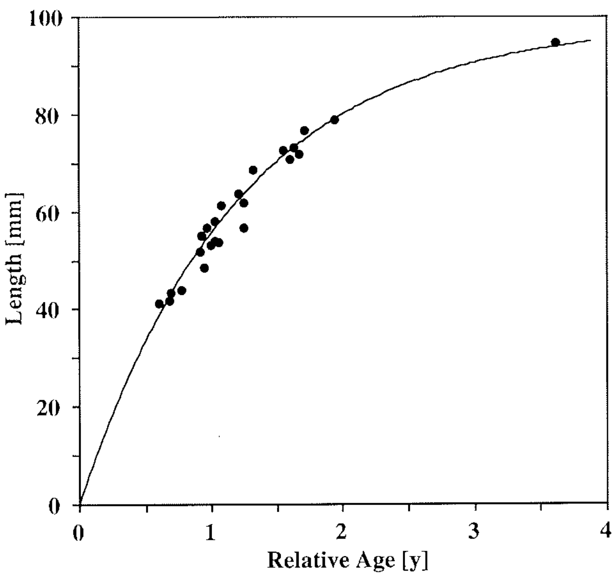

Figure 4: Von Bertalanffy growth curve of *E. radiata* based on 24 tagging-recapture data pairs, $L_t = 98.85 \cdot [1 - e^{0.828 \cdot t}]$. Dots represent measured length at recapture L_2. Age is denoted "relative" because t_0 is not known. Relative age at time of recapture was computed by: age = $\ln(1 - L_2^*/L_\infty)/-K$, where L_2^* is length at date of recapture estimated from length at tagging by the growth function.

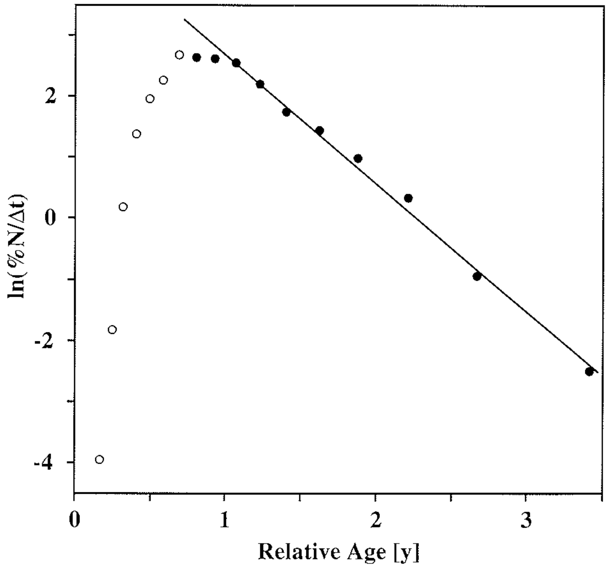

Figure 5: Size-converted catch curve of *E. radiata* based on the pooled length-frequency samples (*Fig.* 2) and the Von Bertalanffy growth function (Fig.4). Dots: Points included in catch curve calculation. Circles: Points excluded. $\ln(N_i/\Delta t_i) = 4.60 - 2.03 \cdot t_i$, $r^2 = 0.988$.

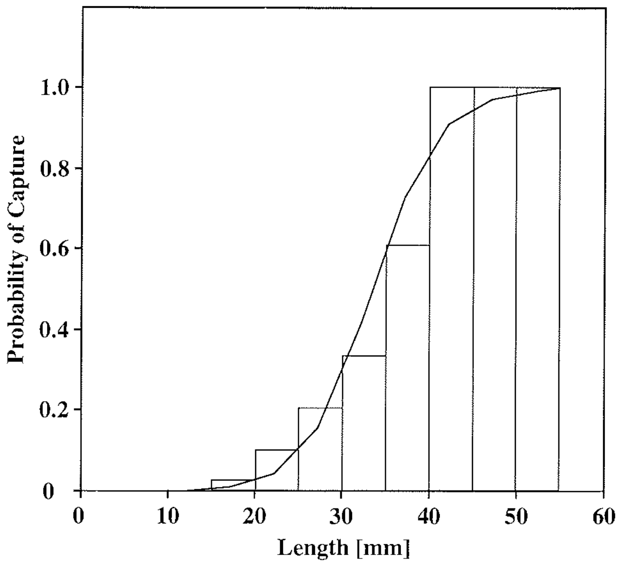

Figure 6: Plot of probability of capture versus length in *E. radiata* based on estimates of $Z = 2.03\ y^{-1}$ and $M = 1.10\ y^{-1}$.

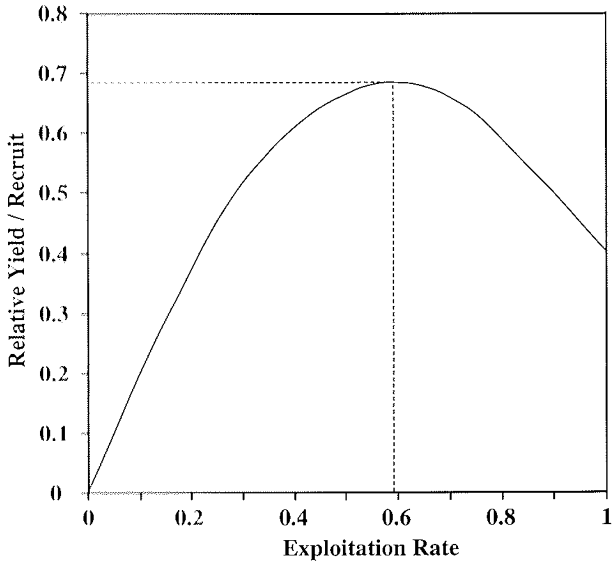

Figure 7: Yield per recruit in *E. radiata* based on the Beverton and Holt (1964) model.

Discussion

In empirical studies, the accuracy of results depends mainly on sampling and sampling design. Our size-frequency data, on which mortality and exploitation rate estimates depend, are not based on a scientific sampling schedule, but on commercial catches. The exact location of each catch is not known, and different fishermen may have developed slightly various sampling techniques, which could introduce different types of bias. However, our strategy is unlikely to have introduced any systematic error, even if single samples may be biased to a certain extent (compare Oct. 90 and Nov. 90 in Fig.3). The pooled data from all sampling dates are therefore assumed to be representative for the population.

Little is known about reproduction and recruitment of *Egeria radiata.* Although the present investigation did not include gonad examinations, the spawning period can be inferred from the seasonal changes in shell free dry mass (Etim 1991a, 1991b, Etim and Enyenihi 1991), as also observed in other African bivalve species (Erkom and Griffiths 1991). Thus, the decrease in shell free dry mass between June and October (Fig. 2) is likely to be a result of spawning. Hence spawning starts at the peak of the rainy season and ends at the beginning of the dry season.

The low recapture rate of 0.045 (24 out of 528 specimens) in the tagging-recapture experiment is most likely due to collection of marked clams by fishermen in the release area, which was marked, but could not be protected. Unfortunately, only one large clam > 80.0 mm was recovered, *i.e.* the validity of the upper range of the fitted growth curve (L_∞ = 98.9 mm and K = 0.83 y^{-1}, Fig.4) is uncertain. However, a second fit excluding this large clam revealed quite similar growth parameter values, $L_\infty = 96.0$ mm and $K = 0.88\ y^{-1}$, indicating that the curve based on all 24 specimens is reasonably valid.

Growth of *Egeria radiata* in the Itu region, Cross River, has been estimated previously by two different investigations. From length-frequency analysis Moses (1990) estimated the parameters of the von Bertalanffy function to be $L_\infty = 93.0$ mm and $K = 0.36\ y^{-1}$. King *et al.* (1992) interpreted growth checks at the shell surface as annual growth marks and estimated L_∞ to be 111.0 mm and K to be $0.30\ y^{-1}$. Both figures for L_∞ are close to our estimate, $L_\infty = 98.9$ mm, but K is less than half of our figure, $0.83\ y^{-1}$, in both studies. Overall growth performance Φ' computed from Moses's (1990) and King's et al. (1992) data, 3.493 and 3.568, respectively, is below our estimate of 3.909 (Table 3). All three investigations are based on clams from the same area, and they overlap in time of investigation: Moses (1990): 1986-87, this study: 1987-89, and King (1992): 1989-90. Therefore these large variations in growth performance are unlikely to be caused by spatial or temporal changes in abiotic parameters of the Cross River system.

Vakily (1992) re-analyzed data of Kwei (1965) from two rivers in Ghana and found Φ' values for E. radiata close to our estimate (Table 3). Therefore we assume our growth curve to be more reliable than those of Moses (1990) and King et al. (1992). In contrast to the analysis of size-increment data, the analysis of size-frequency distributions and the examination of growth checks imply some subjective interpretation. For example, two growth rings per year may be formed (see e.g. Salzwedel 1979) instead of one as suggested by King et al. (1992).

Table 3: Growth and growth performance in *Egeria radiata.*

L_∞, K: Parameters of the Von Bertalanffy function
$\Phi' = \lg(K) + 2 \cdot \lg(L_\infty)$, index of overall growth performance
[1] L_∞ computed from H_∞ by a length-height regression (Etim 1991).

Author	Location	L_∞	K	Φ'
Vakily (1990), Kwei (1965)	Volta River (Ghana) 6° 16'N	145.1[1]	0.75	4.198
Vakily (1990), Kwei (1965)	Volta River (Ghana) 5° 59'N	107.4[1]	0.71	3.912
Moses (1990)	Cross River (Nigeria) 5° 11'N	93.0	0.36	3.493
King et al. (1992)	Cross River (Nigeria) 5° 11'N	111.0	0.30	3.568
This study	Cross River (Nigeria) 5° 11'N	98.9	0.83	3.909

Our value of total mortality Z, 2.03 y^{-1}, is twice the estimate of Moses (1990), 0.82 y^{-1}, and King et al. (1992), 0.79 y^{-1}. This is clearly a consequence of the under-estimation of growth in these investigations. The same is true for natural mortality M, since the estimates, 0.32 y^{-1} (Moses 1990) and 0.31 - 0.60 y^{-1} (King et al. 1992), depend on empirical relations involving K. The application of three different empirical relations (Table 2) is likely to have improved the validity of our figure, M = 1.10 y^{-1}. However, M depends on the proper estimate of maximum age A_{Max}, and A_{Max} may have been underestimated due to fishery pressure. Hence M = 1.10 y^{-1} may to a certain extent overestimate natural mortality.

The estimated fishing mortality of 0.93 y^{-1} seems to be fairly high, and together with the current exploitation rate of 0.46, it presupposes a rather high fishing pressure on the stock. Exploitation rate is still below the maximum at E = 0.59 (Fig. 7). Taking into account a probable overestimation of natural mortality, the stock could be well in the range of optimum exploitation. Mean age at first capture is below one year (corresponding to a mean length at first capture of 35 mm, Fig. 6), but there seems to be no actual danger of recruitment over-exploitation, since reproduction (rainy season) and fishing (dry season) do not overlap temporally. However, if age at maturity is greater than one year, the present state of exploitation will cause a serious breakdown of the stock in the near future, if there is no import of recruits from upstream areas.

The fishing season covers the dry months from October to April, during the rainy season there is no fishing since the currents are too strong and the water is too deep. At the peak of the fishing season about 200 fishermen are engaged in active fishing each day in an area of about 10 km^2 (about 50 km of river length, on average 200 m wide). A day's catch consists of about 450 clams per fisherman. Based on a six-day working week and a seven-month fishing season, total catch is estimated to about 16 million clams per fishing season. This is equivalent to 600 tons wet mass (based on mean individual mass = 37.6 g WM), 132 tons shell free wet mass, or 35 tons shell free dry mass per season. The annual yield per km^2 is about 60 t WM, which is in the range of the estimates of Moses (1990) and of King *et al.* (1992), 33 t WM km^{-2} y^{-1} and 78 t WM km^{-2} y^{-1}, respectively.

Our results leave little doubt that the stock of *E. radiata* in the Cross river is heavily exploited and that any further increase in fishing intensity will soon lead to over-exploitation and subsequently to a long-term decrease in yield. Hence there is an urgent need for management of this important resource, as also suggested by Moses (1990) and King *et al.* (1992). Basic approaches should be (i) to establish protected areas with unexploited adult stocks, (ii) to define and control a minimum size at landing, and (iii) to develop aquaculture techniques. However, more knowledge on reproduction and recruitment of *E. radiata.* is required for successful stock management and aquaculture.

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