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(Received 4 April 1989, accepted 20 July 1989)

ABSTRACT

The growth of three species of mussels in the White Nile near Khartoum was studied from caged specimens and natural populations. True annual rings develop as a result of a silting-induced resting state during the annual flood from July to October. False rings also develop, possibly as a result of unfavourable factors like the change of habitat, inadequate food, handling of the mussels.

Growth is inhibited during November-January as a result of the lower water temperature and reproduction. However, there was evidence that during this period juveniles grew at a higher rate than the adults. It could be concluded that there is a trade-off between reproductive effort and growth in the adults; growth is inhibited until the eggs are released from the gonads into the demibranchs.

The period from February to July is the growth season; it is characterised by high water temperature and high transparency. The mussels had already spawned by February. Significant increments were observed on the shells of caged specimens especially after May. These increments were, however, smaller than comparable growth in natural populations. This indicated that the cages had suppressed the growth of the mussels.

Growth rates are slow. Estimation of maximum sizes for the unionids using Ford-Walford plots was almost in full agreement with the actual maximum sizes. The poor agreement in the case of *M. dubia* is related to the fact that this species is not well established in the habitat.

INTRODUCTION

It has been shown that the seasonal population cycle and the growth of individual bivalves in the White Nile near Khartoum are controlled by the silting (from the adjoining Blue Nile) of the river during the flood (Adam, 1986). Annual rings are formed on the shells as a result of checked growth during this period (el Moghraby & Adam, 1984).

The aim of this article is to describe the g
in length of the shell in three species of n
from the same habitat. These are the ur
Caelatura aegyptiaca (Cailliaud, 1835),
atura teretiuscula (Philippi, 1874) and the
lid *Mutela dubia* (Gmelin, 1791).

Using size frequency analysis, L
(1971), Lévêque & Saint-Jean (1983) s
the growth of the same species from Lak
in Central Africa, but the factors which
growth were not determined. In this
carried out in 1977-1978, seasonal grow
ring formation were observed from mu
riverine cages while the environmental
were recorded. The growth of the shell w
studied from natural populations using t
method.

MATERIALS AND METHODS

Two cages made of wooden frames and two l
wire netting were used for the culture expe
The front height of cage was 0.6 m, the back
and the width were 0.75 m. The whole cag
towards the front with the shorter side facing
stream. Such a position may help washing a
object from settling on top of the cages. Th
sizes of the wire netting were 1.0 mm for th
layer, and 2.5 cm for the outer. The wooden
of the cages were filled with sediments from t
(15 cm deep). The cages were placed in th
Nile at el Shajara 10 km south of the city at
site near the Fisheries Research Laboratorie
were anchored at a depth of three metre
increased to about six metres during the flo
positions of the cages were indicated by buo

A total of 45 bivalves individually marke
knife were put in each cage. This figure is lo
their natural maximum density of 75 specim
(Adam, 1981). Of these 30 were *C. aegyptiac*
variable species, and only the elongate form
the commonest, was selected), 20 *C. teretius*
M. dubia and 30 *Corbicula*. Small young bival
not found, so they were not represented in th

The total antero-posterior length of each s
was measured using vernier calipers to the
mm and the number of growth rings were co

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J. Molluscan Studies 56(2): 301-308
1990

Table 1. The mean absolute rates of growth (as mm/months) for the specimens in the c

	Dec. 1976	Feb. 1977	May 1977	July 1977	Jan. 1978	Seasonal growt Summer season
C. aegyptiaca:						
Number of specimens	30	21	17	13	8	
Growth rates		0.022	0.286	0.292	0.069	0.288
C. teretiuscula:						
Number of specimens	20	13	10	9	6	
Growth rates		0.01	0.12	0.122	0.029	0.121
M. dubia						
Number of specimens	10	6	5	3	3	
Growth rates		0.025	0.426	0.635	0.046	0.51

4 December, 1976 and repeated on 4 February, 1977, 5 May, 1977, 1 July, 1977 and 13 January, 1978. The absolute monthly and seasonal growth rates were calculated according to the formula:

$$\text{growth rate} = L_n - L_{n-1}/t$$

where L_n and L_{n_1} are the mean values of two successive readings of shell length in mm and t is the time between the two readings in months. Unfortunately, after six months the mesh wiring of the cages started to deteriorate, and holes developed on them.

The water temperature (°C) was read from an EIL temperature-oxygen meter and transparency (cm) was recorded using a 20 cm Secchi dish. These readings were taken near noon once a month.

The length of a growth ring is its total antero-posterior distance measured in mm by a vernier calliper (Fig. 3). The difference between any two such successive measurements is an increment. The specimens used for the measurement of growth rings were collected from the river bottom by hand, or using an Ekman grab operated from a 9-foot dinghy. The living mussels were killed by soaking them in hot water for a few minutes (Green, 1957). The shells gaped wide and the soft tissues were then cleaned out. The shells were further washed in a dilute commercial soap solution and air dried at room temperature. Fifty shells of each species were investigated. The data were grouped from variably sized mussels and, therefore, the calculated values of the mean ring sizes correspond to age, not to a specific year. These mean values were used to plot the growth curves and to calculate the maximum potential sizes of the mussels.

The maximum potential size (L_i) for each species was estimated by plotting the mean size of growth rings at t years of age against the mean size at $t+1$ years (Ford-Walford plots). L_i is given when the line of the best fit with a slope of e^-K intercepts the 45° line where L_t equals L_{t+1} and K is the rate of growth (Holme & McIntyre, 1971). Both the growth curves and Ford-Walford were plotted using a BBC microcomputer.

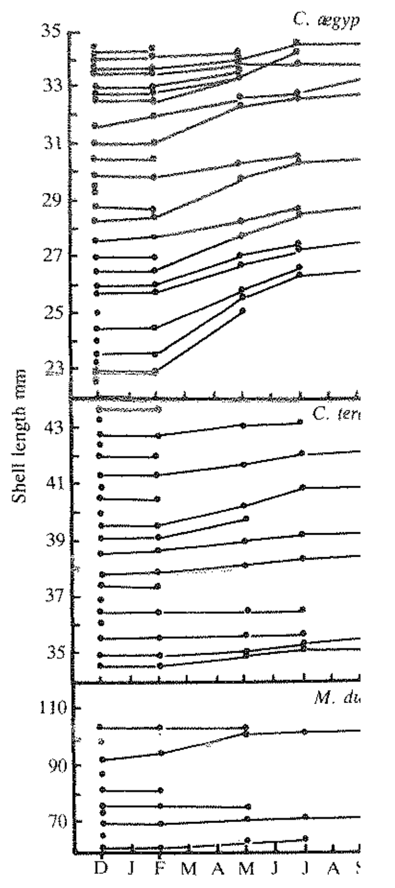

Fig. 1. The growth of *C. aegyptiaca*, and *M. dubia* in the experimental cage ber, 1976 to January, 1978.

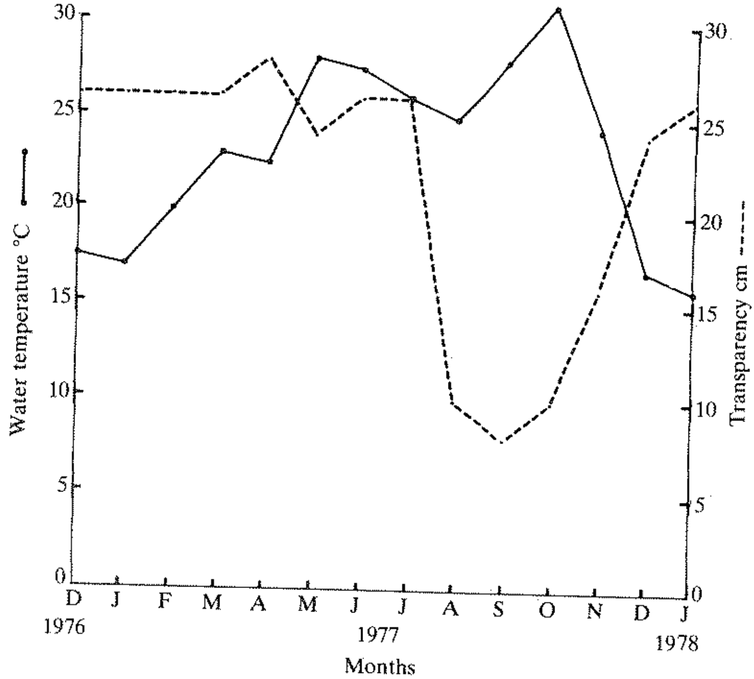

Fig. 2. The monthly variations of water temperature and transparency in the White Nile near Khart
from December, 1976 to January, 1978.

RESULTS

As appears from Table 1, there were high mortality among the caged bivalves (100% for *Corbicula* and about 70% for the mussel species) during the thirteen months of the experiment. Most of the *Corbicula* were probably eaten by fish, though this could not be confirmed for the mussels. In both groups some individuals might have died naturally as a few empty shells were found in the cages.

The cages were anchored in relatively deep water (3-6 m) with higher rates of flow than in shallower parts. This is not the preferred habitat for *C. teretiuscula* and *M. dubia*. The former is only found in the shallow sandy stretches near the river bank, while the latter inhabits quiet rather muddy parts of the river (Adam, 1981). It is then possible that cageing has contributed to the mortality of the bivalves.

From Table 1 and Fig. 1, it is clear that the absolute rates of growth were very low during the period from December, 1976 to February, 1977. Only slight increases were observed, and in many specimens there was no growth at all.

The water temperature drops signi
during November-February (Fig. 2). Th
sels start reproductive activity a few weel
recovering from the resting state. Eggs a
duced in the gonads and by February tl
released in the demibranchs (Adam, 19:

Between February, 1977 and May, 1!
absolute growth rates increased to 10 tim
during the previous period for the unioni
to almost 20 times for *M. dubia*. Growt
continued to rise even higher from May
to July, 1977 (Fig. 1). At the final measu
in January, 1978, little growth was note
the previous six and one-half months. Tl
rate of growth was, however, higher th
rates for December, 1976 to February,
The measurements in July, 1977 were
a fortnight before the first signs of sil
observed. So, the increments measured i
uary, 1978 may have been added durir
short period.

Thus the period from February to July
season of high growth. This correlates wi
rising water temperature and the light
parency (Fig. 2). The mussels had a

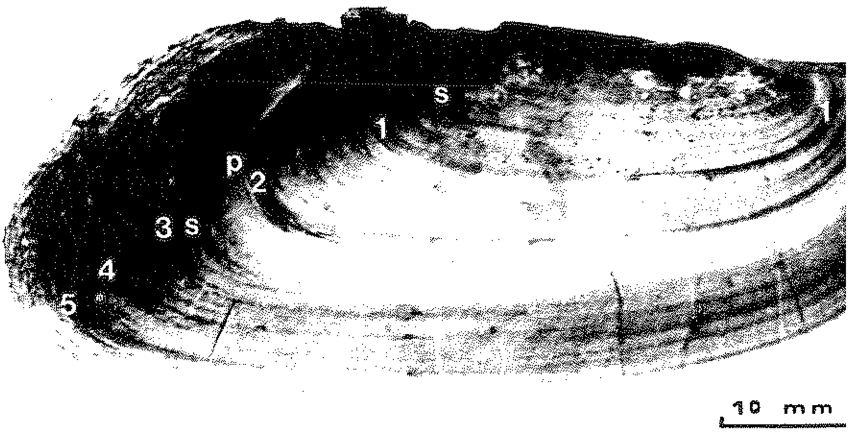

Fig. 3. The shell of *M. dubia* showing the growth rings (numbered) and the false rings, S. T
of the shell is the largest antero-posterior distance, i.e. from right to left. The size of a gı
similarly measured, i.e. a-p.

spawned their eggs. The lecithotrophic larvae develop in the demibranchs independent of maternal supply of nutrients up to April-May (Adam, 1981). The period from July to January is the season of no or low growth and includes the flood season and silting of the river during which the mussels undergo a resting state.

Growth rings were formed as a result of the resting state (July-October) but were not observed in the adults before May, 1977 after which time significant increments were slowly added to the shells. In 15 juvenile *C. aegyptiaca* found in the cages in January, 1978 at sizes of 9-12 mm, the first year growth rings were followed by additional increments of 0.5-2.5 mm. These increments were added after silting was over in October, indicating that juveniles grow during the cool season. The average size of the first year growth rings in the juveniles (9.33 ± 1.68 mm) is not significantly different from that of the adults which is 10.04 ± 1.48 mm (Fig. 4), ($t = 2.712$ at $P = 0.001$ for 63 degrees of freedom). However, the absolute rate of growth by which the average increment (1.187 ± 0.608) was added to the juvenile shells until January, 1978 is 0.31. This average increment equals only 22.6% of the growth required to reach the average size of a second year growth ring which is 14.7 ± 1.19 mm (Fig. 4). An absolute rate of growth of 0.51 during February-July is then needed to achieve that. Thus, the rate of growth is higher during the warm season.

The growth rings were first counted in December, 1976. True growth rings are prominently thick, dark and continuous marks from the anterior to the posterior side of ı
false or supernumerary rings are ı
sometimes discontinuous (Fig. 3
of the experiment, numerous fal
found on the shells of the cage
especially *C. teretiuscula* and *M. a*
resulting from the unfavourable ı
the anchoring spot, handling of t
insufficient food.

Figs. 4 and 5 shows the growtł
three species. The greatest gaiı
achieved during the first year an
gently slows down.

The range of the maximum size
ids found in the field (45 mm
48 mm *C. teretiuscula*) agree clos
theoretically calculated (47 mm
48 mm *C. teretiuscula*). Howev
significant difference betweeı
(104 mm) and theoretical size (
dubia. This is brought about by
wider variations in the sizes of
growth rings (Fig. 5).

The overall growth rates are l
of K indicate that *M. dubia* gr
the unionids for which the gro
similar (Fig. 4) and the values
(Fig. 6).

Growth ring counts indicate
mum age of *C. aegyptiaca* in
years, although live specimens
were rare. Empty shells indica
etiuscula may also reach an age
but the oldest living specimen
Although the oldest living *M. a*

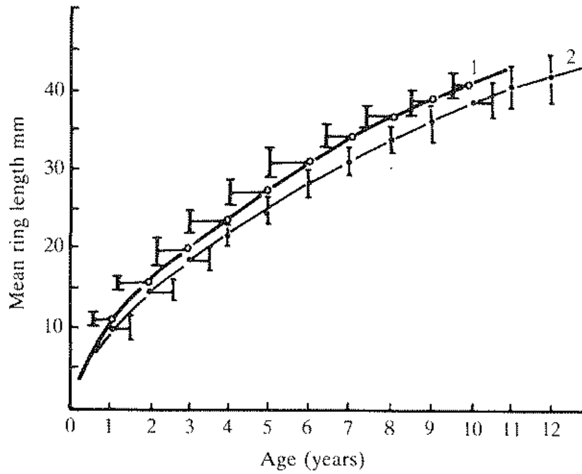

Fig. 4. The growth curve of *C. aegyptiaca* (1) and *C. teretiuscula* (2) from the White Nile near Kha
The values of the standard deviation of the mean sizes of the rings are indicated by vertical ba

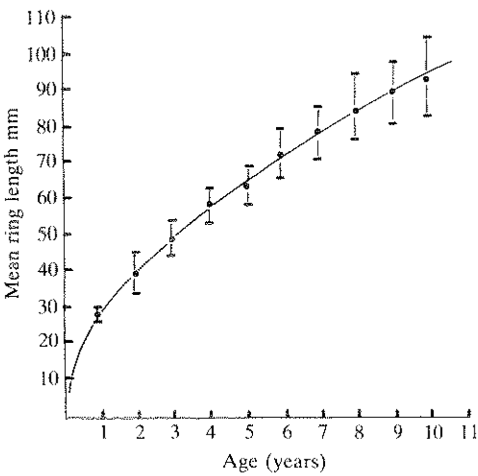

Fig. 5. The growth curve of *M. dubia* from the White Nile near Khartoum.

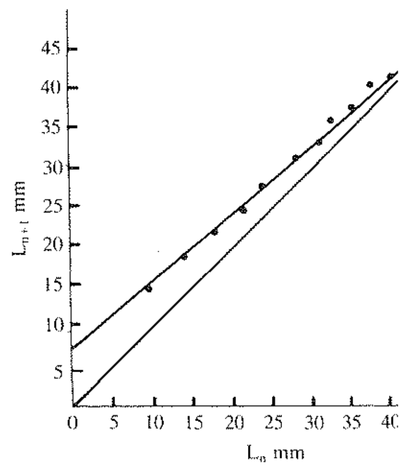

Fig. 6. Ford-Walford plot; *C. aegyptiaca*
White Nile near Khartoum. The arrow fal
x-axis indicates the theoretical value of the
size of the shell. The slope of the line (e^{-K})
and K = 0.0932. The value of K for *C. ter*
0.0995 and for *M. dubia* is 0.118.

10 years of age, empty shells of up to 16 years were not rare.

DISCUSSION

Studies of growth in bivalve molluscs are usually carried out by size frequency analysis, observation of caged specimens or analysis of growth interruption lines on the shell. The results in this study were obtained using the l
methods.

A critical evaluation of the cageing
used in this study shows several disad
The mesh of the cages was found to b
by the suspended matter in the water.
observed when the third reading was

Table 2. A comparison between the magnitudes of the increments in the shells of the caged spe during thirteen months of growth and the calculated average annual mean increments from m ments of growth rings of similarly aged naturally occurring specimens. The percentage dif indicates how much less are the increments in the caged specimens than the mean increment naturally occurring specimens.

Species	Age (Years)	Size of the shell measured in Dec. 1976 (mm)	Size of increment measured in Jan. 1978 (mm)	Average annual mean values of increments from ring measurements	% diff
C. aegyptiaca	V	23.5	3.5	3.40	—
	V	25.7	2.3	3.40	32.4
	V	26.5	2.0	3.40	47.5
	VI	27.5	1.5	2.86	47.5
	VI	28.3	2.3	2.86	19.6
	VII	31.0	2.0	2.66	24.9
	VIII	33.6	1.5	1.90	21.0
	VIII	33.7	1.1	1.90	42.1
C. teretiuscula	VII	34.6	0.6	2.62	77.1
	VII	35.6	0.2	2.62	92.3
	VIII	37.8	0.8	1.90	58.0
	IX	38.5	0.8	2.00	60.0
	IX	39.5	1.5	2.00	25.0
M. dubia	V	61.3	4.2	8.10	48.1
	VI	70.0	2.5	6.40	60.9

May, 1977, though it was first thought that the force of the current was adequate to clean the mesh. This would decrease the flow of potential food particles into the cages, and might have forced the mussels to spend more effort filtering the relatively little food available.

The mesh eventually deteriorated and holes appeared on it, leaving the specimens exposed to predation by fish, which probably consumed all *Corbicula*. Other organisms, e.g. crabs (*Potamon* sp), shrimps (*Cardinia* sp), fish fry and oligochaetes were found in numbers greater than normal for the river bottom. This possibly physically perturbed the mussels.

The anchoring spot of the cages was in relatively deep water (3-6 m) where the rates of flow are higher than those in the preferred habitats of *C. teretiuscula* and *M. dubia*. This could have caused the death of some specimens. It is therefore not surprising that the average increments added by mussels which survived the cageing during thirteen months of study were smaller than the yearly averages calculated from the measurements of the growth rings of naturally occurring specimens (Table 2). Suppression of growth was greatest in *C. teretiuscula*. The frequent handling of the mussels to measure the shell and observe the growth rings could also have disturbed the growth. The false rings which were observed on the shells of the cag mens could have resulted from unfa factors. Several factors for the develo false rings have been mentioned in stuc the temperate zone including change perature (Haskin, 1954); scarcity of foc fort, 1957); pollution (Crowley, 1957 & 1966). These difficulties would not, l affect the pattern of seasonal growth.

It seems that cageing has little or no mussels living in still water. Lévêque Jean (1983) did not report any diffic this method in studying the growth of including the species considered here Chad. In marine populations Harg observed that the growth of caged mussels was hindered because the ca fied the wave action, while sublittora were not affected.

There is little known about the ca true growth rings in tropical mussels. Carter (1980) pointed out that aestiv result of drought could be responsib development in the inhabitants of water bodies. They also speculated turbidity is a possible factor for strean mussels. Both of these views were disc confirmed by el Moghraby & Ada Apart from the causative factors, th development of growth rings in the White Nile mussels seems to be similar to that in their temperate counterparts in the sense that it is instigated by the withdrawal of the mantle margins from the growing part of the shell. However, the banding of the growth rings of the temperate mussels, which indicates repeated withdrawals of the mantle margins as a response to the cold spells during winter and spring (Chamberlin, 1931) was not observed here. This is due to the uninterrupted arrest of growth as a result of the silting-induced resting state, recorded by a solid unbanded growth ring on the shell.

Seasonal growth of the mussels is also influenced by temperature and reproduction. Temperature-dependent growth has been demonstrated in fresh water in the temperate zone (Chamberlin, 1931; Russell-Hunter, 1964 & Negus, 1966) as well as in marine populations (Thiesen, 1973). In the tropics where temperature is much more constant, it is traditionally believed that such dependence does not exist. However, the drop of temperature during November-January was found to inhibit the growth of bivalves in L. Chad (Lévêque, 1971; Lévêque & Saint-Jean, 1983). In this study the absolute rates of growth whether in the juveniles or adults also correlated with water temperature.

Inhibition of growth during the cool season may not only have been due to lower temperature, but also to reproduction. After spawning the adults can transfer more energy to growth, concurrently with rising temperature from February to July. In non-breeding juveniles, reproductive pressure on growth is not experienced and, therefore, they could use their energy to achieve higher rates of growth than than the adults during the cool season.

The theoretical maximum sizes were almost similar to the actual maximum sizes in the case of the unionids. The disagreement in these data for *M. dubia* arises from the variability in the sizes of similarly aged individuals. This species is a lake-dweller (Mandahl-Barth, 1954) and since all the shells studied were of medium size or larger it is suspected that live specimens (together with empty shells) were brought to the locality by downstream transportation from Jebel Aulia dam 45 km south of Khartoum where a large population is found. The mussels are subject to several changes in the river. The most important is the water level which quickly drops after January. The parts of the river most affected are the shallow banks which *M. dubia* favours. However, this effect is uneven in the various parts of the river, which could resu[lt in] an uneven growth among the individuals o[f the] species.

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