Fecundity and Population Structure of Cockles, *Anadara antiquata* L. 1758 (Bivalvia: Arcidae) from a Sandy/Muddy Beach near Dar es Salaam, Tanzania

Semvua Mzighani

Tanzania Fisheries Research Institute (TAFIRI), P.O.Box 475, Mwanza

Abstract—The fecundity and population structure of the cockle, *Anadara antiquata* L., from sandy/muddy intertidal habitats in the intertidal of Ocean Road beach was examined from January to December 2001. *A. antiquata* is hand harvested, for domestic consumption, mainly by women and children, with the empty shells sold to traders. The sex ratio from combined data of all classes deviates significantly from 1:1 with the ratio of females to males increasing significantly above 41 mm shell length. Hermaphrodites were also observed in this size range indicating a protrandric hermaphrodite situation with males maturing earlier than females. Fecundity increases with an increase in shell length, with a mean of 1,652,000 (+/- 562,000 [or 40%] SE) eggs per female and correlated significantly with shell length and whole live weight. Two peaks were observed from length frequency analysis, one dominated by juveniles and other with mature *A. antiquata*. The slope b from length-weight relationship for *A. antiquata* was 2.7134 (n = 1,951) indicating isometric growth.

INTRODUCTION

In the developing world, there is a need to increase food production and one of the ways of achieving this goal is the rearing of shellfish, especially bivalve species, which are a source of cheap animal protein. Culture of marine organisms may increase production and also decrease pressure on coastal natural resources, and bivalves are amongst the most important marine resources (Mgaya *et al.*, 1999). In the shallow seas of the Western Indian Ocean molluscs and fish represent about half of the entire marine biodiversity of the region, with a clear domination by molluscs (gastropods and bivalves). However, one of the main problems in tropical regions is the lack of information on the basic biology of exploited bivalve species (Richmond, 1999).

Many bivalves are reported from the Tanzanian coast, including *Anadara* spp. (Mwaiseje, 1982; Kayombo & Mainoya, 1987; Mgaya *et al.*, 1999; Mzighani, 1999; Semesi *et al.*, 1999), *Trachycardium flavum* (Mgaya *et al.*, 1999), *Scarphaca erythraonensis* (Kayombo, 1986; Kasigwa & Mahika, 1991), *Saccostrea arakenensis* (Sirrila, 1995) and *Donax* spp. (Mwaiseje, 1973).

The most utilized bivalves in Tanzanian coast are *Anadara antiquata* and *A. natalensis* (Mwaiseje, 1982). Matthes (1974) recommended *Anadara* spp., which have high commercial and nutritional value, for aquaculture in Tanzania (Broom, 1985; Kayombo & Mainoya, 1986).

The main objective of this study was to establish the relationship between fecundity and population structure of *Anadara antiquata*. Specific objectives included: to determine sex

E-mail: mzighani@yahoo.com

ratios and their relation to size, size at first maturity, and, whether growth pattern is isometric or allometric.

MATERIALS AND METHODS

Study area

Samples of *Anadara antiquata* were collected at monthly intervals from the intertidal sandy-muddy flats at Ocean Road beach, Dar es Salaam City (6° 49' S Latitude and 39° 11' E Longitude), Tanzania, from January to December 2001. This beach is situated on the northern side of the harbour just outside the entrance. The study was conducted on the northern side of the sewage pipeline. The samples were collected from the intertidal zone that falls between the extreme high water spring tide and extreme low water spring tide.

Sampling procedure

Field sampling was done once per month during low tides. Specimens of *Anadara antiquata* were collected along the transect line from extreme high water spring tide to the extreme low water spring tide. At each 5 m, an area of one square metre was dug out using a shovel and a garden rake. Large specimens were taken by hand and small ones were taken using a 5 mm mesh size sieve. Additional samples of *A. antiquata* were purchased from the Ocean Road market or at landing stations along that beach. These accounted to about a quarter of samples collected per month. These samples were randomly taken representing all classes. Fishers harvest all classes because shells are sold to shell traders.

Samples were kept in an icebox with ice pellets and then transported to the laboratory. In the laboratory the samples were washed to remove all adhering organisms and other debris. A total of 1,951 specimens of *A. antiquata* were collected during the twelve month sampling period. The identification of *A. antiquata* was verified using the descriptions of Aussehen-Vorkommen (1990), Branch *et al.* (1990) and Richmond & Rabesandratana (1997).

Laboratory procedure

Shell length (SL) was measured by using a vernier caliper to the nearest 0.1 mm, while whole live weight (WLW) was measured using a top loading electronic balance to the nearest 0.1 gm. Whole live weight was determined after removal of excess water by blotting paper.

Microscopic examination of the condition of the gonad was assessed according to Kayombo (1986), without histological examination. The colour of the products of ripe gonad was used to determine the sex. The female's ripe gonad product is light orange in colour whereas that of male is white. Four stages were defined, namely, "Developing" or "Maturing" (filling), "Mature" (full), "Partially Spent" and "Spent". These were termed stages I to IV respectively. Any specimens whose sex could not be determined were initially placed in stage I. However, when it became clear from the results at what size gonads usually develop, those indeterminate longer than 35 mm were assumed to have spawned and were placed in stage IV. Fecundity was assessed by estimating number of eggs for each female from stage II. Eggs were taken out from the gonad and kept in a calibrated burette with water. The eggs were shaken so that to be distributed evenly inside the burette. The syringe was used to take a known amount of water from the burette and kept on petri dish. The petri dish was placed under microscope and eggs were counted. The proportion of water taken from known amount of water inside burette was used as a multiplication factor to obtain number of eggs per female.

Data analysis

The data for shell length, whole live weight and fecundity were subjected to correlation analysis and correlation coefficient determined according to Mosaheb *et al.*, (2001). All statistical analyses, except for the Chi square χ^2 test analysis (Zar, 1984), were performed using the software package Instant.

RESULTS

Fecundity

Fecundity in *Anadara antiquata* increases with an increase in shell length (Figure 1), following the established relationship. A wide variation in fecundity was observed among *A. antiquata* of the same whole live weight. The mean fecundity stands at $1,652,000 \pm 562,000$ SE eggs female^{-1} with the number of ripe eggs ranging from 549,001 in *A. antiquata* as small as 22.67 mm SL to 5,756,211 in large *A. antiquata* of 69.01 mm SL.

Hermaphrodites were observed from and above 41 mm SL. In this situation *A. antiquata* was observed to have one half of the gonad male and the other female. One part of the gonad was observed to contain oocytes or light orange in colour and the other part spermatocytes or white in colour. The probability of a hermaphrodite to occur within a population was 5.49%.

A plot of shell length of *A. antiquata* against percentage frequency of maturation for males and females indicated that males mature earlier at 31 mm SL than females which matured at 35 mm SL (Figure 2).
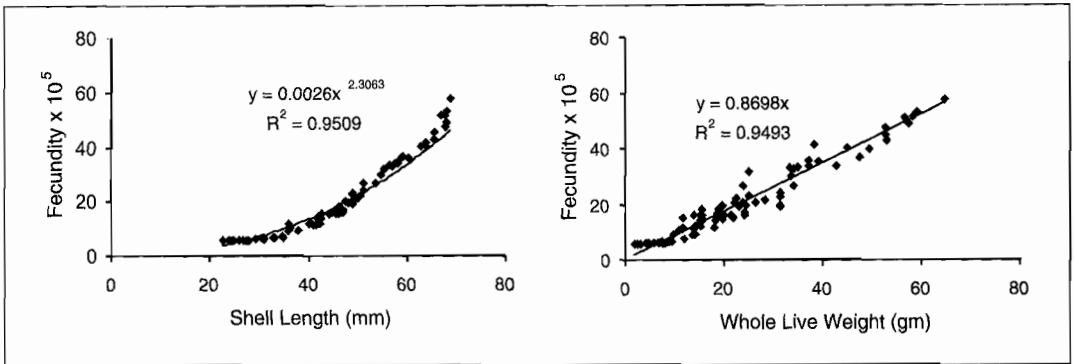

Fig. 1. Relationship between fecundity, shell length and whole live weight of *Anadara antiquata* from Ocean Road Beach, Dar es Salaam, Tanzania, January to December 2001 (n = 199)

Sex ratios, hermaphroditism and length at first maturity

Table 1 indicates the sex ratios of different classes of *Anadara antiquata* analysed from January to December 2001 in which 207 were males, 275 were females and 28 were hermaphrodites, out of 1,951 individuals only about 600 individuals were analysed. Calculation of the χ^2 test suggests that females significantly outnumber males at shell lengths from and above 41 mm SL, but below 41 mm SL the numbers of males and females are not significantly different. The overall sex ratio for *A. antiquata* was estimated from the analysed total number of samples (510 specimens). Overall male to female ratio was 1:1.33, $\chi^2 = 9.593$, DF = 1, p < 0.005, which was significantly different from 1:1 sex ratio.

Growth and morphometrics

Figure 3 shows length-weight relationship for overall data (1,951 specimens) obtained from January to December 2001. Correlation coefficient **r** obtained was 0.9850, P < 0.0001. The slope **b** and condition factor were 2.7134 and 0.0006 respectively. The condition factor calculated from length-weight relationship for *A. antiquata* in this research at Ocean Road Beach was very low compared to that calculated at the same place in 1999. In that year the condition factor was 0.2426 from established relationship,

$W = 0.2426 L^{2.9172}$, r = 0.9845 (Mzighani, 1999).

Population Structure

The size frequency distribution of the cockles, *A. antiquata* measured during January-December

Table 1. Determination of sex ratios using χ^2 test analysis of length classes of *Anadara antiquata* from Ocean Road Beach, Dar es Salaam, Tanzania, January to December 2001 (n = 600)

| Length Class (mm)	Males	Number of Specimens Females	Hermaphrodites	Sex Ratio	Significant Level
1-10	NI	NI	NI	-	-
11-20	36	36	-	1:1.00	$\chi^2 = 0.0000$, DF = 1, $0.995 < P < 0.999$ *
21-30	33	34	-	1:1.03	$\chi^2 = 0.0149$, DF = 1, $0.900 < P < 0.950$ *
31-40	37	41	-	1:1.11	$\chi^2 = 0.2050$, DF = 1, $0.500 < P < 0.750$ *
41-50	42	63	6	1:1.50	$\chi^2 = 4.2000$, DF = 1, $0.025 < P < 0.050$ **
51-60	36	55	14	1:1.53	$\chi^2 = 3.9670$, DF = 1, $0.025 < P < 0.050$ **
61-70	23	46	8	1:2.00	$\chi^2 = 7.6660$, DF = 1, $0.005 < P < 0.010$ **
Total	207	275	28	1:1.33	$\chi^2 = 9.5930$, DF = 1, $0.001 < P < 0.005$ **

NI: Not Identified
* : There is no significant difference from population having 1:1 sex ratio
**: There is significant difference from population having 1:1 sex ratio
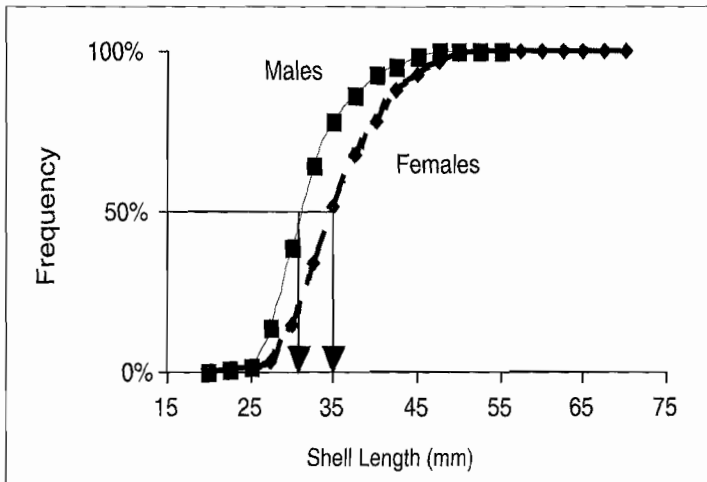
Fig. 2. Length at first maturity of *Anadara antiquata* from Ocean Road Beach, Dar es Salaam, Tanzania, January to December 2001 (n = 138 for males and 199 for females)
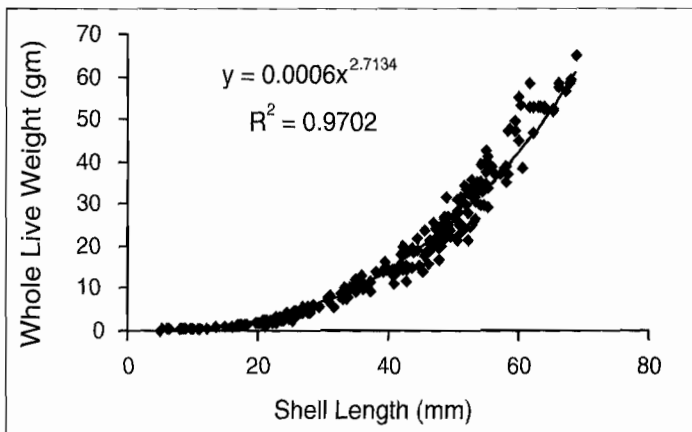
Fig. 3. Length-weight relationship of *Anadara antiquata* from Ocean Road Beach, Dar es Salaam, Tanzania, January to December 2001 (n = 1,951)
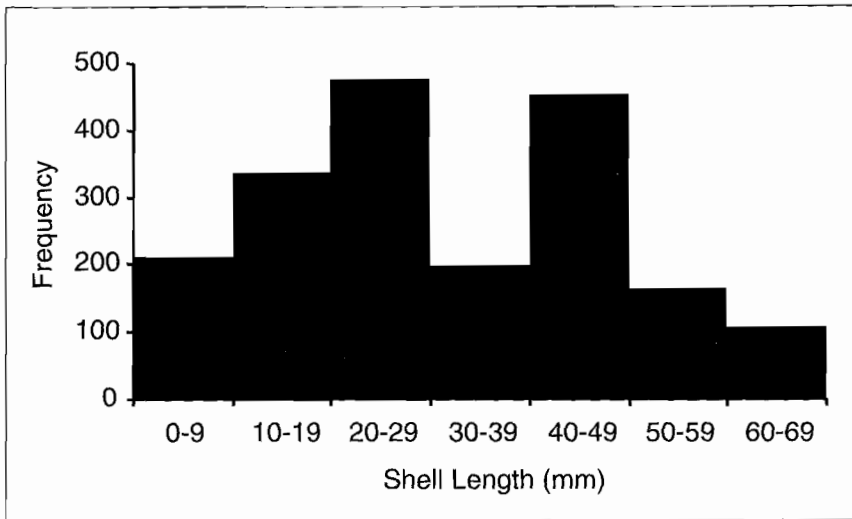
Fig. 4. Length frequency distribution of *Anadara antiquata* from Ocean Road Beach, Dar es Salaam, Tanzania, January to December 2001 (n = 1,951)

2001 in the surveyed area is shown in Figure 4. Population of A.antiquata is dominated by juveniles, which composed 52.5% of the overall sample. The dominant size classes of the population were 20-29 and 40-49 mm SL. The minimum and maximum size recorded were 5 mm SL and 69.01 mm SL respectively. Above 50 mm SL the number of *A. antiquata* decreased.

DISCUSSION

The large number of eggs, about 6 millions eggs per female, produced by *A.antiquata* is important because external fertilization results in losses due to predation, pollution and other environmental factors. Johns & Hickman (1985) reported on snapper predation of spat of the mussel, *Perna canaliculus* seeded on ropes. Young mussels are also predated by the crab, *Scylla serrata* (Beales & Lindley, 1982; Choo, 1983). Large *A. antiquata* provide more internal space for gonad to grow and as they consume more food maximize the chance for increase in gonad size. The best parameter for estimating number of eggs is shell length rather than whole live weight, because of the wide variation in fecundity of *A. antiquata* and the fact that the weight of the eggs would be included in the live weight of individuals.

The dominance of females in the *Anadara antiquata* population in this study agrees with the report of Kayombo (1986). Females outnumber males, possibly because of sexual inversion from males to females, as observed in the pearl oysters, *Pinctada maxima, P. margaritifera, P. fucata* and *Pteria penguin* (Gervis & Sims, 1992), and the tropical oyster, *Crassostrea gryphoides* (Durve, 1965). Females also grow larger than males (Asif, 1979; Kayombo & Mainoya, 1987). The numerical superiority of large females may be due to higher mortality of males. Congregations of members of one sex in a particular area or the greater ability of females to survive in harsh conditions. However, *Anadara scapha* populations in New Caledonia show a different structure in which males outnumber the females (Baron, 1992).

The dominance of females from length class 41 mm SL and above, may be indicative of protandrous hermaphrodites in *Anadara antiquata*. Both male-to-female and female-to-male sex changes can occasionally be seen in gonad sections of pearl oysters (Gervis & Sims, 1992), but usually in bivalves sex changes occur from male-to-female. Hermaphroditism may result from stress (Chellam, 1987, Rose *et al.*, 1990), unstable hereditary sex determining mechanism (Tranter, 1958; Sastry, 1968), or seasonal environmental factors (Durve, 1965) and nutrients (Yankson, 1982).

Males of *Anadara antiquata* mature earlier at 31 mm SL compared to females at 35 mm SL, this agrees with the results of Kayombo & Mainoya (1987) in which *A. antiquata* was observed to mature at 28 mm SL for males and 31-33 mm SL females. Early maturity in males may confer advantages in competition in egg fertilization from highly fecund females. This might be the biological factor to ensure all eggs are fertilized because of protandrous situation experienced by this species.

Condition factor **a** is a constant which can provide an indication of the "well being" of a given species, therefore it can be regarded as an indicator of the food abundance for the given species in a given area or time. Variations in the condition factors over different years may be synonymous with fluctuations and changes in food availability in the coastal waters. Specimens from 1999 showed the highest **a** value, possibly implying that nourishment availability was highest in that year. *Anadara antiquata* is phytophagous (Kasigwa & Mahika, 1991), therefore it is possible that the phytoplankton food might have be more abundant in 1999 than 2001. Differences in the condition factor between this study and the previous study may be attributed to different sampling periods, availability of food and reproductive status. King (1995) explained that condition factors might vary with food abundance and the average reproductive stage of the stock.

Anadara antiquata grows at the same rate in all linear dimensions, which is isometric growth. Mzighani (1999) also reported isometric growth in *A. antiquata*. The correlation coefficient, which is very close to unity, indicates that there is a high degree of correlation between morphometric variables analysed. Not only length and weight which are important but other morphometrics (such as shell height and shell depth) are important factors in growth and production comparison and can be used for monitoring changes within a given species.

Small individuals of less than 30 mm SL dominated the *A. antiquata* population suggesting good annual recruitment. The observed size composition is inconsistent with observation made by Kayombo (1986) in which minimum and maximum shell length recorded were 10 mm and 62 mm. These differences in size composition may be is a function of fishing pressure, environmental factors (Uthicke & Benzie, 1999) or difference in sampling periods. The decrease in the number of *A. antiquata* above 55 mm SL was possibly caused by commercial exploitation, but exploitation pressure in this area cannot be too great as mature *A. antiquata* were reasonably abundant in the samples. The two peaks, one for juveniles and another for mature *A. antiquata*, shows that the resilience of this species to fishing pressure is so good. The mature individuals of *A. antiquata* ensure the recruitment of juveniles while juveniles ensure the growth of matured species.

For sustainable management of *A. antiquata* fishery, it is recommended that certain periods of time or areas be closed to fishing allowing *A. antiquata* to be recruited, grow to the maximum size and spawn at least once before harvesting.

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