

Mud Crab (*Scylla serrata*) Culture: Understanding the Technology in a Silvofisheries Perspective

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Abstract—A study was conducted in Mtwapa creek on the north coast Kenya, during 2005-2007 to evaluate the viability of pens and drive-in cages for mud crab (*S. serrata*) culture as a mangrove management strategy and alternative source of income for local communities. Other objectives were to assess the effectiveness of drive-in cage construction materials (fito and bamboo) in improving mud crab culture and influences return on investment. The applicability of morphometric equations in estimating growth was also tested. Four replicate pens (6 m x 2 m) were stocked with 2 crabs/m² while individual drive-in cages (30 cm x 30 cm x 30 cm) were joined to form ten in one group (1 replicate) and a total of four replicates used. Uniform feeding was applied for all crabs in pens and drive-in cages using a mixture of fish offal and gastropod meat once a day at 10% body weight. Specific growth rate and survival of mud crabs were evaluated together with the cost of investment for the three months culture period. Drive-in cages recorded a significantly better survival and growth rate ($53.2 \pm 12.78\%$; 1.25 ± 0.42 g/day) compared to pens ($31.25 \pm 2.95\%$; 0.68 ± 0.24 g/day) $p < 0.05$ while no significant difference was observed between drive-in cages made of different materials (fito and bamboo). A link between growth rate and size of crab was observed, where growth rate decreased with increasing weight. Moulting associated factors contributed highly (45%) to the total mud crab mortality recorded ($p < 0.05$); mortality also had a strong positive relationship with moulting ($R^2 = 0.79$, $p > 0.05$). Strong relationships existed in morphometric equations between carapace length and weight ($W = 0.0006L^{2.9941}$; $R^2 = 0.86$, $p > 0.05$). The construction costs for pens were three times more than those for a similar number of drive-in cages. Cost-return analysis on a per year basis/50 crabs showed that the use of either bamboo or fito as cage construction material was economically viable with a return on capital investment of 122.3 -181.7%. Therefore the integration of mud crab culture in mangrove forest is feasible in Kenya.

INTRODUCTION

The mud crab (*Scylla serrata*) is the only species of the genus *Scylla* in the Indian Ocean. It has both ecological and economic importance to the marine environment and to the coastal fishing villages (Keenan *et al.*, 1998). The crabs inhabit mangrove forests and are fished commercially throughout the Indo-Pacific. Mud crabs are sought as quality food for local village consumption and for sale in tourist hotels, where they fetch high prices due to their

excellent taste, texture and nutritive value (Cowan, 1984; Trino and Rodriguez, 2002).

The mud crab fishery in the Western Indian Ocean (WIO) region is dependent on artisanal fishermen who use traditional capture methods (hook sticks, pots, traps and seine nets). Mud crab aquaculture in the region is small in comparison to Southeast Asia (Mwaluma, 2002). The demand for mud crabs both from local tourist hotels and, in particular, from the export market is large and is growing rapidly in both Kenya and Tanzania (ASCI-

VOCA 2005). However, due to the unregulated nature of the fishery, there are indications that some local crab populations have decreased significantly as a result of increased fishing effort over time (Francis & Bryceson; 2001; Mahika *et al.* 2005). Mud crab population decline along the Kenyan coast has also been associated with mangrove degradation (Abuodha and Kairo, 2001).

Mangrove forest areas have shown positive correlations with annual fishery catches from adjacent offshore fishing grounds in Philippines (Bagarinao, 1998). Similar results were obtained in Kenya, where high abundance and diversity of juvenile fish were found in forested mangrove areas compared to sandy beach flats (Mirera *et al.*, 2005). Loss of mangroves means loss of fishery, income and livelihood for many coastal inhabitants. Since the mangrove recovery process is slow (Kairo *et al.*, 2001), an alternative source of income for coastal communities supportive of mangrove resource management is vital. Such alternatives can be achieved through small scale mud crab aquaculture in the WIO region. These small scale and low investment grow-out crab farms are located within natural mangrove habitats and designed to produce high yields of crabs while maintaining the integrity of the mangrove ecosystem as nursery and feeding grounds for fish (Trino & Rodriguez 2002).

Mud crabs are successfully cultured in Southeast Asia using wild seed stock for grow-out, where survival is between 30% and 85% based on stocking density and feed under pen (200 m²) culture systems (Trino and Rodriguez, 2002). The survival variations have been associated with the cannibalistic nature of *S. serrata* and change in habitat conditions. This aquaculture industry has expanded very rapidly and produced 85,000 tons of crabs in 2005 at a value of US \$281 millions (FAO, 2007). Similar mud crab aquaculture initiatives in Kenya have been minimal with few trials focusing on pen culture (Mwaluma, 2002).

Initial attempts to culture mud crabs in pens at stocking density of 2 crabs/m² by Mwaluma (2002) yielded a survival of less than 7%, results, which can be attributed to the cannibalistic nature of the crabs and difficulties in harvesting due to lack of adequate drainage in the pens. In the same study, a higher specific growth rate was recorded for crabs in the size group 80.0 - 99.9 mm carapace

length, compared to those of less than 19.9 mm carapace length. Attempts to increase the weight of undersized sub-adult mud crabs (< 300 g) in drive-in individual cages for a shorter period (< 1 month) in Tanzania showed a mortality of 10% per month compared to the wild mortality of 2% per month (ASCI-VOCA, 2005 and Mahika *et al.*, 2005), making such efforts unsustainable.

Previous mud crab culture studies in Kenya have been undertaken in Mtwapa creek, the site of the current study, which uses modifications of the previous methods (Mwaluma, 2002). This study was undertaken to compare growth and survival of mud crabs in pens and drive-in cages built on top of the mud using 'fito' sticks or bamboo with a cover on top. The study also evaluated the return on investment from drive-in cage culture with different cage construction materials in addition to establishing quick growth monitoring morphometric equations.

MATERIALS AND METHODS

The study was carried out at Mtwapa mangrove creek near Kwetu Training Centre (03° 56. 896' S and 039° 42. 746' E) at about 20 km north of Mombasa city (Figure 1). The site is an intertidal mangrove area with small natural channels, which tend to make the upper layer of the substrate sandy and the lower section muddy. The channels help to completely drain the area at low tide and provide for rapid influx of ocean water as the tide rises. The site was inundated twice daily at each high tide. The culture area was covered by natural mangrove stands, being dominated by *Rhizophora mucronata*, *Sonneratia alba* and *Avicennia marina* at a ratio of 4: 2: 1 (per meter square) respectively as counted during the experimental period. The general tree height in the area was approximated to be between 3 m and 8 m and a canopy cover of more than 60%.

All the culture structures were designed following silvofisheries techniques such that the function of mangroves as nursery grounds for commercially exploited finfish and crustaceans were not hampered (Trino and Rodriguez, 2002). Four replicate rectangular pens of size 6 m x 2 m were enclosed with 'uzio' (sticks tied together to form a mat) as used by local fishermen to trap fish in mangrove channels and other intertidal areas. The

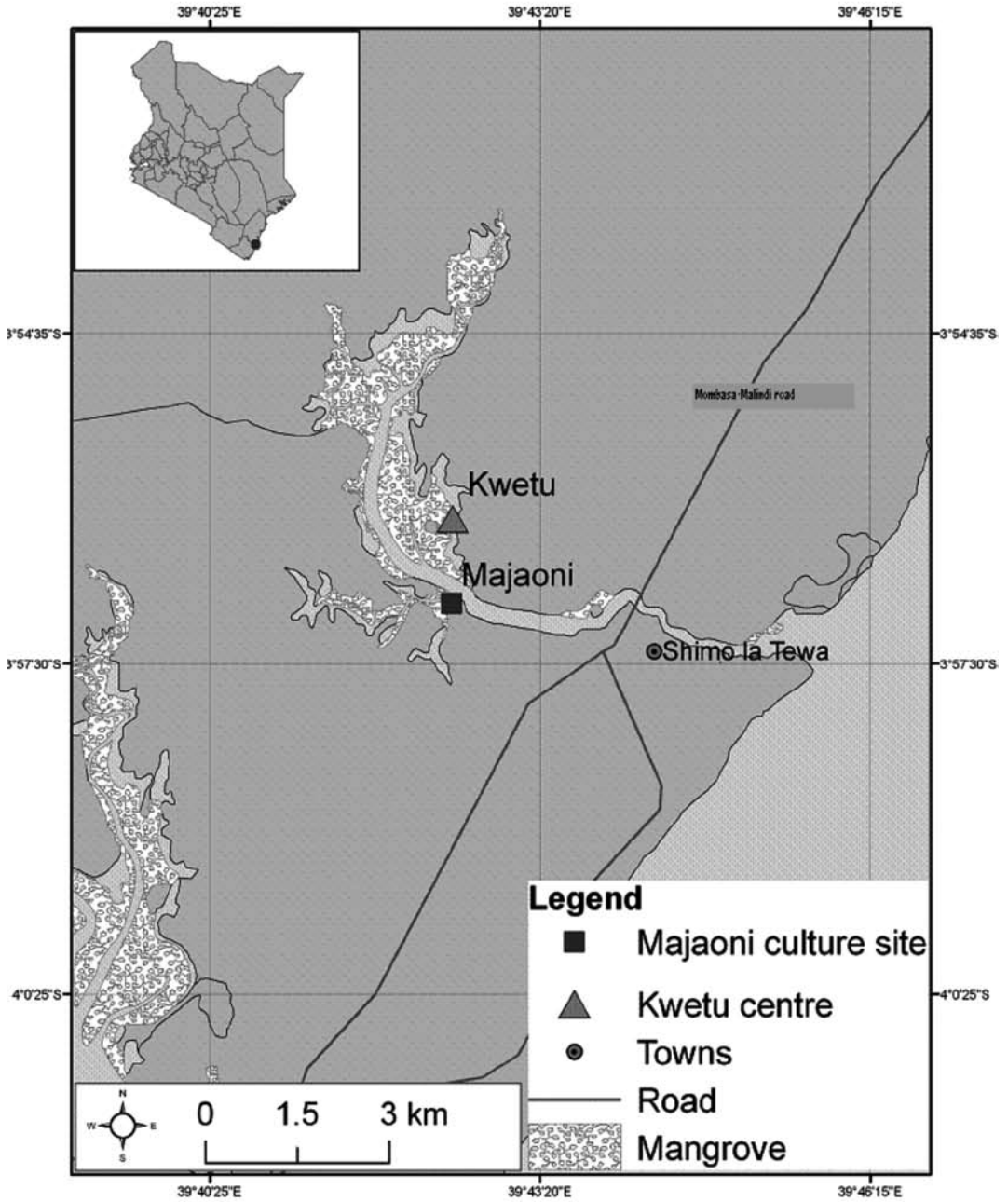


Fig. 1. Map showing Mtwapa creek and the mangrove area near Kwetu Training Centre where the study was carried out

uzio was lined from the inside with ‘pokomo’ mats and the two tied onto a framework of mangrove poles as support structures at intervals of 2 m with an effective height of 3 m. The bottom margins of the Uzio and pokomo mat were buried 60 cm into the mud by digging channels along the pen area and trimming some mangrove roots without mangrove

tree felling. Two small canals (50 cm x 50 cm x 30 cm) were dug in each pond to maintain water in the pen during the low tides.

In the same mangrove forest site, four replicate drive-in individual mud crab cages each 30 cm x 30 cm x 30 cm were constructed using each construction material (fito and bamboo) (see Figure

2). The drive-in cage structure was constructed in the open sections with minimal root trimming and taking into consideration the characteristic of *S. serrata* to bury itself into the mud. Lower margins of the drive-in cages were buried about 30 cm while the above ground margin was also 30 cm high. Half of the cages were constructed using split bamboos that were 60 cm in length and the other, fitos (small sticks of the neem tree and other coastal thickets). The bottom sections of the drive-in cages were not covered purposely to allow for the crab to burrow and hide itself in the mud at low tide, while the upper section was covered with a lid made of either bamboo or fito. The cages were sewn together using binding wire or thin manila ropes. Cage covers were permanently attached at one point and the other tied with ropes to allow opening only for monitoring and daily feeding to ensure no crab escape at high tide.

To avoid further degradation of the mangrove benthic biodiversity and roots, a boardwalk about

1 meter above the ground was constructed using boriti (mangrove poles) and timber. This improved accessibility during monitoring and feeding, in addition to reduced mangrove root rot from constant trampling. Also the number of mangrove tree stands in and around the pens and cages was counted, while intactness of the root system was assessed to enable comparison at the end of the experiment. Daily tidal flushing was adequate to prevent deterioration of water in this study (Trino and Rodriguez, 2002) however; incoming tidal water was monitored weekly for temperature, pH, salinity and dissolved oxygen.

Crab fishers were contracted to collect crabs from the creek for stocking in this study. Their main capture methods were hook sticks and seining. The former was used to get them out of their holes in the mangroves at low tide while the later was used to seine them along the shores at both low and high tides. In total 480 crabs were collected and used for the two culture trials that took three



Fig. 2. A drive-in mud crab cage set among mangrove prop roots near Kwetu Training Centre showing the ten individual compartments and cover installation to prevent escape

months each. Stocking was done for both males and females without regard to sex ratio considerations, while the crab stocking size was less than 350 g but more than 50 g total weight. The stocking density in pens was 2 crabs/m² with mixed sex while cages were stocked with one crab per compartment. At stocking all crabs were examined for morphological condition, total weight in grams was recorded and carapace width and length measured to the nearest millimeter using vernier calipers.

Daily monitoring of cages and pens was undertaken and the numbers of moulted crabs were recorded along with their mortality. Mortality was correlated with stage of moulting, i.e. at the beginning of the process, midway through and after successful moulting as well as predation or cannibalism after a successful moult. Escape by cutting walls or poor covering or poor construction was also noted. Crabs in both treatments were fed with a mixture of fish offal and gastropod meat at 10% body weight daily at incoming tide. The feed was chopped into small pieces before being weighed and spread in the pens and individual cage compartments. Body weight, carapace width and length of crabs were measured monthly. Sampling was carried out in the early morning at low spring or neap tide and all crabs in the cages were sampled while only 10% of those in the pens were sampled to reduce stress, due to the tedious capture exercise of getting them from their holes. Harvesting was done at the end of three months when an economic analysis was undertaken.

The mean body weight, growth rate, survival, and cost of production were calculated from the total harvest. Means of these parameters were compared

by analysis of variance and Duncan's multiple range tests at 5% level of significance. Cost benefit analysis for cages was calculated to establish return on investment while morphometric equations were calculated from all the crab populations involved in the study.

RESULTS

The range of values for incoming Indian Ocean water quality parameters recorded during the culture experiment were: salinity 25-34 ppt, temperature 28-30°C, pH 7.5-8.9 and dissolved oxygen 5.5-12 mg/l which tended to vary slightly with time of day. No physical effect was observed on the mangrove tree stands at the end of the culture experiment in the pen and cage culture sites apart from the less than 5% mangrove prop root trimming during construction of the culture facilities.

Table 1 shows the mean weight and carapace length (initial and final), overall growth, growth rate and survival of crabs stocked in drive-in cages and pens. Growth rate and survival of crabs showed no interaction within treatments (cages and pens). Therefore data were pooled for each treatment and tested with ANOVA for between treatment differences. There was a significant difference in growth rate between pens (0.7 g/day) and cages (1.3 g/day) (Table 2). Significant differences were also recorded in survival and final weight attained (Table 1). There were no significant differences $p > 0.05$ observed for initial stocking weights, carapace widths and growth.

Growth rate was dependent on crab size. Small crabs had higher growth rates, which

Table 1: Mean \pm stdev pooled initial and final weight, carapace width (CW), growth, specific growth rate (SGR) and survival of mud crabs (*Scylla serrata*) reared in pens and drive-in cages with their n-values

Parameter	Cages	n	Pens	n
Initial weight (g)	258.6 \pm 123.5 ^a	140	122.8 \pm 59.1 ^a	340
Final weight (g)	336.5 \pm 106.5 ^a	75	146.1 \pm 73.4 ^b	106
Growth (g)	67.9 \pm 16.9 ^a	140	50.6 \pm 14.9 ^a	340
Initial carapace width (mm)	106.9 \pm 1.8 ^a	140	85.3 \pm 1.7 ^a	340
Final carapace width (mm)	118.6 \pm 1.7 ^a	75	89.2 \pm 1.7 ^b	106
Specific growth rate (g/day)	1.3 \pm 0.4 ^a	140	0.7 \pm 0.2 ^b	340
Survival (%)	53.2 \pm 12.8 ^a	140	31.3 \pm 2.9 ^b	340

* Data were pooled for each culture treatment since there were no interactions within the culture systems (pens and drive-in cages). Values with similar superscripts for the same parameters in the treatments are not significantly different ($p > 0.05$). n: represents the number of crabs involved when making the calculations for both cages and pens

Table 2: Analysis of variance and Duncan multiple range test results comparing mud crab growth rate in pens and drive-in cages

Source of variation	SS	Degr. of Freedom	F	P
Intercept	6.77	1	34.89	0.000
Cage* pen	0.60	1	3.11	0.047
Error	3.10	82		

decreased with increase in size (Figure 3). Moulting associated factors were found to contribute to 45% of mortalities in both cages and pens (Figure 4), while cannibalism contributed 10% and escape 20%. There was a strong positive relationship ($R^2 = 78.6\%$) between mortality and moulting (Figure 5) indicating that if moulting associated mortalities were controlled, mud crab survival could be more than 70% and therefore more profitable.

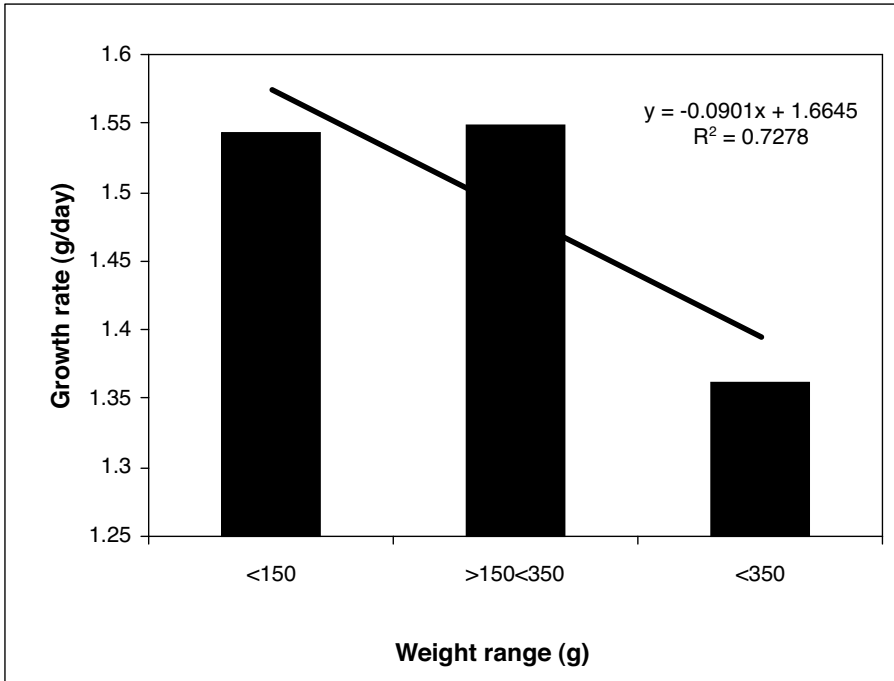


Fig. 3. Influence of weight on growth rate in mud crabs (*Scylla serrata*) stocked in drive-in cages over a three months culture experiment

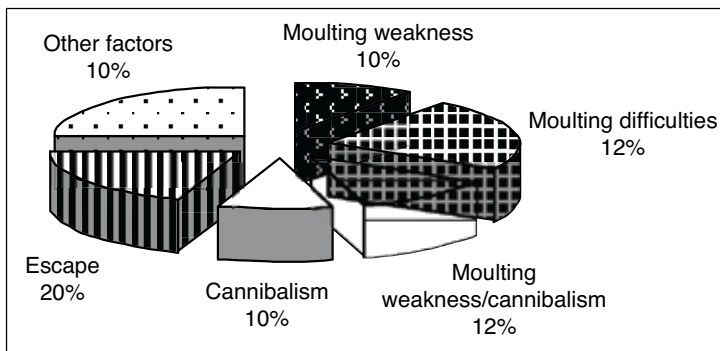


Fig. 4. Contribution of factors towards survival of mud crabs as observed during the three months study for the two culture systems. (All mortalities that occurred on successfully moulted crabs within 48 hours without having any physical injuries were classified as “moulting weakness”; mortalities that occurred before a crab could successful moult, were considered to have “moulting difficulties” while those that moulted successfully and then cannibalized or predated on within 48 hours were classified as “moulting weakness/cannibalism”)

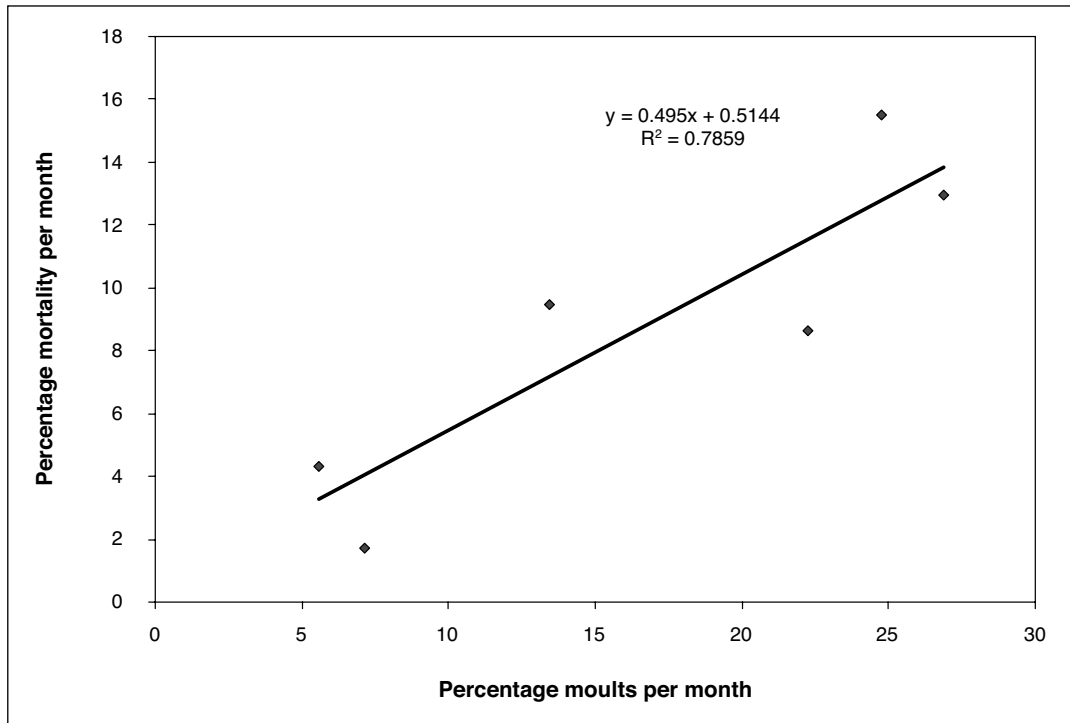


Fig. 5. Relationship between mortality and moulting of mangrove mud crab in pens and cages during the three months culture period

In comparison of drive-in cage culture structures made of bamboo and fito, there was no significant difference in growth rate (bamboo- 1.29 g/day, fito- 1.24 g/day; $P > 0.05$); survival (bamboo- 48.9%, fito- 57.7%; $P > 0.05$); or moulting frequency (bamboo- 38.1%, fito- 47.6%; $P > 0.05$). However, construction cost for one pen holding 24 crabs at rate of 2 crabs/m² was 100 USD, which was effective only for two culture periods of 3 months while drive-in cages with similar culture capacity was 30 USD with an efficiency of more than 4 culture periods (1 year), based on the long term culture observations after the three month experiments. Other advantages of a drive-in cage culture over pen culture systems included easy individual crab management and monitoring, assured feed allotment for individual crabs, feeding adjustment, cleaning and repair of the culture set up and higher culture capacity within a small space.

Morphometric analysis indicated a strong relationship between biomass and carapace length ($R^2 = 0.86$, $p > 0.05$) for combined males and females (Figure 6). There was a similarity

between the relationships obtained for individual sexes (females- $W = 0.002L^{2.6889}$; $R^2 = 0.89$, $p > 0.05$; males- $W = 0.0002L^{3.2053}$; $R^2 = 0.89$, $p > 0.05$) and that of combined sexes (male and female) suggesting dual applicability. The results suggest that the combined equation can be used to calculate mud crab biomass or carapace length given either of the parameters that could help to reduce sampling related stresses.

Analysis of drive-in cage building materials (fito and bamboo), was found to be effective on the short term using bamboos by reducing the rate of crab escape while continued culture experiments using the same structures over one year, bamboos tend to rot faster than fito. The total investment (Table 3) comprised capital investment cost and operating costs (variable and fixed costs). Labour and feeds contributed the highest percentage to costs for both fito cages (70.2%) and bamboo cages (65.2%). The annual net profit for fito drive-in cages was more (129.38 USD) than for bamboo (93.76 USD) which provided a higher return on investment in the former.

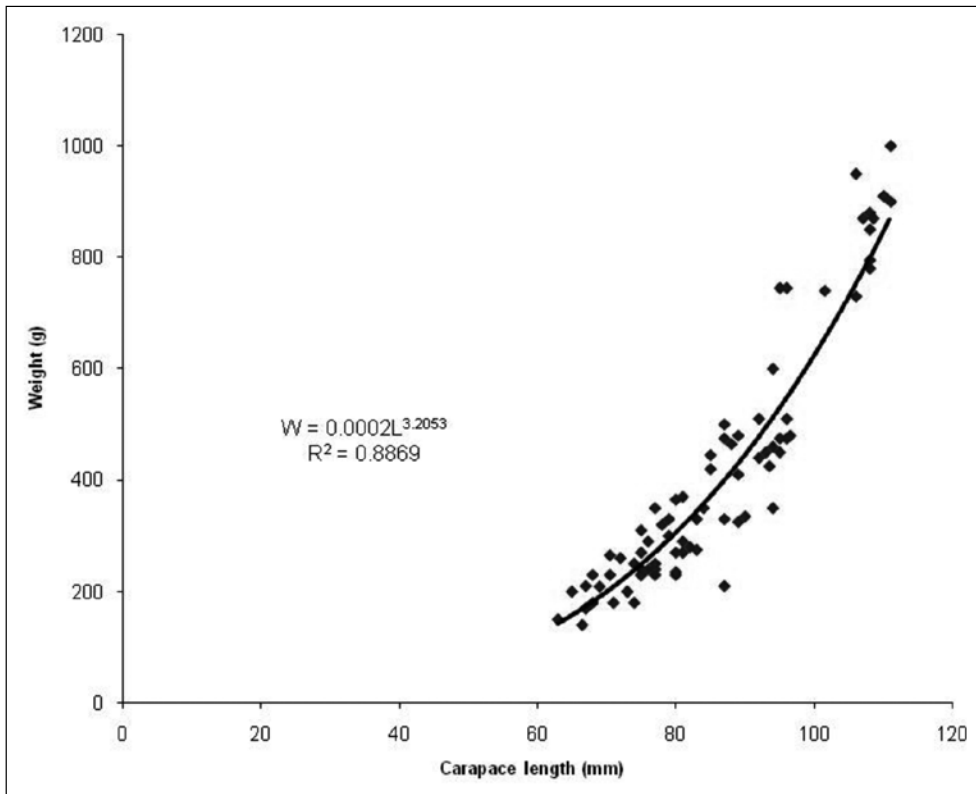


Fig. 6. Morphometric relationships (weight / carapace length) in mud crabs for combined sexes

Table 3: Cost-return analysis of mud crab culture using drive-in cages in a mangrove forest comparing fito sticks and bamboo as cage construction materials

1. Technical basis	Details	Fito	Bamboo	
Stocking rate/run		50pcs	50pcs	
Average weight at stocking		300g	300g	
Survival at harvest		57.74%	48.96%	
Average daily growth		1.24g	1.29g	
Culture period		3 months	3 months	
Number of cropping/year		4	4	
Average wgt at harvest		411.6g	416.1g	
Total yield per run		10.03kg	8.52kg	
2. cost of production/yr (USD)				
	Fito		Bamboo	
	Quantity	Cost USD	Quantity	Cost USD
Bamboo (pc)			3	6.08
Fito(roll)	5	2.02		
Binding wire(roll)	2	2.43	2	2.43
Labour	1.5	4.05	2	5.41
Crab seed stock	50	10	50	10
Repair and maintenance	0.68/run	2.72	0.68/run	2.72
Feeds and labor	12.5USD/run	50	12.5USD/run	50
Total costs		71.22		76.64
3. Cost and return (USD)				
sales of production/run (5USD/kg)		50.15		42.6
sales of production per year		200.6		170.4
Net profit (USD)		129.38		93.76
Return of investment		181.7%		122.3%

DISCUSSION

Mud crabs in pens do not damage enclosed mature trees suggesting that pens may be set up in sites with fully grown trees, but not in mangrove seedling areas, where they may cause damage (Dahdouh Guebas *et al.*, 1998). The observation was quite different in cages, where in the first week crabs aggressively cut both the fito and bamboo in order to escape. Daily monitoring of cultures will also likely result in a reduction of illegal mangrove cutting, and thus helps sustain mangrove forest management. The boardwalk helped to reduce disturbance and deterioration of benthos.

The culture area was flooded daily by tidal ocean water that reduced local effect on water quality. Water quality values recorded in this study were within the optimal ranges for mud crabs as recorded by previous studies in the area (Mwaluma, 2002) and elsewhere (Baliao *et al.*, 1999; Chang, 1997; Trino *et al.*, 1999a,b and Hill, 1980). Daily tidal flushing in the culture area was seen to be adequate in preventing deterioration of environmental quality variables.

Mud crabs grew in drive-in cages (individual cages) faster than in pens at a stocking density of 2 crabs/m² as indicated by the specific growth rates and final weight and carapace width attained. Specific growth rates were higher than those observed by Trino and Rodriguez (2002) though their culture period was 160 days compared to the present study of 90 days. The current growth rates were also higher than those recorded by Mwaluma (2002), whose lower growth rates could be associated with the lack of a daily flooding tide leading to high water temperatures in the pens. Significant growth in drive-in cages compared to pens could be associated with the reduced energy loss from movement in the 'zero grazing' cage-unit and its subsequent conversion to growth compared to animals kept in pens where movement is not so restricted. The study observed a decrease in mud crab growth rate as biomass increased, a feature which has been documented by other workers (Mwaluma, 2002; Bensam, 1986). Bensam (1986) found an increase in weight ranging from 2.3 times in crabs in the weight range 51-60 g, to 3.5 times in the weight range from 1-10 g during a period of

3 months. Such a trend is most likely linked to the sexual maturation occurring when the carapace width is about 75.0 mm. From this stage onwards much of the food intake goes to reproduction (Tongdee, 2001) at the expense of growth.

An investigation of the effect of culture facilities on survival indicated lower values for pens compared to cages. Survival in pens was 31.3%, being higher than those reported by Mwaluma (2002), but similar to those by Trino and Rodriguez (2002) at a stocking density of 1.5 crabs/m², though the survival was significantly lower than that recorded by Trino *et al.*, (1999a) at a stocking density of 0.5 crabs/m². Lower survival in the current study may be related to the larger size of crabs stocked, or higher density, which may have resulted in increased cannibalism. Drive-in cage culture significantly increased survival as observed in other studies using pen culture (Chang and Ikhwanuddin, 1999). Continued use of the drive-in cage culture facilities over one year, revealed that bamboo or fito did not significantly affect growth or survival. Therefore both materials can be used interchangeably depending on availability as a strong point for mangrove conservation.

Despite the many factors causing mortality in cultured mud crabs, the highest percentage was attributed to moulting associated factors (45%); inability to successfully moult, mortality immediately after moult and injury on soft moulted bodies. Studies in Indonesia by Cholik and Hunafi (1992) pinpointed the main cause of mortality as moulting, while Fielder *et al.* (1988) observed that moulting and post moult soft crabs are easily cannibalized and predated upon as observed in this study. This could be the reason for higher survival in the individual drive-in cage compartments observed in this study where the chance of cannibalism and predation were limited compared to culture in pens. Moulting stress may be another cause of associated mortalities. Application of the morphometric equations developed in this study, which are similar to those of Khan and Alam (1991), might be used in the reduction of such mortalities.

Due to higher construction cost for pens, no profit could be realized from the system. They were therefore eliminated from the cost-benefit analysis in community mud crab culture. Production, net profit and return on investment were higher in mud

crab cages made of fito compared to those made of bamboos. Culture of more than 50 mud crabs at a time in drive-in cages yields more than 120% return on investment in one year similar to what has been established in Philippines using pens due to the cheap cost of construction materials (Agbayani, 2001; Trino and Rodriguez, 2002). Net profit and return on investment increases with number of mud crabs cultured after the minimum of fifty. There are also chances for further improvement in profitability through reduction in moulting-related mortalities, escape and better harvesting of crabs as they attain marketable size.

CONCLUSION

It is evident that mud crab culture in drive-in cages improves both growth and survival, and is low cost and profitable in the long run compared to pen culture. The use of either pen or drive-in cage culture in mangroves is both economically and ecologically viable since there is no need to remove mangroves or build aquaculture ponds. In addition, the use of fito sticks or bamboo in construction of mud crab cages has no significant effect on profitability in the long run; however, bamboo planting is encouraged for its multipurpose use to ease pressure on mangrove forests.

For effective mud crab aquaculture in East Africa, there is a need to address the issue of seed supply, which calls for further studies on the recruitment and juvenile settlement of *S. serrata*. More research is needed to understand mud crab biology particularly moulting and its impact on survival as a key factor in successful mud crab aquaculture.

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