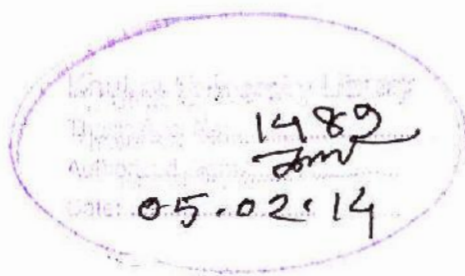


**Commercial feasibility of monosex culture of female
mud crab (*Scylla olivacea*) in bamboo pens from
Southwest Bangladesh**



**A thesis
By**

**Md. Forhad Uddin
Examination Roll No. MS-010616
Session: 2000-2001**

The thesis submitted to the Fisheries and Marine Resource Technology Discipline in
partial fulfillment of the requirements for the degree of

Masters of Science

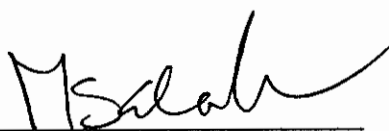
In

Fisheries and Marine Resource Technology

August, 2004

**Commercial feasibility of monosex culture of female
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Southwest Bangladesh**

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DECLARATION

This results submitted in this thesis are entirely of the candidates own investigation and no part of this results has been accepted for any degree, nor it is being concurrently submitted for any degree.

Supervisor



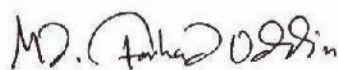
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***Dedicated
to
My beloved parents***

Acknowledgements

The author is gratefully acknowledged to his supervisor Dipak Kamal, Associate Professor, FMRT Discipline, Khulna University, Khulna, Bangladesh for his close suggestion to conduct this study. The author is also thankful to the Head of the FMRT Discipline, Khulna University, Khulna, Bangladesh. Author is thankful to the authority of SUFER Project, DFID-UGC for financial support of the research work. Author would like to thanks to SHUSHILON, a local NGO at Munshiganj, Satkhira, Bangladesh for their logistic support and two poor women crab fisher who participated in the field research. Thanks are also due to all teachers, seniors, classmates and friends of the Author.

The Author

Abstract

The feasibility of female mud crab (*Scylla olivacea*) culture in 100 m² bamboo pens was assessed in terms of growth, survival, production FCR and ROI, through three stocking densities (SD) (0.25, 0.5 and 1 crab/m²) with three replicates for each SD for 60 days at Munshiganj of Satkhira district (22°12'19.7" N; 89°09'1.8" E), Bangladesh from October to December, 2003. The average body weight of crab at stocking were 141.69±2.38, 120.27±1.93 and 102.69±1.66 g for SD 0.25, 0.5 and 1 crab/m² respectively. The crabs were fed with low cost trash fish (Tk. 20/kg) at 5% of there biomass per day during morning and evening time. The water height in the earthen pond was maintained between 0.7 and 1 m. Water in the pens was changed during spring tide phases fortnightly. The water temperature, salinity, DO and pH in the pens were ranged from 27.8 to 29.9 °C, 9 to 14 ppt, 4.8 to 6.0 ppm and 7.5 to 7.9 respectively. After 60 days the mud crab attained an average size of 230.0±2.65, 218±2.65 and 163.0±2.0 g for SD 0.25, 0.5 and 1 crab/m² respectively by body weight. The best average growth both by length (33.12±1.46 mm) and weight (97.73±2.05 g) attained for SD 0.5 crab/m² followed by 0.25 and 1 crab/m². The highest survival (83.33±2.31%) was found for SD 0.25 crab/m² followed by SD 0.5 and 1. The highest production (9.67±0.53 kg/100 m²) was achieved at SD 1 followed by SD 0.5 and 0.25. The lowest FCR (1.69±0.11) was found for SD 0.5 followed by 0.25 and 1. The best return on investment (172.43%) was found for SD 0.5 followed by SD 0.25 and SD 1. The capital cost could be returned after minimum time 0.71 year with SD 0.5. A significant negative correlation was found for growth rate and survival with SD. While, the production and FCR showed significant positive correlation with SD. However, ROI showed a significant negative relationship with SD. The survival and production were found to be better with SD 0.25 and 1 respectively. Considering growth, FCR and ROI a comparatively better performance was achieved with SD 0.5 over the 0.25 or 1 crab/m². Therefore, a SD 0.5 crab/m² with a body weight of 110-130 g female crabs could be suitable for commercial farming in bamboo pen system in Bangladesh.

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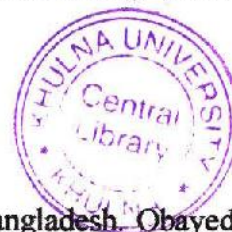
Introduction

1.1 Background

The mud crab, commonly known as mangrove crab of the genus *Scylla* (Decapoda, Portunidae) are the most commercially important brachyuran fauna distributed widely in the estuaries and coastal waters with a close association with mangrove ecosystem (Stephenson, 1962; Macnae, 1968; Macintosh, 1984; McGuinness, 1998) and support substantial artisanal fisheries in many part of the Asia-Pacific region including Bangladesh (Overton and Macintosh, 1997 & 2002; Radhakrishnan, 2000; Azam *et al.*, 1998; Sivasubramaniam and Angell, 1992; Devi, 1985). The farming of mud crab has traditionally been a small-scale activity in Indo-West-Pacific region, supported by artisanal fisheries. The mud crab farming activities started as a way to improve the value of the catch by holding them as value added products as a family level occupation to the coastal fisherfolk. It has proved to be quite profitable provided there is an adequate supply of crabs from the local fishery (Overton and Macintosh, 1997).

The mud crabs (*Scylla* sp.) are abundant throughout the coastal water of Bangladesh (Shafi and Quddus, 1982; Bhuiyan and Das, 1976; Chantarasri, 1994) particularly in and outside of the Sundarban Reserved Forest (SRF) and tidal rivers outside the SRF in Khulna-Bagerhat-Satkhira districts (Khan and Alam, 1992; Acharya and Kamal, 1994; Azam *et al.*, 1998; Kamal, 2002). The mud crab fishery in Bangladesh is artitional, absolutely dependent on the wild catch from the swamp of SRF, tidal rivers and canals and tide fed traditional shrimp *ghers* by using different types of gears (Azam *et al.*,

1998). The mud crab business is exclusively export-oriented which was started in 1977 and grown up rapidly by the '90s (Ahmed, 1992; EPB, 2002). About 7,000-10,000 MT mud crabs have been harvested from this region in 2001-2002 (Kamal *et al.*, 2003; Zafar, 2004). High protein (16% in meat) content (Hossain, 2003) and distinctive flavor makes mud crab one of the most delicious table food items to the consumers in the world especially in the SE Asian countries (Thongkum, 1988). The major export market of live mud crab includes Taiwan, Singapore, Hong Kong, Malaysia, Thailand, USA and a few European countries (EPB, 2002). The export earnings from live mud crabs had increased steadily from 2,000 US\$ in 1977-78 to over 5.8 million US\$ in 1995-96 (EPB, 2002) and it ranked 3rd in the frozen food export earnings in the country (EPB, 2002).



A few studies have been conducted on the culture of mud crab in Bangladesh. Obayed (1998), Kamal (2002) and Zafar (2003) conducted research on the fattening of mud crab using rejected thin crabs. While, Saha *et al.* (1999) has conducted an experiment on the culture of mud crab in brackish water pond in Bangladesh. Although the culture practice is originated as small-scale activity in China (Kwang Tung Province) over 100 years ago and spreading across Asia over the last 40 years (Overton and Pushpakumara, 2001; Overton and Macintosh, 2001). Recently it has been cultivated successfully with 50-100% profit within 3-5 months in small-scale households in the Philippines, Vietnam, Malaysia, Thailand and India (Overton and Pushpakumara, 2001; Triño *et al.*, 1999; Triño and Rodriguez, 2002). The experimental culture of mud crab in pen system was carried out overseas by Triño and Rodriguez (2002) and Mwaluma (2002).

where

1.2 Problems

Comparatively good price and high market demand for live mud crabs (Kamal *et al.*, 2003) have been contributed to a huge entry of unemployed local poor in mud crab fishing both legal and illegal ways (Anon, 2000). In addition, a number of black tiger shrimp (*Penaeus monodon*) post larvae (PL) collectors have been switched over to the mud crab fishery as a consequence of declination of PL abundance over the past few years and the recent ban on PL collection inside the SRF (Anon, 2000; Frankenberger, 2002). The excessive fishing pressure on the mud crab stock in and outside the SRF has already been resulted in a sharp declination in production and export earnings over past few years (EPB, 2002). In addition, the catch-per-unit-effort (CPUE), and hence, the per capita income of mud crab fishers has declined significantly in recent years in comparison to past few years (Kamal *et al.*, 2003).

1.3 Rational?

For the past several years environmental problems experienced in shrimp farming, especially disease and the resulting drop in income from shrimp, has created a global interest in finding alternative species to culture that could promise comparable profits to the shrimp farmers. The mud crab is widely regarded as one of the most promising alternatives to penaeid shrimp (Overton and Macintosh, 1997). In addition, the current trend of over fishing and consequent declination of mud crab stock in natural production could be minimized in two ways—a) by introducing stock enhancement program through sea ranching and b) by introducing culture practice of mud crab using small crabs. There is a huge scope to introduce the small-scale commercial culture practice of mud crab in Bangladesh as there are huge areas of tide-fed low land, canals and creeks in the SouthWest region of Bangladesh and mud crab seeds are available in tidal rivers and

canals round the year. The price of female mud crab with ripe gonad is at least two times higher than the male crabs of same size. Hence, fattening of thin (without egg) crabs has been developed by mud crab depot owners in the SW Bangladesh in recent years which is suffering from unsteady supply of thin crabs as rejected from export points located in Dhaka (Kamal, 2002).

The development of small-scale mud crab culture technique using small seeds from wild sources and low cost feed can be a good avenue in generating a new alternative income option to the local poor living within the impact zone of the SRF which includes Khulna, Bagerhat, Satkhira, Pirojpur and Borguna districts of Bangladesh. Such income generating activity can reduce current dependency of thousands of local poor on natural resources of the SRF. On the other hand, it can help in improving their current livelihood condition. The demand of juvenile mud crab for cultivation may create a seed business and an extra income to the shrimp fry collectors.

1.4 Objectives

1.4.1 General objective

The present study was conducted to evaluate the technical and commercial feasibility of monosex female mud crab (*Scylla olivacea*) culture in bamboo pens from SouthWest (SW) Bangladesh.

1.4.2 Specific objectives: The specific objective was–

- i. to assess the optimum stocking density for the culture of female mud crab;
- ii. to assess the size of female mud crab at stocking.

1. What is the...

Review of literatures

2.1 Mud crab farming

The farming of the mud crab is done by two methods. The first: growout, the young crabs under 150 gm are grown in earthen ponds for a period of 2 to 6 months and the second: known as crab fattening, this method is used for fatten the thin crab or soft-shelled crab or water crab or post molt crab to fill up their meat or getting fat in a shorter period (10-30 days). For female crab, it is necessary to fulfill eggs in the body (Pripanapong and Tongdee, 1998; Overton and Pushpakumara, 2001).

2.1.1 Mud crab farming in Bangladesh

A few studies have been conducted on the mud crab farming in Bangladesh (Obayed, 1998; Saha *et al.*, 1999 & 2000; Kamal, 2002; Zafar, 2003). Obayed (1998), Kamal (2002) and Zafar (2003) conducted experiment for developing fattening technology, while, Obayed (1998) and Saha *et al.* (1999 & 2000) conducted the experimental culture of mud crab in Bangladesh.

Obayed (1998) conducted an experiment on the fattening and culture of mud crab (*Scylla serrata*) from Mitakhali, Mongla of Bagerhat district, Bangladesh for 120 days. The size of pond was 600 m² for fattening with stocking density (SD) of 0.8 crab/m². While, two ponds P1 and P2 of 600 m² and 1,450 m² in size were used for growout culture with SD of 1 crab/m². The water temperature 9.2-31 °C, salinity 4.8-9.5 ppt, DO 3.5-6.0 ppm and pH 6.2-8.52 was reported during the culture period from September to

December, 1995. The survival rate was reported at 55% from fattening pond and 63.3-64.2% from growout ponds. The FCR and SGR was measured from crab fattening pond were recorded at 1.8 and 1.96 %/day respectively, while for growout ponds, the FCR and SGR were reported at 2.09 to 2.5 and 1.89 to 1.9 %/day respectively.

Kamal (2002) developed fattening technology for female mud crab (*S. serrata*) in small brackish water ponds using bamboo pens in Kopilmuni, Paikgacha of Khulna district, Bangladesh. In the first experiment thin females of 170-240 g were fattened with Tilapia feed at a rate 10% biomass of the stocks per day with SD 1, 2 and 4 crab/m² for 21 days. The maximum survival rate, production rate, FCR and profit were found with 1 crab/m² density. The survival rate of mud crabs with SD 1, 2 and 4 crab/m² were reported at 90.91%, 64.13% and 42.16% respectively that was inversely correlated with the stocking density. The production rate was the maximum (0.325 kg/m²) for stocking density 4 crab/m² and the minimum (0.18 kg/m²) for stocking density 1 crab/m². The FCR was the minimum (2.16) and the maximum (4.77) with the SD 1 and 4 respectively. The growth gain were 12.68, 14.8 and 14.28 g with SD 1, 2 and 4 crab/m². Stocking density was reported to be the positively significant with the production rate ($r=0.995$) and FCR ($r=0.983$). In the second experiment, two types of feed (50% Tilapia + 50% small shrimp and Tilapia only) were used for mud crabs of same body weight at a stocking density of 1 crab/m². The growth of the fattened crab was reported at 92 g (SGR 6.57 g/day) in BW in 14 days. More than 95% crabs attained fat in two weeks. The water temperature, salinity and pH of the experimental fattening ponds were varied from 23 to 31°C, 10.38 to 17.69 ppt and 8.39 to 10 respectively.

Zafar (2003) conducted an experiment on the fattening of *S. serrata* in cell (7×3×1 inch in size) and open cage (7×3×2 inch in size) through participation of poor coastal people in Bangladesh. The crabs were fed with fresh eel and salted eel at a rate of 5% of crab biomass for 14 days. The water temperature, salinity and pH were varied from 25 to 28 °C, 0 to 10 ppt and 7 to 8 respectively. The SGR for male crab (1.5-1.76 g/day) was higher than the female crab (0.61-1.14 g/day) in cell system. The SGR both the male (1.32 g/day) and female (0.54 g/day) was lower in open cage than the cell type cage. The maximum survival (98.2-98.4%) was reported for the cell cage and the minimum (87.5%) for the open cage. Lower water salinity and cannibalistic behavior of mud crab were reported be responsible for higher mortality of stocked animals. The cell cage system is more profitable and sustainable for the marginal poor coastal people of Bangladesh.

Saha *et al.* (1999) studied on the effects of cowdung application on the production of *S. serrata* in brackish water pond in Paikgacha of Khulna district, Bangladesh. The juvenile crabs with the initial carapace width (ICW) of 32-32.5 mm and the body weight (BW) of 24.98-25.38 g were stocked in three earthen ponds of 500 m² in size with the stocking density of 1 crab/m². The mud crab was reared for 84 days using rice bran and wheat flour at a rate of 2% of body weight of their biomass daily. In addition, trash fish and fresh shrimp head at a rate of 8% per day of crab biomass were used at alternate weeks. The growth, SGR, survival and production rate were reported at 88.33-99.57 g, 0.78-0.83%/day, 58-69% and 6.69-8.62 kg/100 m² respectively. They recommended that the application of cowdung in addition to feed could be used for mud crab culture at a rate of 500 kg/ha/fortnight.

Saha *et al.* (2000) studied the effect of stocking density on brood stock development of *S. serrata* in brackish water earthen ponds in Bangladesh with the SD of 0.6, 0.8, 1.0 and 1.2 crab/m². They feed mud crabs with 50% slaughterhouse, 25% tilapia (*Oreochromis niloticus*), and 25% soft shrimp head at a rate of 10-6% body weight, twice daily. After 45 days of feeding feed composition was changed to 50% slaughter house waste and 50% tilapia at a rate of 5% body weight twice daily. The SD 0.6 crab/m² showed the best survival rate both for male (93.33%) and female (45%) crabs. The male crab gains the maximum 35.83 g in weight from SD 1 crabs/m² whereas, the female gains the maximum 52.02 g from SD 0.6 crabs/m² in 84 days. The water temperature, DO and pH from 28 to 33 °C, 5.6 to 6.5 ppm and 7.9 to 8.6 respectively were suitable for crab culture and gonad maturation. Whereas, the salinity from 6 to 18 ppt was lower for crab maturation as only 2 to 3% of the harvested females attained sexual maturity. Lime also used at a rate of 375 kg/ha a week before stocking.



2.1.2 Mud crab farming in overseas

Few studies have been reported on the culture of mud crabs (*Scylla* sp.) from SE Asia, India and Australia (Agbayani *et al.*, 1990; Srinivasagam and Kathirvel, 1992; Triño *et al.*, 1999; Overton and Pushpakumara, 2001; Marichamy and Rajapackiam, 2001; Moser, *et al.*, 2002; Mwaluma, 2002; Triño and Rodriguez, 2002; and Rodriguez, *et al.*, 2003).

Agbayani *et al.* (1990) analyses the economic feasibility of mud crab (*S. serrata*) monoculture at different SD (0.5, 1, 1.5 and 2.0 crab/m²) in 100 m² earthen ponds in the Philippines. The experimental culture of mud crab was operated for 90 days using trash fish mainly chopped tilapia *Oreochromis mossambicus* at 10% of crab biomass

consecutively reducing to 8% and 6% after every 30 days. Better growth (205.2), SGR (2.28%/day), FCR (1.72), survival rate (88%) was obtained for SD 0.5 crab/m², although the best production rate 11.04 kg/100 m² was recorded from SD 2 crab/m². From the economic point of view, the mud crab monoculture with SD 0.5 was more profitable (ROI=124% and payback period 0.70 yr.) than the other stocking model.

Triño *et al.* (1999) studied the effect of stocking density (0.5, 1.5 and 3 crab/m²) and monosex culture on the growth, FCR, survival and production of *Scylla serrata* and *S. tranquebarica* in the Philippines. The juvenile crabs were stocked in 150 m² earthen ponds with seaweed as shelter and fed a mixed diet of 75% fresh mussel flesh and 25% trash fish. The highest SGR (3.23 g/day), survival (98.22%), FCR (2.20), return on investment (ROI=176%) and lowest production cost were found with SD 0.5. However, no net benefit accrued from SD 1.5. Both male and female monosex culture gave high net revenue and ROI of more than 100%. They concluded that the culture of male or female mud crabs at 0.5-1.5 m² stocking density is economically viable, but male monosex culture was more profitable because male crabs attained significantly higher final weight (437.58 g) and specific growth rate (3.28 g/day) than female crabs.

The Department of Agriculture, Sarawak, East Malaysia introduced the pen culture of mud crab to help the artisanal fishermen improve their income and to conserve the mangrove resource in 1992 (Overton and Pushpakumara, 2001). The pens were 18×9×2.4 m in size constructed by local palm (*Oncosperma tigillarius*) and stocked 1000-1500 crabs/pen for 5 months. The body weight of the harvested crabs was recorded at 300 g for each fed by low cost small fish and horse mussels. The FCR and survival rate was reported 2.6 and 47% respectively. They concluded that lower survival

rate was noticed for the higher stocking density. The average net income per pen attained at MR 424.31/month (US \$ 1= MR 3.78)

Marichamy and Rajapackiam, (2001) reported that the growth rate is higher in male crabs than the females. The maximum growth of 17 mm CW (67.5 BW) was observed in male crabs with >130 mm CW. Subsequently, there was a decrease in growth rate at 12 mm CW (53 g BW) in both sexes. Males released in high saline ponds at 88 mm CW (120 g BW) grew to 136 mm CW (644 g BW) in 142 days whereas female attained 135 mm CW (525 g BW) in the same period.

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Moser, *et al.* (2002) studied on the growth of *S. olivacea* based on the tagging and recapture system in the Ranong mangrove ecosystem in Thailand. The moult increment of the mud crab was estimated to be 5 to 30 mm in external carapace width (ECW) for both sexes. The male crabs gain more weight than the females. The growth increment of the pond raised crabs was significantly smaller (11.7 ± 3.2 mm) than that of the released crabs in the nature (16.7 ± 4.8 mm).

Mwaluma (2002) studied on the introduction of *S. serrata* culture in 800 m² pen at Mtwapa mangrove creek in Kenya as an alternate income and food for local community. Trash fish (fish head, fish skin, broken fish, fish entrails and squid heads) was used once a day during high tide for 120 days. Stocking density were maintained at 2 crabs/m² however, feeding rate was not reported there. The favorable physico-chemical variables were reported at salinity (12-35 ppt), temperature (25-36 °C), DO (2.65-4.0 mg/l) and pH (7.95-8.25). A total of 1,697 crab seeds (20-39.9 mm carapace length) were stocked and harvested only 114 crabs weighting by 5 kg in 120 days. However, crab culture was

reported feasible in Kenya as extra income without extra cost was achieved from the other species such as milkfish (*Chanos chanos*), mulets (*Mugil mugil*), prawns (*Ferropenaeus indicus*, *P. monodon*) etc. as bycatch from the same pens. The SGR was reported at 1.47-4.2% per day and the slower growth rate was observed for crabs attained sexual maturity.

Triño and Rodriguez (2002) studied the growth and survival of mixed sex *S. serrata* in 200 m² pens in tidal flats reforested with mangrove trees using two types of feed (salted fish bycatch or a mixed diet of 75% salted brown mussel flesh and 25% salted fish bycatch) at a rate of 10% of body weight (<6 cm length) and reduced to 5% of body weight (>6 cm length) for 160 days in the Philippines. The optimum physico-chemical variables were recorded at water temperature 27-32 °C, salinity 18-32 ppt, DO 4.2-11 ppm and pH 8.5-9. They found no significant differences in growth, FCR, survival and production between two feeds. However, a better FCR (5.30 ± 0.34) and survival ($56 \pm 1.90\%$) were found with the SD 0.5 than SD 1.5. Although growth and production rate was not affected significantly by different stocking densities. However, comparatively better SGR and production were found with the SD 1.5 (1.79 ± 0.03 g/day and 31.34 ± 3.48 kg/200 m² respectively) than 0.5 m² (1.74 ± 0.08 g/day and 17.77 ± 0.93 kg/200 m² respectively). Both the feeds and stocking densities were found economically viable with 49-68% ROI. The feed (42-47%) and seed (47-54%) were the major variable costs. However, the production cost was significantly lower with SD 0.5, although crabs with the SD 1.5 and fed with mixed diet was more profitable due to higher yield per unit area.

Rodriguez, *et al.* (2003) conducted an experiment in the Philippines on the effects of diet (fish bycatch or a mixed diet of 75% brown mussel and 25% cooked cracked corn) and harvesting regimen (bimonthly selective harvesting or single terminal harvesting) for the production of *S. olivacea*. The male and female mud crabs with an initial body weight of 27-35 g were reared for 118 days in 16,100 m² brackish water pond with the stocking density of 0.6 crab/m². The optimum physico-chemical variables were water temperature 23.0-27.6 °C, salinity 11.5-29.6 ppt, DO 4.8-8.6 ppm and pH 7.9-9.0. The growth, SGR, survival rate, production rate and ROI were reported at 153.3-173.1 g, 1.5-1.6% per day, 31.9-47.9%, 2.93-4.97 kg/100 m² and 4.9-60.2% respectively. They found that the bimonthly selective harvesting (ROI=60.20%) and mixed diet (ROI=57.20%) could be effective for mud crab culture with ROI of 60.20 and respectively.

Materials and methods

3.1 Study area and culture period

The study was conducted at Burigoalini (22°12'19.7"N; 89°09'1.8" E), Munshiganj of Satkhira district in the SouthWest (SW) Bangladesh (Map 1). The study site was located in the high saline zone in the SW region of Bangladesh (Karim, 1994). The mud crab culture experiment was operated for 60 days during October to December 2003.

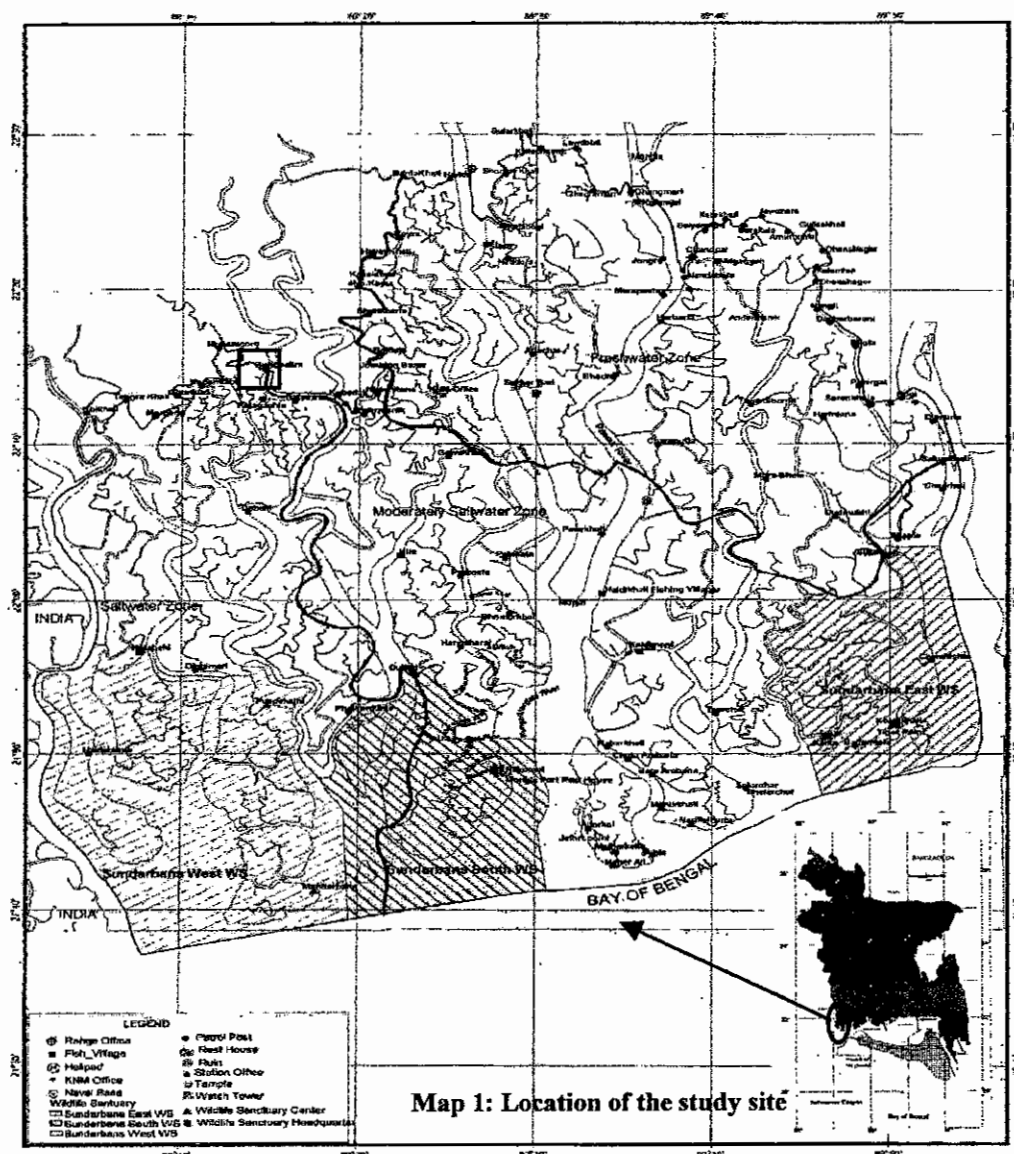




Photo-1: Location of the study pen system.



Photo-2: Construction of the pens.

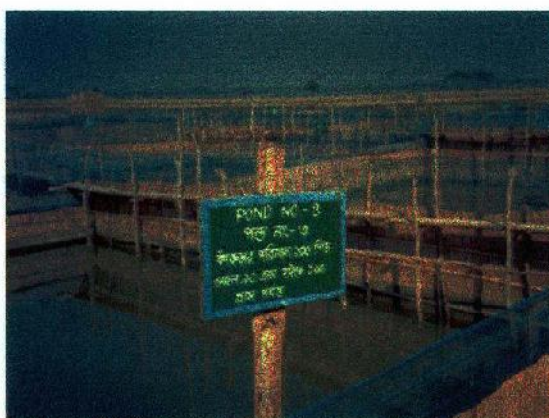


Photo-3: Design of the pen system.



Photo-4: Stocking of the female crabs in the pens.



Photo-5: Harvesting of mud crabs.



Photo-6: Participants of the research work.

3.2 Experimental design

A total of nine pens were constructed with bamboo sticks surrounded by nylon mesh net for preventing the crab escaping out, measuring 10m×10m (i.e. 100 m²) each in size with 1.75 m in height. The pens were connected with regular tidal fluctuation and the water depth was controlled between 0.7 and 1 m through external sluice gate. The perimeter dike was constructed into the pens for allowing crabs to burrow. Earthen pots (50% of stocked animals) were placed into each pen for sheltering crabs during moult or predation. The female mud crab seeds of 90-150 g in body weight were collected from the local crab fishermen and crab landing centers (*depot*). Three treatments of stocking density (SD), viz., 0.25, 0.5 and 1 crab/m² with three replicas for each treatment were maintained. The body weight of the stocked animals was within 131-150 g for SD 0.25, 111-130 g for SD 0.5 and 90-110 g for SD 1 crab/m². Two local poor women fishers were participated in the research activities in the premises of the Eco-demo farm of SHUSHILON, a local NGO at Munshiganj, Satkhira Bangladesh (Photo 1 to 6).

3.3 Growth measurement

Before releasing the freshly collected crabs, 20% of the animals were tagged with individual numbered T-Bar anchor tags (Floy® Tag FD-68B, USA) to measure absolute growth. The tags were inserted into the muscle tissue at the base of the swimming leg by shooting the tag, slightly off center, through the ligament connecting the caudal part of the carapace and the abdomen. The individual body weight and internal carapace width (ICW) of the stocked animals were recorded nearest to 1 g with a digital balance and 0.1 mm by using a dial vernier calipers respectively prior to stocking in a same day.

3.4 Feed and feeding rate

The crabs were fed with low cost trash fish at a rate of 5% of their biomass daily given at morning and evening. Feeding rate was adjusted after observation at 30 days of the experimental period.

3.5 Water variable measurement

The water temperature, salinity, pH was measured by using a Celsius Thermometer, Refractometer, Digital Pen-type pH meter (Hanna, USA) respectively. DO content was measured with LT Lutron DO meter (Model-DO 5508, Taiwan).

3.6 Data analyses

The relative growth, survival, feed conversion ration (FCR), production rate and cost of the production were calculated after total harvest. Data on growth, survival rate, production rate, and physico-chemical variables were analyzed by using MS Excel XP software. The significance of the growth, survival, FCR and production rate were analyzed by one-way ANOVA using S-PLUS 2000 statistical software (Math soft, USA) to determine the best stocking density. Linear regression analyses were also performed to measure the relationship between the growth rate, survival, production rate and FCR with the stocking densities.

3.7 Economic analyses

In order to evaluate the economic feasibility of mud crab culture were done through return on investment (ROI) and payback period. The total cost or investment comprised of capital cost and operating cost (variable and fixed cost). The capital cost consisted of cost of materials and labor for the installation of bamboo fencing and earthwork. Salary

of the participants was not computed within the fixed cost item, as it was an experimental work. Repairs and maintenance were excluded, as there was no repair done within the experimental period. Annual depreciation was considered as 10% of the capital cost over 5 years of useful life and 5 crops in each year. Partial budgeting analysis was used to determine the incremental net benefit for increasing stocking density from 0.25 to 0.5 and 1 crab/m² (Shang, 1990). The equation to measure the economic feasibility of mud crab culture following (Shang, 1990) are as follows:

Total investment = Capital cost + Operating cost (variable cost and fixed cost);

Gross revenue/income = Total production × sale price per unit production;

Net revenue = Gross revenue – Total investment (may exclude capital cost);

ROI = (Net revenue/Total investment) × 100;

Incremental benefit = Difference of gross revenue for increasing stocking density;

Incremental cost = Difference of total investment increasing stocking density; and

Incremental net benefit = Incremental benefit – Incremental cost.

Payback period (yr.) = Total investment/ Net revenue



Results

4.1 Physico-chemical variables

The water temperature, salinity, dissolved oxygen and pH were found to be fairly constant around 27.8-29.9 °C, 9-14 ppt, 4.8-6.0 ppm and 7.5-7.9 respectively during the culture period.

4.2 Growth performance

4.2.1 Absolute growth

The absolute growth of female mud crab both by internal carapace width (ICW) and body weight (BW) was measured from recaptured tagged crabs. The mean initial ICW of the tagged crab was recorded at 86.5 ± 1.12 , 83.6 ± 1.67 and 78.5 ± 1.1 mm for the stocking density (SD) of 0.25, 0.5 and 1 crab/m² respectively. The final ICW was obtained 113.4 ± 1.56 , 106 ± 2.1 and 98.8 ± 1.9 mm with SD 0.25, 0.5 and 1 crab/m² stocking density respectively (Table 1 and Fig. 1). The maximum absolute growth by ICW 26.9 mm was found from the SD 0.25, while the minimum was 20.3 mm (ICW) from SD 1 crab/m² that was significantly ($F=25.08$, $n=9$, $p<0.05$) different among the stocking densities (Table 1). The mean initial BW of the stocked animals was measured 131 ± 2.1 , 117 ± 3.11 and 100 ± 1.67 g for the stocking density (SD) of 0.25, 0.5 and 1 crab/m² respectively. The mean final BW was recorded at 238 ± 3.3 g with SD 0.25, 216 ± 4.16 g with SD 0.5 and 186 ± 3.4 g with SD 1 crab/m² respectively after 60 days at harvest (Table 1 and Fig. 2). The significantly ($F=80.01$, $n=9$, $p<0.05$) highest absolute

growth by BW 107 ± 2.00 g was found with the SD 0.25 followed by 99 ± 2.52 g for SD 0.5 and 86 ± 1.61 g for SD 1 (Table 1). The maximum (70%) and the minimum (40%) recapture rate of the tagged crab was recorded from the SD 0.5 and 0.25 crab/m² respectively (Table 1).

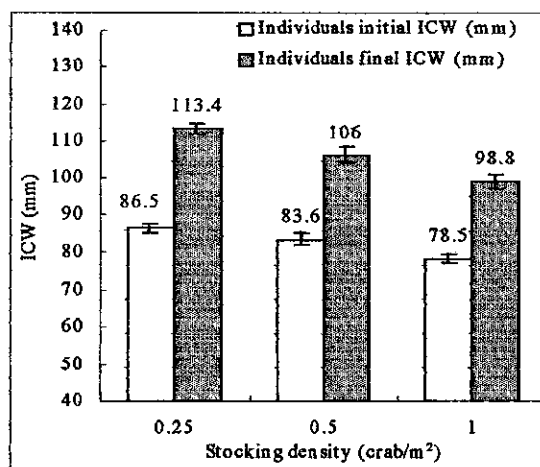


Fig. 1: Mean initial and final ICW of the tagged female mud crab (*S. olivacea*) at different stocking densities.

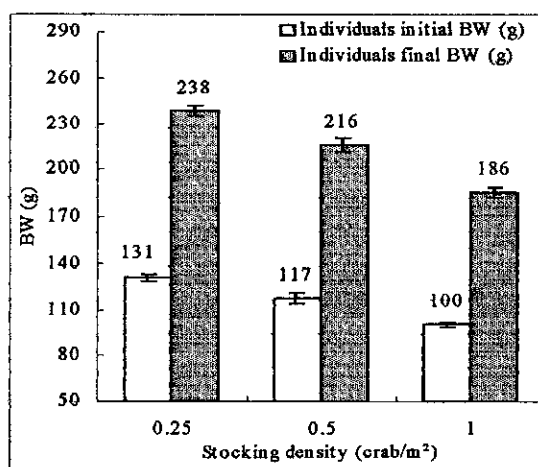


Fig. 2: Mean initial and final BW of the tagged female mud crab (*S. olivacea*) at different stocking densities.

Table 1: Absolute growth and recapture of the tagged female mud crab (*S. olivacea*) in bamboo pens in SW Bangladesh.

Variables	Stocking density (crab/m ²)		
	0.25	0.5	1
Individuals initial ICW (mm)	86.5±1.12	83.6±1.67	78.5±1.1
Individuals final ICW (mm)	113.4±1.56	106±2.1	98.8±1.9
Individuals growth by ICW (mm)	26.9±1.32	22.4±1.3	20.3±0.8
Individuals initial BW (g)	131±2.1	117±3.11	100±1.67
Individuals final BW (g)	238±3.3	216±4.16	186±3.4
Individuals growth by BW (g)	107±2.00	99±2.52	86±1.61
Recapture of tagged crab at harvesting	2 (40%)	7 (70%)	12 (60%)

4.2.2 Relative growth

Relative growth by ICW: The relative growth of female mud crab was evaluated both by ICW and BW after total harvest. At stocking the mean initial ICW of mud crab was recorded at 87.69 ± 0.74 , 77.45 ± 0.22 and 74.91 ± 1.10 mm for the SD of 0.25, 0.5 and 1 crab/m² respectively. The mean final ICW at harvesting was measured at 116.21 ± 1.05 ,

110.58±1.26 and 99.60±1.16 mm for the SD of 0.25, 0.5 and 1 crab/m² respectively. The mean growth gain by ICW after 60 days culture period was found to be the highest 33.12±1.46 mm for SD 0.5 crabs/m² followed by 28.52±1.56 mm for SD 0.25 and 24.69±1.44 mm for SD 1 crab/m² (Table 3 and Fig. 3). The one way ANOVA noticed that the growth performance among the stocking density was significantly (F= 16.325, n=9) different at p<0.05 level (Table 4). On the other hand, a significant negative (R²=0.2055, t=10.936, n=3, p<0.05) relationship was found when the growth data was plotted against different stocking densities on logarithmic scale (Table 5 and Fig. 4).

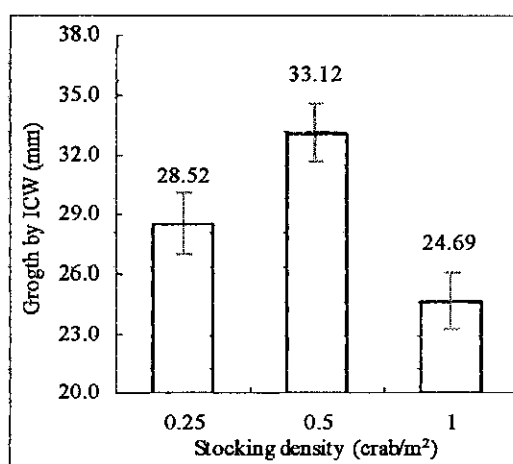


Fig. 3: The relative growth of female mud crab (*S. olivacea*) by ICW at different stocking densities.

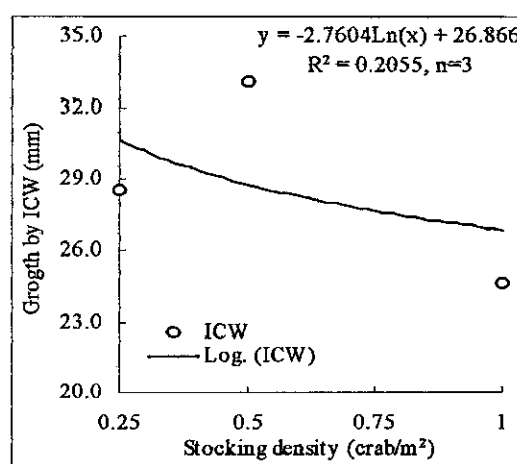


Fig. 4: Logarithmic relationship between the relative growth (ICW) and stocking densities in female *S. olivacea* at pen culture system.

Relative growth by BW: The mean BW of mud crab at stocking was 141.69±2.38, 120.27±1.93 and 102.69±1.66 g for SD 0.25, 0.5 and 1 crab/m² respectively. At harvesting the mud crab attained a mean body weight of 230±2.65, 218±2.65 and 163±2.0 g for the SD of 0.25, 0.5 and 1 crab/m² respectively. The relative growth of mud crab by BW was subjected to the three stocking densities; the significantly (F=154.538, n=9) maximum growth 97.73±2.05 g was obtained with SD 0.5 followed by 88.31±3.42 g with SD 0.25 and 60.31±2.48 g with SD 1 crab/m² (Table 3 and Fig. 5).

In addition, a significant negative ($R^2=0.5175$, $t=7.061$, $n=3$) relationship was found when the growth by body weight of mud crab was plotted against the stocking densities at $p<0.05$ level (Table 5 and Fig. 6).

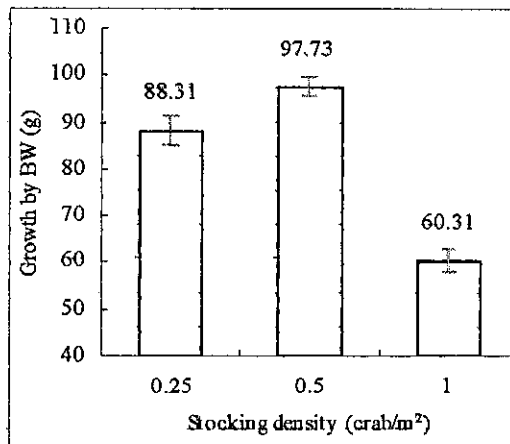


Fig. 5: The relative growth of female mud crab (*S. olivacea*) by body weight at different stocking densities.

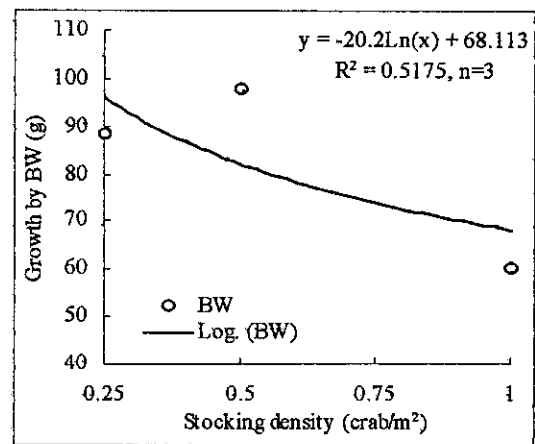


Fig. 6: Logarithmic relationship between the relative growth (BW) and stocking densities in female *S. olivacea* at pen culture system.

4.3 SGR (%/day) by ICW and BW

The maximum SGR both by ICW and BW was measured at $2.53\pm0.03\%$ and $3.32\pm0.02\%$ respectively with the SD 0.5 crab/m² and the minimum $2.32\pm0.04\%$ in ICW and $2.97\pm0.03\%$ in BW with SD 1 crab/m² (Table 3 and Fig. 7 & 8). The SGR of female mud crab by ICW ($F=23.996$, $n=9$) and BW ($F=159.316$, $n=9$) were significantly

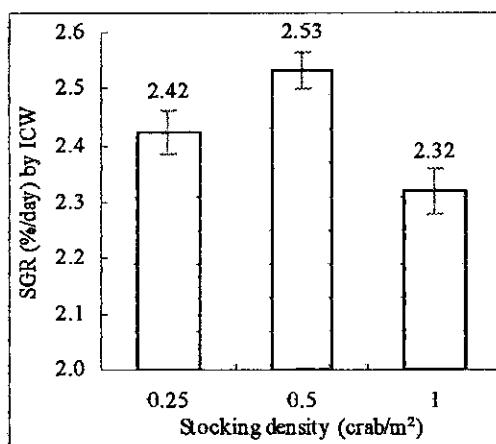


Fig. 7: SGR of female mud crab (*S. olivacea*) by ICW at different stocking densities.

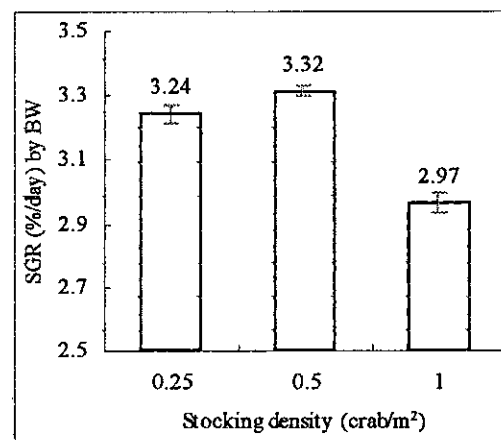


Fig. 8: SGR of female mud crab (*S. olivacea*) by body weight at different stocking densities.

($p < 0.05$) different among the three stocking densities (Table 4). In addition, the significant and negative relationships were found both for the SGR by ICW ($t = 6.969$, $n = 3$) and BW ($t = 8.183$, $n = 3$) with stocking densities at $p < 0.05$ level (Table 5).

4.4 Length-weight relationship

The length and weight relationship of the mud crab in culture pens was measured by plotting the mean ICW gain against the mean weight gain on logarithmic scale. The lengths of mud crabs cultured with SD 0.5 showed the positive and significantly higher relation with their body weight ($R^2 = 0.9623$, $t = 166.319$, $n = 3$) followed by SD 0.25 ($R^2 = 0.9175$, $t = 52.118$, $n = 3$) and SD 1 ($R^2 = 0.5622$, $t = 36.163$, $n = 3$) crab/m² at $p < 0.05$ (Table 2 and Fig. 9).

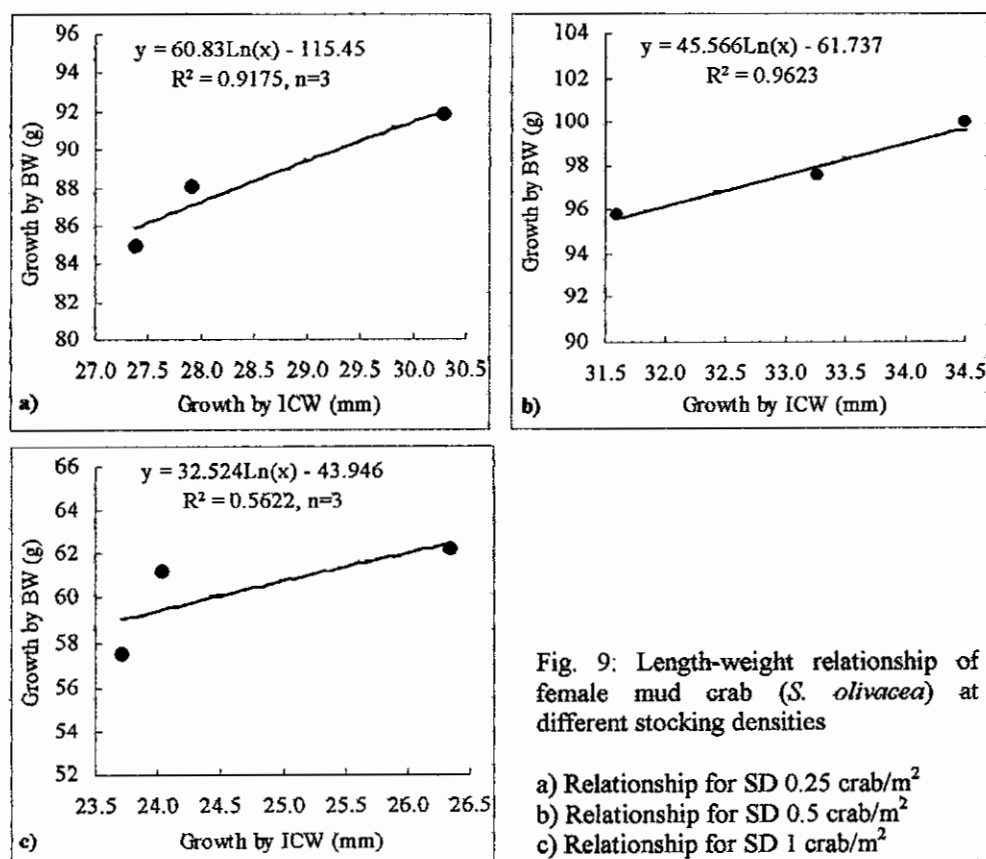


Fig. 9: Length-weight relationship of female mud crab (*S. olivacea*) at different stocking densities

- a) Relationship for SD 0.25 crab/m²
- b) Relationship for SD 0.5 crab/m²
- c) Relationship for SD 1 crab/m²

Table 2: Length weight relationship of the female mud crab (*S. olivacea*) in bamboo pens in SW Bangladesh.

Variables	Regression equation (y on x)	R ²	t-value	t' crit
SD 0.25 crab/m ²	$y = 60.83\text{Ln}(x) - 115.45$	0.9175	52.118*	
SD 0.5 crab/m ²	$y = 45.566\text{Ln}(x) - 61.737$	0.9623	166.319*	4.3026
SD 1 crab/m ²	$y = 32.524\text{Ln}(x) - 43.946$	0.5622	36.163*	

* Significant at $p < 0.05$ level at 2 degree of freedom.

4.5 Survival rate

The maximum and the minimum survival rate of the mud crab during the experiment period was recorded at $83.33 \pm 2.31\%$ and $59.33 \pm 2.52\%$ for SD 0.25 and SD 1 crab/m² respectively (Table 3 and Fig. 10). The significantly ($F=65.777$, $n=9$) different survivability was obtained among stocking densities (Table 4). The survival rate was found to be increased significantly ($R^2=0.9963$, $t=9.837$, $n=3$) with the lower stocking density at $p < 0.05$ (Table 5 and Fig. 11).

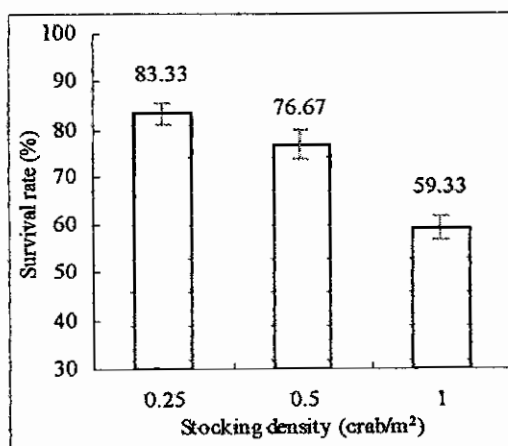


Fig. 10: Survivability of female mud crab (*S. olivacea*) at different stocking densities.

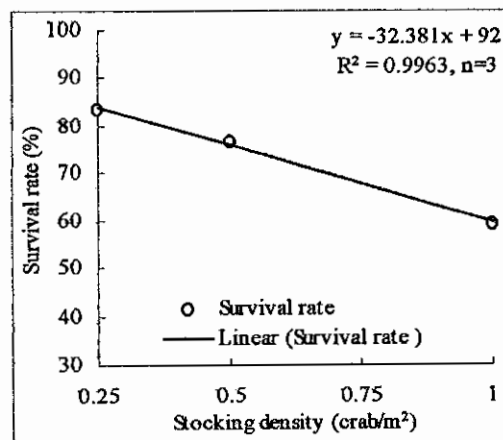


Fig. 11: Linear relationship between the survivability and stocking densities in female *S. olivacea* at pen culture system.

4.b.6 Production rate

The production rate was found to vary significantly ($F=121.646$, $n=9$) with stocking densities being the highest 9.67 ± 0.53 kg/100 m² with SD 1 crab/m² and the lowest 4.79 ± 0.17 kg/100 m² with SD 0.25 crab/m² (Table 3 and Fig. 12). The production of

female mud crab showed significant positive relationship ($R^2=0.8107$, $t=5.559$, $n=3$) with stocking densities at 5% level of significance (Table 3 and Fig. 13).

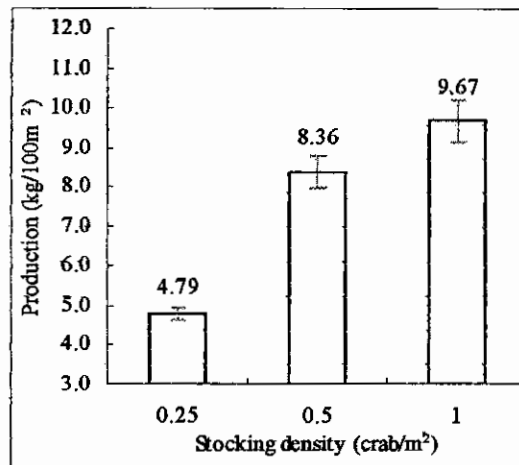


Fig. 12: Production rate of female mud crab (*S. olivacea*) at different stocking densities.

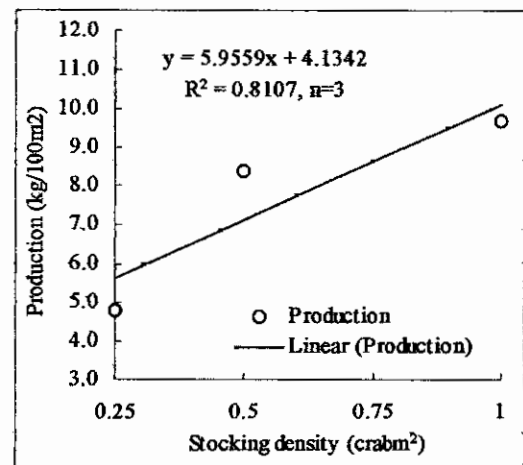


Fig. 13: Linear relationship between the production rate and stocking densities in female *S. olivacea* at pen culture system.

4.7 Feed conversion ratio (FCR): The most efficient FCR were achieved at 1.69 ± 0.11 with SD 0.5 crab/m^2 although it was not significantly ($F = 1.483$, $n = 9$, $p < 0.05$) different from the 1.90 ± 0.14 with SD 0.25 and 1.78 ± 0.20 with SD 1 (Table 3 and Fig. 14). The least and positive significant relationship ($R^2 = 0.5097$) were found between the values of FCR and stocking densities at 5% level (Table 5 and Fig. 15).

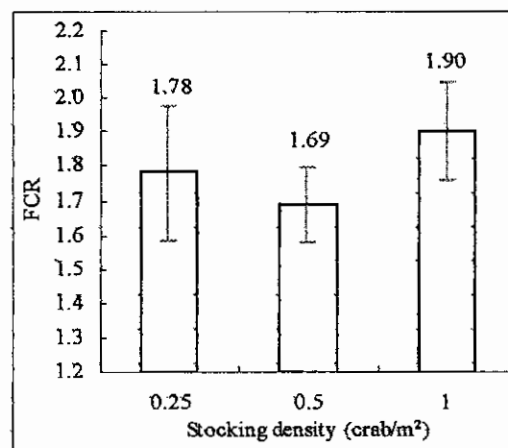


Fig. 14: FCR of female mud crab (*S. olivacea*) at different stocking densities.

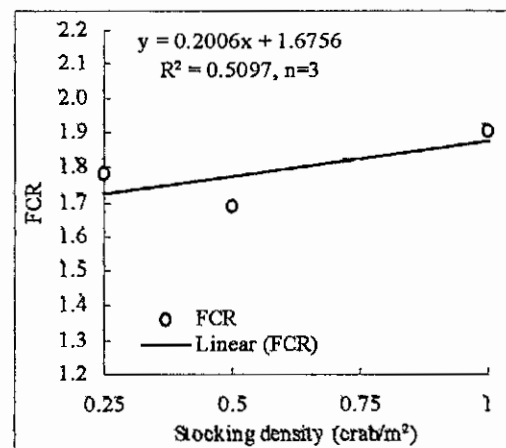


Fig. 15: Linear relationship between the FCR and stocking densities in female *S. olivacea* at pen culture system.

Table 3: Mean internal carapace width (ICW), body weight (BW), SGR, survivability, production and FCR of monosex female mud crab (*S. olivacea*) culture in the bamboo pens in SW Bangladesh.

Variables	Stocking density (crab/m ²)		
	0.25	0.5	1
Individuals initial ICW (mm)	87.69±0.74	77.45±0.22	74.91±1.10
Individuals final ICW (mm)	116.21±1.05	110.58±1.26	99.60±1.16
Individuals growth by ICW (mm)	28.52±1.56	33.12±1.46	24.69±1.44
Individuals initial BW (g)	141.69±2.38	120.27±1.93	102.69±1.66
Individuals final BW (g)	230.0±2.65	218.00±2.65	163.00±2.00
Individuals growth by BW (g)	88.31±3.42	97.73±2.05	60.31±2.48
SGR (%/day) by ICW	2.42±0.04	2.53±0.03	2.32±0.04
SGR (%/day) by BW	3.24±0.03	3.32±0.02	2.97±0.03
Survivability (%)	83.33±2.31	76.67±3.06	59.33±2.52
Production (kg/100 m ²)	4.79±0.17	8.36±0.40	9.67±0.53
FCR	1.78±0.20	1.69±0.11	1.90±0.14

Table 4: One way ANOVA for the growth rate, survivability, production and FCR of female mud crab (*S. olivacea*) culture at three stocking densities in the bamboo pens in SW Bangladesh.

Variables	n	df	P-value	F-value	F crit
Growth by ICW (mm)	9	8	0.003	16.323*	
Growth by body weight (g)	9	8	0.00001	154.538*	
SGR (%/day) by ICW	9	8	0.001	23.996*	
SGR (%/day) by BW	9	8	0.00001	159.316*	5.143
Survivability (%)	9	8	0.0001	65.777*	
Production (kg/100 m ²)	9	8	0.00001	121.646*	
FCR	9	8	0.299	1.4832	

* Significant at p<0.05 level.

Table 5: Relationship of the growth rate, survivability, production, FCR and ROI with the different stocking densities of female mud crab (*S. olivacea*) culture in the bamboo pens in SW Bangladesh.

Variables	Regression equation (y on x)	R ²	t-value	*t' crit
Growth by ICW (mm)	y = -2.7604Ln(x) + 26.866	0.2055	10.936*	
Growth by BW (g)	y = -20.2Ln(x) + 68.113	0.5175	7.061*	
SGR by ICW (%/day)	y = -0.0753Ln(x) + 2.3737	0.2403	6.969*	
SGR by BW (%/day)	y = -0.1992Ln(x) + 3.0374	0.5607	8.183*	4.3026
Survivability (%)	y = -32.381x + 92	0.9963	9.837*	
Production (kg/100 m ²)	y = 5.9559x + 4.1342	0.8107	5.559*	
FCR	y = 0.2006x + 1.6756	0.5097	6.662*	
ROI (%)	y = -182.83x + 209.78	0.682	2.093	

* Significant at p<0.05 level at 2 degree of freedom.

4.8 Economic evaluation of monosex female mud crab culture

All the cost and return for the present experiment have been showed in Table 6. Seed (13.73-17.45%) and feed (45.31-55.98%) were the major variable cost component. The sales price per kg of mud crab produced (Tk. 200 for >180 g female with eggs, Tk. 100 for <180 g female, Tk. 80 for <150 g female and Tk. 72 for <120 g female crab) based on the local market price during harvest. The net revenue was the highest at Tk. 952.44 with SD 0.5 and the lowest Tk. 55.50 with SD 1 crab/m². The production cost per kg mud crab was the lowest at Tk. 64.26 with SD 1 and the highest Tk. 98.94 with SD 0.25 crab/m². The insignificantly ($p < 0.05$) highest ROI was found 172.43% with SD 0.5 crab/m² followed by 128.03% and 8.93% with the SD 0.25 and 1 crab/m² respectively (Table 6 and Fig. 16). The ROI was found to be higher with lower stocking densities but not statistically significant (Table 6 and Fig. 17). The net benefit could be increased by Tk. 484.10 if stocking density increased from 0.25 to 0.5 crab/m² however, no incremental net benefit accrued if stocking density further raised from SD 0.5 to 1 crab/m² (Table 6). The capital cost per pen could be returned early after 0.71 year with SD 0.5 over 1.40 year with SD 0.25 and 12.24 year with SD 1 crab/m² (Table 7).

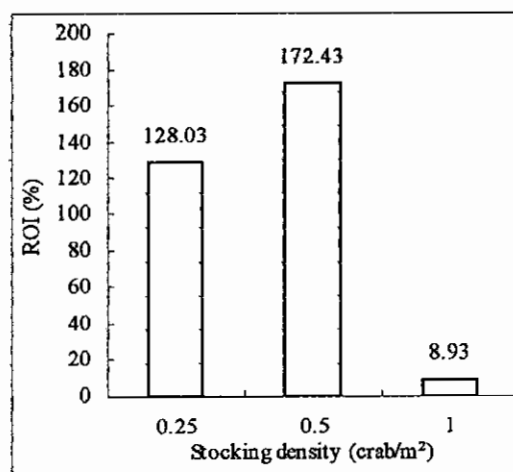


Fig. 16: ROI from female mud crab (*S. olivacea*) culture at different stocking densities.

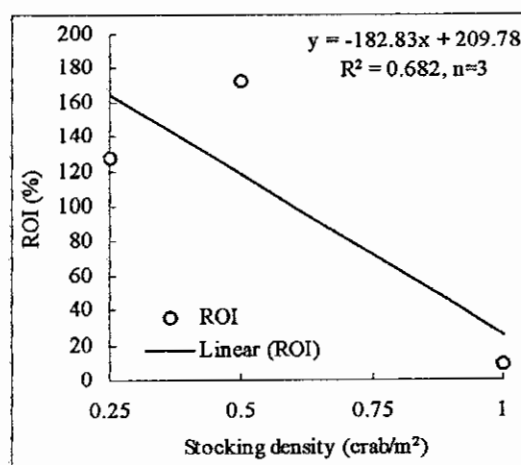


Fig. 17: Linear relationship between the ROI and stocking densities in female *S. olivacea* at pen culture system.

Table 6: Cost-return and partial budgeting analyses for female mud crab (*S. olivacea*) culture in bamboo pens in SW Bangladesh.

Items	Stocking density (crab/m ²)		
	0.25	0.5	1
Capital cost			
Earth work for pen construction	166.67	166.67	166.67
Fencing with bamboo sticks	3,198.11	3,198.11	3,198.11
Labor	33.33	33.33	33.33
Sub total	3,398.11	3,398.11	3,398.11
Operating cost			
Variable cost			
Seed cost (Tk.)	50.00	100.00	100.00
Feed cost (Tk.)	170.60	282.00	367.60
Stocking cost (Tk.)	26.67	26.67	26.67
Harvesting and Marketing cost (Tk.)	33.33	33.33	33.33
Miscellaneous (Tk.)	17.24	30.10	13.54
Sub total	297.84	472.10	541.14
Fixed cost			
Salary (Tk.)	-	-	-
Repair (Tk.)	-	-	-
Depreciation (Tk.) (10%, 5 years, 5 crops/yr.)	13.59	13.59	13.59
Land rent (per crop, 5 crop/yr.)	66.67	66.67	66.67
Sub total	80.26	80.26	80.26
Total operating cost	378.10	552.36	621.40
Total investment	3,776.21	3,950.47	4,019.51
Total harvest (kg)	4.79	8.36	9.67
Sales price Tk./kg	180.00	180.00	70.00
Total revenue at sales	862.20	1,504.80	676.90
Net revenue (Tk.)	484.10	952.44	55.50
Revenue per kg production (Tk.)	180.00	180.00	70.00
Production cost per kg (Tk.)	78.94	66.07	64.26
Return on investment (ROI)	128.03	172.43	8.93
Incremental benefit (Tk.)		642.60	(827.90)
Incremental cost (Tk.)		174.25	69.04
Incremental net benefit (Tk.)		468.35	(758.86)

* The values in Taka are on per 100m² per crop basis (5 crops/yr.), US\$1=Tk.60.00.

Table 7: Payback period (yr.) for female mud crab (*S. olivacea*) culture in bamboo pens in SW Bangladesh.

Items	Stocking density (crab/m ²)		
	0.25	0.5	1
Capital cost			
Earth work for pen construction (Tk.)	166.67	166.67	166.67
Fencing with bamboo sticks (Tk.)	3,198.11	3,198.11	3,198.11
Labor (Tk.)	33.33	33.33	33.33
Total capital cost	3,398.11	3,398.11	3,398.11
Net revenue (Tk.) (per crop/100 m ²)	484.10	952.44	55.50
Net revenue (Tk.) (yr./100 m ²)	2,420.48	4,762.22	277.51
Pay back period (yr./100 m ²)	1.40	0.71	12.24

Discussion

The experimental culture of female mud crab was operated in bamboo pens in high saline zone (Karim, 1994) at Munshiganj, Satkhira for searching out the commercially feasible optimum stocking density and size considering the growth, survival, production, FCR and economic return over 60 days. The water temperature was remained fairly constant around 27.8-29.9 °C throughout the experiment that was suitable for mud crab culture success reported by Baliao *et al.* (1999), Triño and Rodriguez (2002) and Mwaluma (2002). The water salinity ranged from 9-14 ppt that was close to Cowan (1983) who suggested that the salinity ranged from 5-21 ppt is suitable for crab culture. The salinity in the present experiment was close to 10.38-17.69 ppt reported by Kamal (2002) from Bangladesh in crab fattening ponds. Whereas, it was higher than 4.8-9.5 ppt and 0-10 ppt reported by Obayed (1998) and Zafar (2003) respectively from Bangladesh. In addition, Triño *et al.* (1999), Triño and Rodriguez (2002) and Rodriguez *et al.* (2003) reported that the optimal salinity range of 25 to 29 ppt, 18 to 32 ppt and 11.5 to 29.6 ppt respectively for mud crab culture in pond system from the Philippines. The dissolved oxygen content was ranged between 4.8 and 6.0 ppm that was close to the result of Obayed (1998), Triño and Rodriguez (2002), Rodriguez *et al.* (2003) and Triño *et al.* (1999). The recommended optimal range of pH for mud crab culture was reported at 8.0-8.5 (Cowan 1983; Wickins, 1981) that was slightly higher than the pH (7.5-7.9) recorded in the present study. Rodriguez *et al.* (2003) reported the optimal range of pH is 7.9-9.0 for mud crab culture from the Philippines.

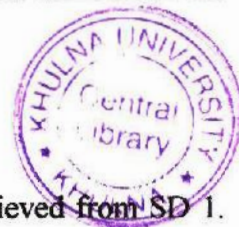
The absolute growth increment of female mud crab was significantly ($p<0.05$) higher (26.9 ± 1.32 mm in ICW and 107 ± 2.0 g in BW) for the SD 0.25 crab/ m^2 . This growth increment was comparatively better than Moser *et al.* (2002) who reported the growth increment of the pond raised crabs was significantly smaller (11.7 ± 3.2 mm) than that of the released crabs in the nature (16.7 ± 4.8 mm). The higher growth in the present study with SD 0.25 crab/ m^2 may be attributed for the lower stocking density per unit area.

The significantly higher relative growth rate in terms of ICW was observed for the SD 0.5 crab/ m^2 , i.e., female mud crab grew at an average of 33.12 ± 1.46 mm in length in 60 days. This growth increment was lower than Triño *et al.* (1999) and Triño and Rodriguez (2002) who reported the mud crab gained 86 mm and 63 mm in ICW for 120 days and 160 days culture period respectively with SD 0.5 crab/ m^2 . Although Triño and Rodriguez (2002) found SD 1.5 crab/ m^2 attained insignificantly better ICW (64.6 mm) in 160 days with SD 0.5 crab/ m^2 . While, Saha *et al.* (1999) reported that mud crab gained 27-30.5 mm with the SD 1 crab/ m^2 after 84 days. The lower growth by ICW in the present study may be attributed for the higher size (74.91 ± 1.10 to 87.69 ± 0.74 mm) of the individuals at stocking time. While, Triño *et al.* (1999), Saha *et al.* (1999) and Triño and Rodriguez (2002) conducted their experiment with the stocking size (ICW) of mud crab at 35-42.6 mm, 51-54 mm and 32-32.5 mm respectively. Shorter culture period and pond area may also be caused for the lower growth. The growth performance by ICW was decreased significantly ($R^2=0.2055$) with increasing stocking density. In contrast, the investigation by Saha *et al.* (1999), Triño *et al.* (1999), Triño and Rodriguez (2002) and Mwaluma (2002) observed that the higher growth ($R^2=0.0317$) attained with increasing stocking density (Table 9).

The growth performance in response to the crab body weight, the average maximum (97.73 ± 2.05 g) weight gain (SGR 3.32 ± 0.02 %/day) was recorded for SD 0.5 crab/m². This finding was higher than Saha *et al.* (2000) who reported the female crab increased their BW 52.02 g with SD 0.6 crab/m² in 84 days. This growth is also higher than Zafar (2003) who reported that the thin crabs gained 0.54 g/day in 14 days but lower than 6.57 g/day reported by Kamal (2002). Obayed (1998) reported that the crab could gain 1.89-1.9 %/day in growout ponds over 120 days. This growth rate in the present study was comparatively lower than Rodriguez *et al.* (2003) who reported that the mud crab gained their body weight 153-173 g over 118 days with SD 0.6 crab/m². Triño and Rodriguez (2002) reported that crab with SD 1.5 performed insignificantly better growth 298.1 g than SD 0.5 (297.4 g) in 160 days. Triño *et al.* (1999) and Agbayani *et al.* (1990) obtained SD 0.5 crab/m² performed better growth 392.08 g over 120 days and 206.3 g after 90 days respectively. In addition, the mud crab grew 88.33 to 99.25 g in BW in 84 days with the SD 1 crab/m² (Saha *et al.*, 1999) (Table 8). In the present study, the lower growth may be attributed to the larger size of mud crab at stocking (102.69 ± 1.66 to 141.69 ± 2.38 g) and shorter culture period (60 days). The BW of mud crab at stocking and culture period were 7.3-11.0 g and 120 days, 17-20 g and 84 days, 24.98-25.38 g and 160 days by Triño *et al.* (1999), Saha *et al.* (1999) and Triño and Rodriguez (2002) respectively. Sex variation may also be attributed for the lower growth. Because female crabs grew slower than that of males (Marichamy and Rajapackiam, 2001; Moser *et al.*, 2002).

The survival rate was decreased significantly ($R^2=0.9963$) with the increasing stocking density. This result agrees closely ($R^2=0.602$) with Agbayani *et al.* (1990), Saha *et al.* (1999), Triño *et al.* (1999), Triño and Rodriguez (2002) and Mwaluma (2002) (Table 9).

A significantly higher ($83.33 \pm 2.31\%$) survival rate was obtained from SD 0.25 crab/m² followed by 0.5 ($76.67 \pm 3.06\%$) and 1 ($59.33 \pm 2.52\%$). Although this result is comparatively lower than Agbayani *et al.* (1990) and Triño *et al.* (1999) who recorded the survival rate of 88% and 98.2% respectively for SD 0.5 crab/m². However, it was higher than Obayed (1998), Saha *et al.* (2000), Triño and Rodriguez (2002), Mwaluma (2002) and Rodriguez *et al.* (2003) who reported the survival of 63.3-64.2%, 45%, 33-56%, 7% and 31-47% respectively with different stocking density. The shorter culture period (60 days) of the present study may expose crabs to a reduce rate of cannibalism over those reared for longer 160 days, 120 days, 118 days reported by Triño and Rodriguez (2002), Mwaluma (2002) and Rodriguez *et al.* (2003) (Table 8). In addition, as the male mud crabs are more aggressive than the females. The higher survival rate of the present study may be attributed to the selection of monosex female over the mixed sex culture system by Saha *et al.* (1999), Triño and Rodriguez (2002) and Mwaluma (2002). The present findings are closely agrees with Saha *et al.* (1999) who reported that the survival rate at 58-69% with SD 1 crab/m² in 84 days (Table 8). Earthen pot were used in the pond to take shelter of crab during moulting, it may also be minimized the mortality rate.



A significantly higher production rate (9.67 ± 0.53 kg/100m²) was achieved from SD 1. The production rate was found to decrease with decreasing stocking densities ($R^2=0.8107$). This relationship was far better ($R^2=0.167$) than that of Agbayani *et al.* (1990), Saha *et al.* (1999), Triño *et al.* (1999), Triño and Rodriguez (2002) and Mwaluma (2002). Although the production rate was lower than Agbayani *et al.* (1990) who reported that the production rate at 10.19, 10.22, 9.7 and 11.04 kg/100m² with SD 0.5, 1, 1.5 and 2 crab/m² respectively. Triño and Rodriguez (2002) reported a production

rate of 8.8 and 15.67 kg/100m² with SD 0.5 and 1.5 respectively (Table 8). The present results are close to Saha *et al.* (1999) who recorded 6.6-8.6 kg production/100m² with SD of 1 crab/m² (Table 8). The higher production rates with the higher stocking densities in the present investigation may be attributed to the higher number of individuals per unit area.

The stocking rate of 0.5 crab/m² showed the most efficient FCR (1.69±0.11) followed by SD 0.25 and SD 1 in the present study which was better than Agbayani *et al.* (1990), Triño *et al.* (1999) and Triño and Rodriguez (2002) who reported the FCR values at 5.3, 2.2 and 1.72 respectively with SD 0.5 crab/m². The FCR for the present study was found to be more efficient than the crab fattening activities where the FCR were reported at 1.8 and 2.16 by Obayed (1998) and Kamal (2002) respectively.

From the economic point of view, the female mud crab culture with SD 0.5 crab/m² in Bangladesh was significantly profitable (ROI=172.43%) over the SD 0.25 and SD 1. Partial budgeting analyses revealed that the net benefit was increased when the stocking density increased from 0.25 to 0.5 crab/m² but no incremental net benefit achieved when it was raised to 1 crab/m². The female mud crab culture in Bangladesh with SD 0.5 was more profitable than Agbayani *et al.* (1990) and Rodriguez *et al.* (2003) who reported the ROI at 124% and 60.20% with SD 0.5 and 0.6 respectively from the Philippines. Triño and Rodriguez (2002) recommended that the mud crab culture could be profitable at ROI 68% with SD 1.5 crab/m². While, Triño *et al.* (1999) reported a more profit at ROI 176% with SD 0.5, which was slightly higher than the present study (ROI=172.43%) with the same SD. The ROI was decreased significantly ($R^2=0.682$) with increasing stocking densities. Similar relationship was reported by Agbayani *et al.*

(1990), Triño *et al.* (1999), Triño and Rodriguez (2002) (Table 9). In the present experiment, the payback period was significantly shorter at 0.71 year with SD 0.5 crab/m². This findings was close to Agbayani *et al.* (1990) who reported that the payback period at 0.70 year for crab culture with SD 0.5 crab/m² in pond system.

Table 8: Pond size, feeding rate, culture period, stocking density (SD), growth rate, survivability, production, FCR and ROI for mud crab culture throughout the world.

Source	Size (m ²)	Feed item	Feeding rate (%)	Culture day	SD (m ²)	Weight gain (g)	SGR (%/day)	FCR	Survival (%)	Production (kg/100m ²)	ROI
¹ Obyed, 1998**	600 & 1,450	Trash fish & shrimp head	10	120	1	56.8-57	1.89-1.9	2.09-2.5	63.3-64.2	13.77-17.16	-
¹ Agbayani <i>et al.</i> , 1990**	100	Trash fish (<i>O. mossambicus</i>)	10 to 6	90	0.5	205.2	2.28	1.72	88	10.19	124
					1	170.1	1.89	2.16	52	10.22	92
					1.5	144.9	1.61	3.85	38	9.75	33
					2	152.1	1.69	4.04	31	11.04	30
¹ Saha <i>et al.</i> , 1999**	500	Trash fish (8%), rice bran + wheat flour (2%)	10	84	1	88.33-99.57	0.78-0.83	-	58-69	6.69-8.62	-
² Triño <i>et al.</i> , 1999**	150	Mussel trash fish	8	120	0.5	387.60	3.23	2.20	98.22	19.79	176
					1.5	375.60	3.13	3.98	56.72	32.36	106
					3.0	360.00	3.00	6.16	30.56	33.63	11
¹ Triño and Rodriguez, 2002*	200	Mussel+fish bycatch	10 to 56	160	0.5	297.4	1.74	5.30	56	8.88	49
					1.5	298.1	1.79	7.6	33	15.67	68
¹ Mwaluma, 2002*	800	Trash fish	-	120	2	19.8	1.47-4.2	-	7	0.63	-
¹ Rodriguez, <i>et al.</i> , 2003**	16100	Mussel+fish bycatch	8	118	0.6	153.3-173.1	1.5-1.6	-	31.9-47.9	2.93-4.97	4.9-60.2
² Present study, 2003	100	Trash fish	5	60	0.25	88.31	3.24	1.78	83.33	9.67	128.03
					0.5	97.73	3.32	1.69	76.67	8.36	172.43
					1	60.31	2.97	1.90	59.33	4.79	8.93

* Mud crab culture in Pen system; ** Mud crab culture in earthen pond system.

¹ Mixed sex mud crab culture; ² Monosex mud crab culture

Table 9: Relationships of growth rate, survivability, production, FCR and ROI with stocking densities in mud crab culture throughout the world.

Variables	Regression equation (y on x)	R ²	t-value	't' crit	Source
Growth by ICW	$y = 7.3758 \ln(x) + 58.025$	0.0317	7.116*	2.306	Saha <i>et al.</i> (1999), Triño <i>et al.</i> (1999), Triño and Rodriguez (2002) and Mwaluma (2002)
	$y = -0.5266 \ln(x) + 6.335$	0.1301	8.428*	4.302	Present study, 2003
Growth by BW	$y = -29.391 \ln(x) + 211.33$	0.0187	6.065*	2.178	Agbayani <i>et al.</i> (1990), Saha <i>et al.</i> (1999), Triño <i>et al.</i> (1999), Triño and Rodriguez (2002) and Mwaluma (2002)
	$y = -4.8114 \ln(x) + 49.557$	0.1329	9.683*	4.302	Present study, 2003
Survivability	$y = -26.521x + 86.719$	0.602	7.237*	2.178	Agbayani <i>et al.</i> (1990), Saha <i>et al.</i> (1999), Triño <i>et al.</i> (1999), Triño and Rodriguez (2002) and Mwaluma (2002)
	$y = -31.333x + 88.167$	0.9879	9.666*	4.302	Present study, 2003
Production	$y = 5.5253x + 6.2127$	0.1673	4.608*	2.178	Agbayani <i>et al.</i> (1990), Saha <i>et al.</i> (1999), Triño <i>et al.</i> (1999), Triño and Rodriguez (2002) and Mwaluma (2002)
	$y = 5.547x + 3.0637$	0.8686	5.151*	4.302	Present study, 2003
FCR	$y = 0.9324x + 2.5357$	0.1211	3.521*	2.306	Agbayani <i>et al.</i> (1990), Triño <i>et al.</i> (1999), Triño and Rodriguez (2002)
	$y = 0.0655x + 1.8143$	0.0309	5.733*	4.302	Present study, 2003
ROI	$y = -45.212x + 136.84$	0.501	4.213*	2.306	Agbayani <i>et al.</i> (1990), Triño <i>et al.</i> (1999), Triño and Rodriguez (2002)
	$y = -169.27x + 194.61$	0.5756	1.930	4.302	Present study, 2003

* Significant at $p < 0.05$ level.

Conclusion

The female mud crab (*S. olivacea*) culture in bamboo pens with the stocking density of 0.5 crab/m² with an average size of 120.27±1.93 g in weight and 77.45±0.22 mm in ICW at stocking would be technically (growth rate, SGR and FCR) and economically (ROI) feasible for the coastal region of Bangladesh using low cost trash fish as feed. However, more scientific studies are needed to increase survival rate and to reduce the capital cost through using low cost pen materials and low cost feeds.



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