Paper III

Production of Mixed *Scylla paramamosain* (Estampador) & *S. olivacea* (Herbst) in Semi-intensive Pond Culture using Two Different Supplementary Diets

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a) Sampled mud crabs after 90 days culture. b) Weekly recording of water quality parameters, oxygen (left) and salinity (right). c) Measuring carapace width (left), tying of crabs’ claws (centre) and measuring bodyweight (right). d) Chain of people walking across pond bottom collecting remaining crabs hidden in sediment at harvest, note Nypa palm shelter. e) Daily preparation of crustacean diet.
Abstract
Production performance of *S. paramamosain* and *S. olivacea* reared together in ponds and provided with different supplementary diets (crustaceans or trashfish) were evaluated with an unfed control group relying on natural food available within the pond. Each treatment was conducted in triplicate. The aim was to evaluate two production strategies over a 130 day grow-out trial: 1) production to 200 g crab$^{-1}$, which is the minimum preferred marketable size in the Lower Mekong Delta (LMD); and 2) production to 300 g crab$^{-1}$, the size that fetches the highest market price. Growth production models were estimated which revealed that the rearing period required to produce crabs of 200 g was 102 days with supplementary feeding, compared to 120 days for the unfed control group. The rearing period needed to produce 300 g sized crabs was estimated to be 144 days and 186 days for supplementary fed and unfed groups, respectively. The additional risk involved in rearing mud crabs to 300 g is not considered worthwhile as a decrease in pond water quality and higher mortality rates were observed in the final month of culture needed to achieve this larger size.

**Keywords:** Mud crab; *Scylla*, Growth; Production; Mekong Delta.
1. Introduction

Coastal land-use conflicts between aquaculture expansion and the conservation of mangrove forest has been an ongoing problem over the past two decades, especially in Southeast Asia. The adverse effects of aquaculture, both ecologically and socio-economically, are well documented (Gujja & Finger-Stich 1996; Primavera 1997, 2000). Pond culture of *Penaeus monodon* is the most important form of crustacean aquaculture in the Southeast Asia region (Rosenberry 1997), with little attention being paid to other shrimp species or to polyculture. However, the frequent occurrence of diseases is a major constraint to shrimp culture sustainability causing growth of the industry to slow since 1991 (Leung *et al.* 2000).

Since 1994-95, severe disease outbreaks among farmed shrimp have been endemic in the Lower Mekong Delta (LMD) of Vietnam (Johnston *et al.* 1999; Chung 1997), and currently white spot syndrome virus (WSSV) is the main disease there (D.T.H. Oanh pers. comm.). As a consequence of repeated disease outbreaks in shrimp ponds, mud crab farming (*Scylla* spp.) has become increasingly popular, with some farmers now suggesting that their income from crab is more reliable than that from shrimp (Duyen *et al.* 1999). Several challenge tests have demonstrated that mud crabs can be infected by WSSV (Chen *et al.* 2000; Rajendran *et al.* 1999; Otta *et al.* 1999) and that the disease can be transmitted from mud crabs to shrimp and vice versa (Kanchanaphum *et al.* 1998; Supamattaya *et al.* 1998). However, the mortality of WSSV infected mud crabs is far lower than that of shrimp (Rajendran *et al.* 1999; Supamattaya *et al.* 1998), a finding that is also in accordance with the experience of mud crab farmers’ in the LMD (S.M. Christensen personal observation).

A recent revision of the genus *Scylla* (de Haan, 1883) by Keenan *et al.* (1998), recognized four species: *S. serrata* (Forskal 1775), *S. olivacea* (Herbst 1796), *S. tranquebarica* (Fabricius 1798), and *S. paramamosain* (Estampador 1949). *S. paramamosain* and *S. olivacea* are the two common species found in LMD (Macintosh *et al.* 2002). Mud crab fishermen in Bac Lieu Province report that *S. paramamosain* is more dominant in the fishery than *S. olivacea* and it is also the preferred species for culture (Macintosh *et al.* 2002).

Mud crab farming relies on wild caught seed, which makes *Scylla* populations vulnerable to over exploitation by fishermen; immature crabs and females are particularly vulnerable (Macintosh *et al.* 1993). However, recent advances in seed production technology may soon close the crab life cycle as has happened in the shrimp industry (Keenan 1999). Currently, fishermen catch mud crab seed on the mudflats in the LMD; the seed are then sold to middlemen who sort them by size and offer them for sale to farmers for aquaculture. Many farmers also catch their own crab seed.

A number of culture systems for mud crabs are being operated in the LMD: grow-out of crabs from juvenile to marketable size in open extensive mangrove forest-aquaculture-
fishery farms or semi-intensive pond units; fattening of immature females to maturity; fattening of ‘thin’ crabs; and soft-shell crab production (Duyen et al. 1999; Dat 1999; Christensen et al. 2002).

Little information is available on the growth characteristics of the four *Scylla* species, or their comparative suitability for aquaculture overall. The majority of experimental trials have been conducted on *S. serrata* and *S. tranquebarica*. For example, in the Philippines *S. serrata* is considered to be the largest and fastest growing of the *Scylla* species (Fortes 1999b). In semi-intensive culture mixed stocks of *S. serrata* and *S. tranquebarica* have demonstrated high growth rates and economic viability (Agbayani et al. 1990; Triño et al. 1999a). To date, most of the information reported on mud crab production in the LMD has been obtained from farmer interviews rather than from monitoring production trials, hence the danger of the findings being subjective rather than objective. Baseline data are needed on the production of *S. paramamosain* and *S. olivacea* stocked together in ponds in order to develop better management and monitoring practices for the local crab farmers who depend on these two species.

There are two main farm gate price categories for mud crabs in the LMD: hard-shell male and females without mature ovaries in the weight range 200-300 g, and crabs above 300 g. The first category sell for VND 30-40,000 kg\(^{-1}\), the second for VND 40-50,000 kg\(^{-1}\) (USD 1.00 = VND 15,000). Mature females (identified by their orange coloured ovaries) above 200 g attract a higher farm gate value in the range VND 70-100,000 (S.M. Christensen personal observation).

The objective of this study was to investigate the production performance of *S. paramamosain* and *S. olivacea* in mixed pond culture, using two locally available feeds, compared to production in equivalent unfed control ponds. The latter group was included because some farmers in the LMD are reluctant to feed crabs because they believe that their growth is not improved by feeding. The three treatment groups involved were also used to determine the best production strategy to satisfy the different mud crab market categories explained above.
2. Materials & Methods

In October 1998, nine similar rectangular brackish water ponds were modified into semi-intensive crab ponds at the Bac Lieu Aquaculture Research and Extension Field Station of Cantho University (Figure 1). The field station is located 6 km South East of Bac Lieu Town and 2 km from the coastline, in an arid area previously transformed from mangrove forest into shrimp, brine shrimp (Artemia) and salt production ponds. The station ponds are representative of those being operated by farmers in Bac Lieu Province. Annual rainfall is around 1,800 mm with the dry season lasting from November/December to April/May during which approximately 10% of the annual precipitation occurs and evaporation ranges from 2.3-5.3 mm day\(^{-1}\). Average monthly temperatures vary between 25-28\(^{\circ}\)C (DOSTE, 2002).

2.1. Pond Design

Each of the nine ponds used measured 40 m x 12.5 m with a depth of 0.8 m. Fences were constructed on the dykes and around each pond to prevent crabs from escaping. The fences were made from a 1.2 m wide fine mesh (1 mm) black nylon net supported by bamboo sticks angled by 20\(^{\circ}\) towards the centre of each pond. The lower ends of the nets were embedded 10 cm along the base of the enclosures. Crabs had free access to burrow into the perimeter dike of the pond. Dry \textit{Nypa fructicans} leaves were placed at a 45\(^{\circ}\) angle in the bottom of the ponds to provide additional refuge.

Each pond had an underwater pipe (diameter 20 cm) for water entry and exit. Water levels in the ponds were controlled by an external sluice gate. Water was exchanged at
spring high tides twice monthly. To prevent crabs escaping through the underwater pipe a bamboo fence with a spacing of 0.5 cm was embedded 50 cm into the pond bottom surrounding the pipe. The top of the bamboo fence had an elevation of 30 cm above maximum water level. The grow-out trial started on October 28th 1998 and was operated for 130 days. The crabs used were collected by local fishermen on the mudflats along the coastline in Bac Lieu Province from October 26th-28th 1998.

2.2. Treatments

Batches of mixed species, *S. paramamosain* and *S. olivacea*, and sexes were allocated to each pond. Their average carapace width was 3.18 ± 0.18 cm and their average body weight 8.69 ± 0.99 g. Each pond group contained 250 crabs representing a stocking density in the ponds of 0.5 crab m⁻².

Three feed treatments were selected for testing in triplicate:

- Trashfish, consisting mainly of *Tilapia mossambica* which breed freely in the ponds and canals.
- Ba Khia (Vietnamese name), or mangrove sesarmid crabs, which are available locally.
- No supplementary feeding, relying on natural food available within the pond.

The two supplementary feeds were chosen because they were relatively inexpensive, and the local farming community were already using them.

<table>
<thead>
<tr>
<th></th>
<th>Trashfish</th>
<th>Crustaceans</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Dry weight</td>
<td>% Wet weight</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>59.89</td>
<td>16.02</td>
</tr>
<tr>
<td>Lipid (%)</td>
<td>6.03</td>
<td>1.61</td>
</tr>
<tr>
<td>Carbohydrates (%)</td>
<td>20.68</td>
<td>5.53</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>13.40</td>
<td>3.58</td>
</tr>
<tr>
<td>Dry matter (%)</td>
<td>26.74</td>
<td>32.51</td>
</tr>
</tbody>
</table>

Table 1 Chemical composition in % dry weight and in % wet weight of two feeds used in the trial. Proximate analyses were conducted after AOAC standards (1975).

Feeding rates were calculated based on sampled average bodyweight and a feed conversion ratio (FCR) of 4:1. In order to estimate pond biomass a survival rate of 100% was used for the first 60% of culture, after which 70% was used (Table 2). Feeding trays were used to monitor actual feeding activity and thereby also provided an indication of the environmental conditions and mud crab biomass within each pond.
Table 2 Feeding rates in % bodyweight (BW) used throughout the experiment and estimated survival (%) from stocking.

<table>
<thead>
<tr>
<th></th>
<th>0-30 days</th>
<th>30-60 days</th>
<th>60-90 days</th>
<th>&gt; 90 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding Rate BW</td>
<td>15%</td>
<td>10%</td>
<td>7%</td>
<td>5%</td>
</tr>
<tr>
<td>Estimated Survival Rate</td>
<td>100%</td>
<td>100%</td>
<td>70%</td>
<td>70%</td>
</tr>
</tbody>
</table>

2.3. Sampling and Harvest

Sixty crabs were measured from each pond population at stocking. Sampling of each pond was conducted at days 30, 60, 90 and 115 by using a hook and line plus a scoop net. Crabs were tied with nylon string and the following parameters were recorded: species, carapace width and length, bodyweight, sex, defects (e.g. a missing claw). A single harvest was carried out at day 130. After an initial harvest using a hook and line plus a scoop net, the water level was lowered to reveal crabs which had burrowed in the perimeter dike. These were dug out and added to the harvest record. Finally, the ponds were pumped empty and a chain of people walked across the pond bottom and collected any remaining crabs hidden in the sediment.

2.4. Environmental Conditions

Water quality was monitored at 0800-1000 hrs once weekly throughout the experimental period. The following parameters were recorded: salinity by refractometer, temperature and oxygen by YSI-Model 95, pH by Knick Portamess, turbidity by Secchi disk, water depth (tape measure) and water colour (by observation).

2.5. Experimental Design

One-way ANOVA was implemented to analyse data (95 to 99% confidence intervals tested). Duncan’s multiple range test (95% confidence interval) was used to determine multiple comparison of means of treatments that were not significantly different after being analysed by one-way ANOVA (Walpole & Myers 1993).

2.6. Estimated Growth Models

Estimated growth models were made by fitting the von Bertalanffy growth equation to the observed growth data:

\[ CW(t) = CW_\infty \times (1 - e^{-K(t-t_0)}) \]

Where \( CW(t) \) expresses the inner carapace width of the crab as a function of its age \( t \). The right hand side of the equation contains the age in years \( t \); mean asymptotic inner carapace width \( CW_\infty \); the Brody growth coefficient \( K \); and \( t_0 \) is named the initial condition parameter (Ricker 1975; Sparre & Venema 1998). The age of crabs on day 1 of the trial was assumed to be 2 months or 0.17 years, which is consistent with the
known early life history of wild mud crabs (Macintosh et al. 1999). Length-weight relationships were determined by logarithmic transformation of length and weight data, followed by linear regression analysis to determine the two constants q and b in the equation:

\[ W(t) = q CW(t)^b \]
3. Results
The growth response of crabs subjected to the three treatments, crustaceans (C), trashfish (T) and no supplementary feed (NF) is illustrated in Figure 2. The sampled crabs on days 30, 60 and 90 did not reveal any significant differences ($P > 0.05$) between treatments for either carapace width or bodyweight, but there was a trend that crabs in treatments C and T performed better than those in the NF group.

By day 115 a significant difference was observed between treatment groups for both carapace width ($P < 0.05$) and bodyweight ($P < 0.05$). Carapace width and bodyweight were significantly ($P < 0.05$) higher for treatments C and T compared to NF.
At experimental termination (day 130), a clear decline in average size for all treatments was displayed, both for carapace width and bodyweight. No significant differences (P > 0.05) were observed between treatments at day 130, but the slight growth advantage shown by the crabs receiving supplementary feeds was maintained.

Table 3 summarises the growth and production data for each treatment. Growth data are illustrated for day 115 as it is believed that the crabs would have continued to grow if not for a number of adverse factors which are described later. Production data were obtained from the final harvest. The average bodyweights of crabs in treatment C and T were above the minimum preferred marketable size of 200 g crab⁻¹ by day 115 (range: 245-289 g), whereas the average sizes of the NF crabs were grouped around the minimum acceptable value (range: 194-230 g). A significant difference in average growth rates was revealed with groups C and T being significantly higher than group NF (P < 0.05). No significant differences (P > 0.05) in production parameters were observed between treatments or replicates and values were in the following ranges: survival (11-38%); crabs with one or two missing claws (3-31%); and gross production (5.4-16.5 kg pond⁻¹ crop⁻¹).

Table 3

<table>
<thead>
<tr>
<th>Treatment</th>
<th>BW₁₁₅ (g)</th>
<th>DWG₀-₁₁₅ (g day⁻¹)</th>
<th>Survival₁₃₀ (%)</th>
<th>Defect₁₃₀ (%)</th>
<th>Gross Production₁₃₀ (kg pond⁻¹ crop⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crustaceans</td>
<td>252.7a</td>
<td>2.11a</td>
<td>20.7</td>
<td>19.1</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td>(±2.4)</td>
<td>(±0.02)</td>
<td>(±8.6)</td>
<td>(±6.3)</td>
<td>(±5.6)</td>
</tr>
<tr>
<td>Trashfish</td>
<td>259.8a</td>
<td>2.19a</td>
<td>24.3</td>
<td>14.5</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>(±25.4)</td>
<td>(±0.21)</td>
<td>(±1.6)</td>
<td>(±5.9)</td>
<td>(±3.8)</td>
</tr>
<tr>
<td>No feeding</td>
<td>213.8b</td>
<td>1.79b</td>
<td>22.4</td>
<td>20.5</td>
<td>9.7</td>
</tr>
<tr>
<td></td>
<td>(±18.5)</td>
<td>(±0.15)</td>
<td>(±13.7)</td>
<td>(±15.1)</td>
<td>(±3.9)</td>
</tr>
</tbody>
</table>

Species composition at harvest did not differ between treatments with the main species being *Scylla paramamosain* (Table 4). The percentage of surviving females, compared to surviving males, ranged from 48 to 71% in the harvests. On average around 50% of them were mature (identified by their orange coloured ovaries). Body weight for each species and sex within the crustacean fed treatment revealed significantly larger (P < 0.05) body weights for *S. paramamosain* (males and female) and *S. olivacea* males compared to *S. olivacea* females. No significant differences (P > 0.05) were observed between treatments for each species and sex, hence the data were pooled. The pooled data revealed that body weights for *S. paramamosain* males and females and *S. olivacea* males were significantly larger (P < 0.05) than for *S. olivacea* females.
Table 4 Analysis of species composition, sex, and maturity of female mud crabs at final harvest, along with body weight (BW) of male and female *S. paramamosain* (S. para) and *S. olivacea* (S. oliv). Stocking density was 0.5 crab m\(^{-2}\) in 500 m\(^{2}\) earthen ponds. Values in brackets denote standard deviation. Different letters, between BW in rows, indicates significant (*P* < 0.05) differences between group means.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>S. para. (%)</th>
<th>Females (%)</th>
<th>Mature females (%)</th>
<th>♂ BW S. para. (g)</th>
<th>♀ BW S. para. (g)</th>
<th>♂ BW S. oliv. (g)</th>
<th>♀ BW S. oliv. (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crustaceans</td>
<td>74.7 (±8.1)</td>
<td>60.1 (±8.3)</td>
<td>55.9 (±5.1)</td>
<td>244.6(^a)</td>
<td>235.4(^a)</td>
<td>279.5(^a)</td>
<td>181.4(^b)</td>
</tr>
<tr>
<td>Trashfish</td>
<td>69.4 (±4.6)</td>
<td>47.1 (±5.3)</td>
<td>57.5 (±30.2)</td>
<td>223.9</td>
<td>230.6</td>
<td>233.8</td>
<td>198.3</td>
</tr>
<tr>
<td>No feeding</td>
<td>65.3 (±17.4)</td>
<td>38.8 (±8.6)</td>
<td>49.3 (±21.1)</td>
<td>233.7</td>
<td>196.1</td>
<td>194.6</td>
<td>138.1</td>
</tr>
<tr>
<td>Pooled</td>
<td></td>
<td></td>
<td></td>
<td>234.0(^a)</td>
<td>220.7(^a)</td>
<td>236.0(^a)</td>
<td>172.3(^b)</td>
</tr>
</tbody>
</table>

3.1. Environmental conditions

During the first month of culture, pond water salinity values ranged between 5-10 ppt, which is well below the recommended range of 15-30 ppt for optimal growth of mud crabs (Triño *et al.* 1999b). However, salinity increased steadily throughout the experiment (Figure 3). From day 55 to 110 salinity remained within the optimum range, but during the last 20 days of culture it reached 32 to 39 ppt.

Temperature remained fairly constant around 30-34°C, apart from one reading of 25°C at 42 days. Throughout the experiment the temperatures were within the optimum range reported by Hill (1980) and Cholik and Hanafi (1992). The recommended optimal range for pH is 8.0-8.5 (Cowan 1983; Wickins 1981) and pH readings were within this range, apart from three readings of 7.5. During the first 120 days of culture the mean dissolved oxygen levels remained above the recommended minimum of 4.0 mg O\(_2\) L\(^{-1}\). During the last 10 days dissolved oxygen fell below 4.0 mg O\(_2\) L\(^{-1}\) (mean range: 2.0-3.8 mg O\(_2\) L\(^{-1}\)).

Turbidity values were highest in the first half of the experiment (average range: 23-33 cm) and decreased during the second half (average range: 19-24 cm). Water level ranged from 50 to 85 cm with an average depth of 70 cm.
Figure 3 Illustration of water quality parameters recorded between 0800 and 1000 hrs during the 130 days experimental trial: (A) salinity, (B) temperature, (C) oxygen and (D) turbidity. Horizontal lines indicate the recommended range for optimal growth of mud crabs.
3.2. Estimated growth

As there were no significant differences between the two fed mud crab treatments on any sampling date these two treatment groups were pooled. Two growth estimates were then made based on the sample data: one for supplementary fed mud crabs and one for the unfed control. The size data at day 130 (final harvest) were not included in the calculations because different harvesting methods were used. The final harvest involved removal of all burrowed crabs, which were slightly smaller on average than those sampled by hook-line and scoop net only.

| Table 5 Values from fitting the von Bertalanffy growth equation with the data sets obtained in the study. The estimated age of mud crabs at stocking was two months and this value must be added to the culture period to denote their actual age. Data from the final harvests were not included in the fit. |
|---------------------------------|---------------------------------|
| **Pooled** | **Supplementary Fed** | **Unfed** |
| T (years) | Culture period + 0.17 years | Culture period + 0.17 years |
| t₀ (years) | 0.08 | 0.08 |
| K | 3.0 | 3.3 |
| CWₘ₀ (cm) | 14.5 | 13.0 |

The two growth models obtained from the fits are displayed in Figure 4. t₀ is set at 0.08 years which is assumed to approach size zero. CWₘ₀ differs between the supplementary and unfed groups as it was assumed that growth deprivation during the early development of mud crabs would impact on their final asymptotic carapace width. All data for inner carapace width and bodyweight for the fed treatments were pooled, logarithmically transformed and analyzed by linear regression (Table 6). Data for the unfed treatments were analyzed in the same manner. The coefficient results from the regression analysis were highly significantly correlated for both groups (P < 0.01).

| Table 6 Values for the two constants in the length-weight relationship equation. This equation was used to calculate the carapace width for fed and non-fed groups at the preferred market-sizes ≥ 200 g and ≥ 300 g body weight. Time to ‘first harvest’ indicates production period required for ‘best growth performing mud crabs’ to reach market size. |
|---------------------------------|---------------------------------|
| **Supplementary Fed Mud crabs** | **Unfed Mud crabs** |
| Q | 0.2471 | 0.2579 |
| B | 2.957 | 2.931 |
| CW₂₀₀ g BW | 9.63 cm | 9.68 cm |
| CW₃₀₀ g BW | 11.04 cm | 11.16 cm |
| First harvest₂₀₀ g BW | 102 days | 120 days |
| First harvest₃₀₀ g BW | 144 days | 186 days |
Figure 4 Estimated growth in inner carapace width (cm) growth for the three pond treatments: crustaceans, trashfish and no feeding. Two von Bertalanffy growth functions were fitted to pooled growth data from the pooled supplementary fed ponds and unfed ponds, respectively. Constant $t_0$, $CW_\infty$ and $K$ used are those illustrated in Table 5.

There are two size categories of *Scylla* preferred local markets: 200-300 g crab$^{-1}$ and above 300 g crab$^{-1}$. Hence, carapace width was back-calculated to 200 g and 300 g body weight for both the supplementary fed and unfed groups. The resulting carapace widths were then used to calculate the production time to reach 200 g and 300 g, which were 102 and 144 days for the fed mud crab groups and 120 and 186 days for unfed groups, respectively (Table 6). Sampling at day 90 revealed that a small proportion of the stock were above 200 g in weight.
4. Discussion

4.1. Growth performance
The average daily weight gain (DWG) for the first 115 culture days was approximately 2 g day\(^{-1}\) for the fed groups (crustaceans or trashfish). This is in the mid range of growth estimates reported for *Scylla* by other authors at the same stocking density, but for different species: *Scylla serrata* 2.3 g day\(^{-1}\) (Agbayani *et al.* 1990); *S. olivacea* 1 g day\(^{-1}\) (Fortes 1999a); and mixed *S. paramamosain / S. olivacea* 2.5-4.3 g day\(^{-1}\) (Christensen *et al.* 2002). Little is known about the growth characteristics for each of the four *Scylla* spp. identified by Keenan *et al.* (1998). However, *Scylla serrata* is considered to be the largest and fastest growing of the mud crabs (Fortes 1999b). In a 120 days mono sex culture trial of mixed *Scylla serrata* and *S. tranquebarica* stocked at 0.5 crab m\(^{-2}\), the average daily weight gain was found to be 3.9 and 2.6 g day\(^{-1}\) for males and females, respectively (Triño *et al.* 1999a). From the same study, the authors suggest that mud crab carapace width, FCR, survival and production were not influenced significantly by using a mono sex culture but rather by stocking density. Hence pond production data obtained in the present trial may be compared to similar experiments with *Scylla* at the same stocking density, regardless of the choice of mixed or mono sex culture stocks were used.

Numerous authors have stated that male mud crabs gain more weight than females (Triño *et al.* 1999a; Poovachiranon 1992; Jayamane 1992). This observation was confirmed in the present study when the overall harvests of male and female *S. olivacea* were compared (236 and 172g, respectively), but in the case of *S. paramamosain*, the size difference between the sexes was slight (234 and 221 g respectively). The size at final harvest data also show that *S. olivacea* females are the least suitable candidates for pond culture, based on the minimum preferred marketable size for mud crabs in the LMD of 200 g. The poor growth performance of female *S. olivacea* may be associated with their early maturity, as their size of first maturity is known to be smaller than that of female *S. paramamosain* (Overton & Macintosh 2002).

4.2. Feed
Surprisingly, there were no significant differences between supplementary fed and unfed groups before sampling day 115. This suggests that there was ample endogenous food in the ponds during the first two to three months of operation. All ponds were supplied with shelters in the form of dried nypa palm leaves, which as a secondary function provided a medium for the formation of detritus. A study conducted on natural food and feeding of the mud crab in India revealed that detritus was the main food source for crabs of less than 70 mm carapace width, while crabs above that size depended mainly on crustaceans and fish (Prasad & Neelakantan 1988). A significant size differentiation between the fed and unfed mud crab groups was not observed until they reached 9-11 cm carapace width (Figure 2).
Stocking density has an important influence on cannibalism, which is the main factor affecting survival rates in mud crab culture (Baliao et al. 1981). In this experiment a stocking density of 0.5 crab m$^{-2}$ was used, which is reported to be optimal for mud crabs (Triño et al. 1999a; Agbayani et al. 1990; Baliao et al. 1981). Regardless of stocking density, it is very likely that crabs will turn to cannibalism when their food supply is insufficient. Hence, increased cannibalism in the unfed group may explain why no difference in growth performance between unfed and fed groups was not observed before day 115. Food conversion ratios (FCRs) were not calculated for this study due to the large mortality observed in all groups at final harvest, which would have greatly distorted the apparent FCR values.

4.3. Environmental parameters

Aquaculture ponds in the LMD are generally shallow (less than 1m deep) and experience significant fluctuations in water temperature, salinity and turbidity, coupled with low dissolved oxygen levels (Johnston et al. 1999). Apart from one low temperature reading during the present study (on day 42, due to a storm), pond water temperatures remained moderate and relative stable. However, the daily readings taken did not reveal the extent of diurnal temperature fluctuations, which for similar crab ponds within the same area can be as much as 5ºC (Le Couffe, unpublished).

Pond salinity ranged from 5-39 ppt, with an increasing trend through the study. Mud crabs have been found to survive salinities of up to 42 ppt for several days (Davenport & Wong 1987); nevertheless, the high salinity range by the end of the trial may have had an adverse effect on the growth of the stocked crabs. Low oxygen levels recorded in the last weeks of the trial may also have stressed the stock. A number of mud crabs were observed on the dike during early morning indicating that dissolved oxygen levels were depressed near the end of the trial. Mud crabs are known to recognise low oxygen levels and their response is to climb out of the water to breathe air (Davenport & Wong 1987). Overall, it is considered likely that insufficient water exchange was a major factor affecting the growth and survival of S. olivacea towards the end of the trial. The pond water depth could not be maintained above 50 cm due to the high rates of evaporation experienced in the dry season of this region (where salt and artemia production have been traditional activities). Lack of an adequate water supply for pond water exchange, leading to a build up of pond waste matter and stress on the stock, is also a major problem facing the great majority of aquaculture farmers in the LMD (Johnston et al., 1999).

4.4. Survival

A low survival rate was exhibited by all groups in the experiment (11-38%). Mortality was probably highest during the last two weeks of culture because of the declining water
quality conditions. Based on observation of the feeding trays, it was also noted that the mud crabs showed less feeding activity at that time.

Mud crabs remain buried during the day, emerging at sunset to spend the night feeding (Hill 1976). Therefore it is important that cultured animals have sufficient shelter opportunities in the pond. The nypa palm fronds used in these trials may have been inadequate as a refuge, especially for moulting crabs, which are particularly vulnerable to cannibalism. Seaweed (*Gracilaria*) has been used successfully to achieve good survival rates with mud crabs in several grow-out experiments (Chen 1990, Baliao *et al.* 1999; Triño *et al.* 1999a;), but has not been tested in the LMD, where the high water turbidity associated with crab ponds may be less suitable for seaweed production.

### 4.5. Sampling / Harvest

Sampling by using hook-line-scoop net was found to be size selective and not representative of the population within the pond. This was well demonstrated by the three harvest methods conducted: hook-line-scoop net; digging out crabs burrowed in the perimeter dike followed by pond emptying and collection of crabs from the pond bottom sediment. This may also help explain the apparent growth loss exhibited between sampling at day 115 and harvest at day 130, which is a result of the pooled bodyweights from the three harvest modes. In fact catches, using the hook-line-scoop net method revealed that mud crabs fed with crustaceans or trash fish reached an average weight of 292 g and 277 g, respectively after 130 days, compared to the total harvest averages of 224 g (crustacean group) and 219 g (trash fish group). Thus, it is recommended that frequent sampling is conducted using the hook-line and scoop net method during the culture period, as this provides a ‘best growth’ estimates of the stock. As soon as sampling reveals that the largest crabs in the pond have reached the preferred marketable size, they should be harvested. This will minimize the competition for food and space of the remaining stock, reduce the incidence of cannibalism, and allow the smaller individuals to grow faster (Baliao *et al.* 1999).

*Scylla paramamosain* and *S. olivacea* ratios were evaluated upon final harvest by using the key to *Scylla* species provided by Keenan *et al.* (1998). *Scylla paramamosain* was the dominant species accounting for approximately two thirds of the harvested population, regardless of treatment. This ratio is in contrast to reports from local fishermen in the area stating that the ratios of *Scylla paramamosain* and *S. olivacea* in their catches is 9:1. The pond harvest data imply that mortality was species dependent and that *S. olivacea* may be more adaptable to high salinity conditions (an observation also made by the crab farmers).

### 4.6. Estimated growth models

To our knowledge, this is the first account of pond production modelling involving a mixed stock of *S. paramamosain* and *S. olivacea*. The two growth functions presented in
this experiment represent values for the fastest growing individuals due to the sampling method employed. The functions also assume a ratio of 9:1, *S. paramamosain* and *S. olivacea*, and a sex ration of 1:1, based on the composition of the normal juvenile population collected from the coastal mudflats of Bac Lieu province. However, the two species cannot be separated morphologically before they are above 4 cm carapace width (Macintosh et al. 2002).

In a growth modelling study from India, asymptotic length ($CW_{\infty}$) for *S. serrata* and *S. serrata serrata* (assumed to be *S. serrata* and *S. tranquebarica* based on Keenan et al. 1998) were found to be 360 mm and 160 mm, respectively (Thomas et al. 1987). In the Indian study $CW_{\infty}$ was in the range 130-145 mm depending on treatment, indicating that *S. serrata* and *S. tranquebarica* attain a larger maximum size than *S. paramamosian* and *S. olivacea*. This conclusion is also supported by pond trials conducted on mixed (mono sex) stocks of *S. serrata* and *S. tranquebarica* showing that these species reached an average size of 475 g for males and 429 g for females after 120 days of culture when stocked as juveniles at 0.5 crab m$^{-2}$ (Triño et al. 1999a). The equivalent sizes reached by *S. paramamosian* and *S. olivacea* in the present study (after 130 days culture) were only approximately 50% of these values, showing the importance of species identification when comparing production studies involving mud crabs. Moreover, the production risks to farmers in the LMD associated with the extra culture period of 42 days required to increase the average size of pond reared *S. paramamosian* and *S. olivacea* from 200 g to 300 g are not considered to be worthwhile, unless the pond environment can also be made more favourable for the survival of large mud crabs.

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