DEVELOPMENT OF INTENSIVE POND FARMING TECHNIQUES FOR THE MUD CRAB <u>SCYLLA SERRATA</u> (FORSKAL) IN NORTHERN AUSTRALIA.

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FINAL REPORT

by

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DEVELOPMENT OF INTENSIVE POND FARMING TECHNIQUES FOR THE MUD CRAB SCYLLA SERRATA (FORSKAL) IN NORTHERN AUSTRALIA.

INTRODUCTION

A large demand for crab meat on both Australian and S.E.Asian markets has provided incentive for the development of a mud crab Scylla serrata farming industry in tropical Australia. Cannibalism of newly-moulted, softshelled crabs however constitutes a major constraint to profitable pond farming.

The main aim of the project was to observe moult-related cannibalism of mud crabs and define causative factors of this phenomenon and then to develop pond design and management techniques which alleviated this problem.

The project was initiated in September 1986 when construction of Sea Hatcheries Ltd.' commercial multi-species hatchery at Mourilyan Harbour, North Queensland (fig. 1) commenced. Facilities for larval rearing had been established by December 1986 and the first attempt to produce juvenile crabs was carried out.

By mid year of 1987 the main hatchery building was completed and a controlled environment laboratory was made available for clearwater behavioural studies. Experimental tank systems for replicated trials were set up in this room and time-lapse video equipment, for continual surveillance, was purchased and installed.

Initial behavioural studies had used wild caught juvenile mud crabs, however the numbers collected were small and their availability was erratic which made experimental design difficult.

After many, largely unsuccessful, attempts at rearing larvae in order to obtain juvenile crabs for the projected behavioural trials, it was decided to postpone the project for six months (between 16.10.87 - 31.3.88) while a more sophisticated rearing system was constructed.

This was carried out and all subsequent rearing attempts have been successful. These hatchery reared crabs were used in intensive small-scale trials and techniques have been identified which allow high stocking density with minimal mortality due to moult-related cannibalism.

SCOPE OF THE PROJECT

The project work can be divided into three main areas:

1: Larval rearing

2: Clearwater laboratory observations

3: Small-scale growout trials

Results of these studies are reported separately below.

LARVAL REARING

1: Broodstock Maintenance

Over the course of the project eighty-eight (88) mature female mud crabs (mean C.W. = 15.5 ± 1.1cm) were collected from Mourilyan Harbour and Conn Creek, Hinchinbrook channel (fig. 2) by set pot or dilly. A histogram comparing the size range of mature female mud crabs collected in northern (this study) and southern Queensland (Heasman,1980) is presented in figure 3. This shows that female mud crabs reach maturity at a smaller size

Figure 1. Sea Hatcheries Ltd. multi-species hatchery site at Mourilyan harbour, North Queensland.

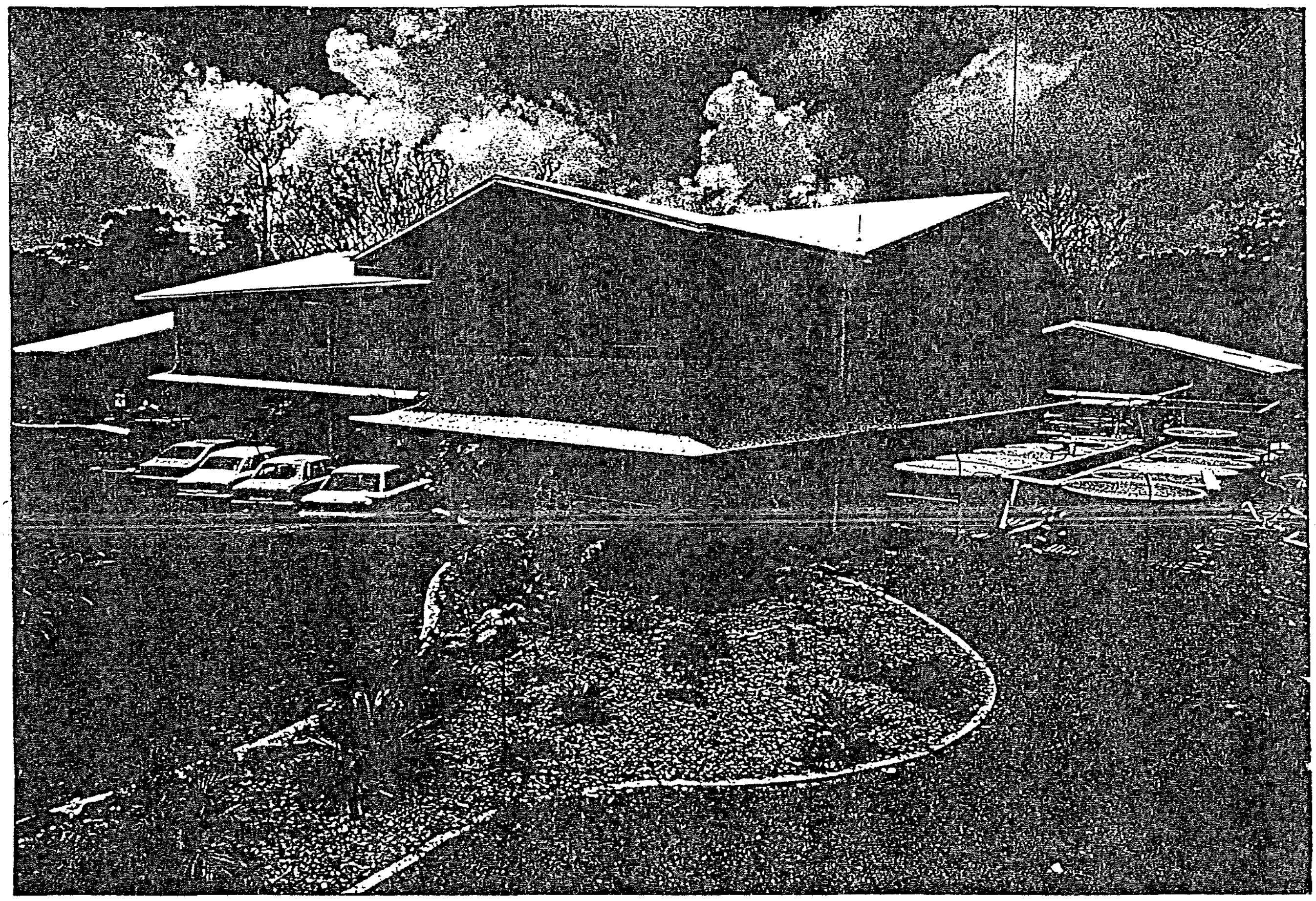


Figure 2. Mourilyan Harbour and Hinchinbrook Channel, North Queensland. Collection sites for mature female mud crabs *Scylla serrata*.

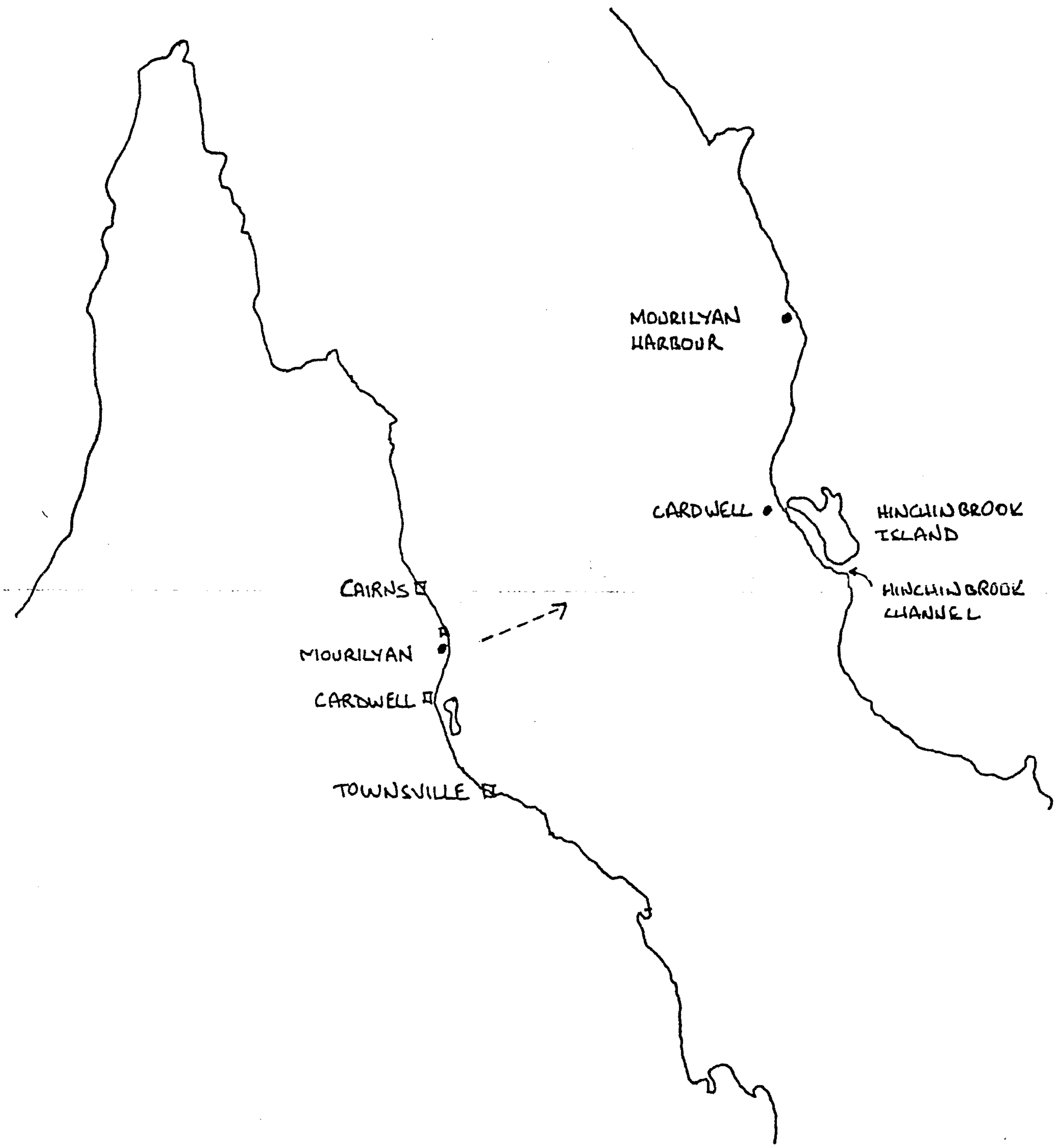
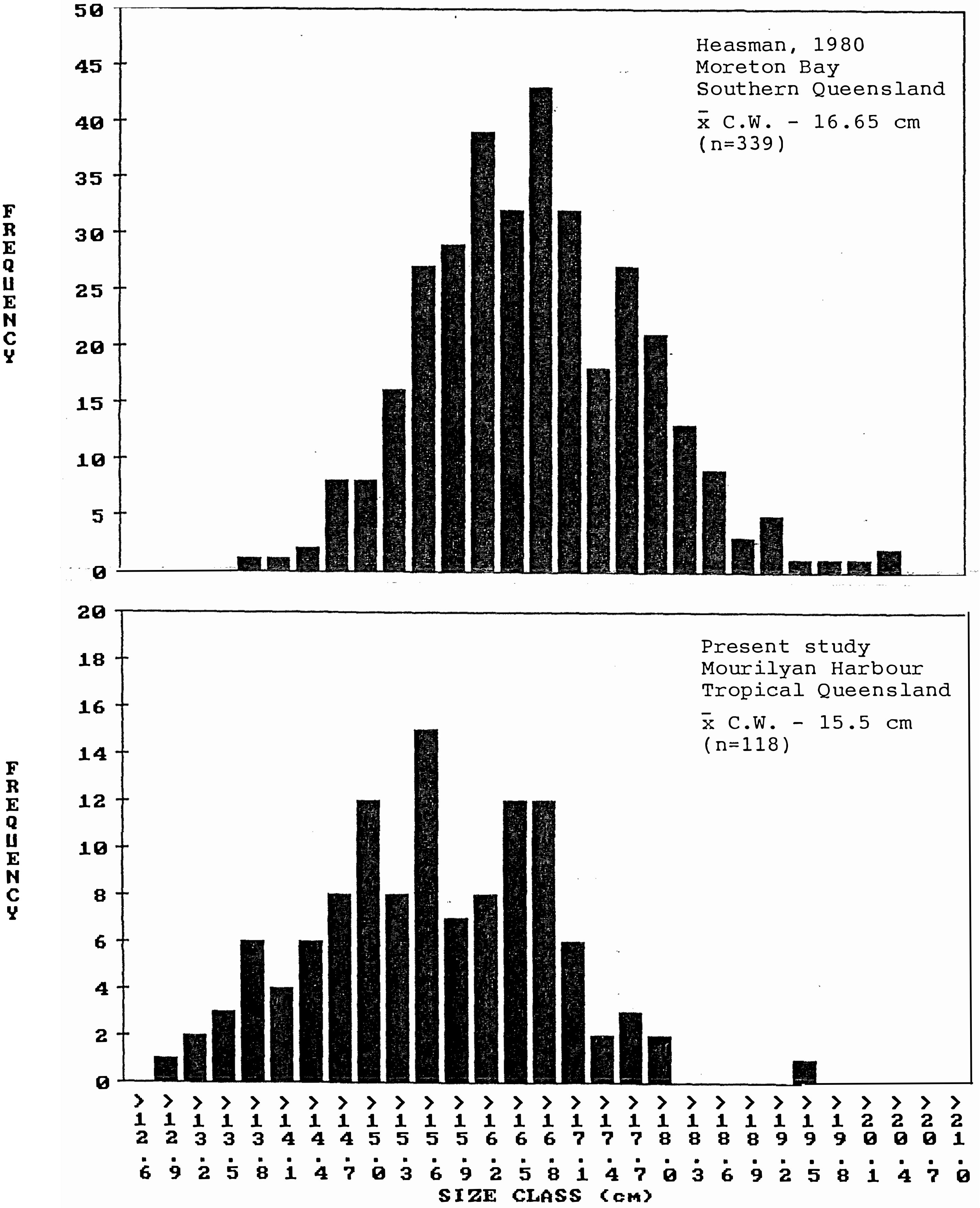


Figure 3. The size frequency of mature female mud crabs *Scylla serrata* collected in Southern (Heasman, 1980) and Northern (present study) Queensland.



(carapace width) in tropical Australia.

Initially the crabs were maintained individually in buoyant clothes baskets held within floating Barramundi (Lates calcarifer) broodstock cages in Mourilyan Harbour. This system proved inappropriate as servicing (feeding and cleaning) was difficult and water quality parameters such as salinity, temperature and turbidity were variable. Consequently a land based crab broodstock holding facility was established.

This consisted of a 2.4m diameter (5000 litre) above-ground fibreglass tank (plate 1) which had a perforated false bottom fitted to allow water circulation through a sand substrate. Approximately 20cm depth of calcareous beach sand was supplied as substrate to permit crab burying as well as provide biofilter media for reconditioning of sea water.

No more than seventeen (17) adult female mud crabs were held communally in the broodstock tank at any one time and all had the propodus of each cheliped clipped to reduce damage sustained during any antagonistic encounters.

Crabs were fed once daily a mixed diet of trawled crabs (Portunid sp.), prawns (Penaeus sp.) and pilchards (Sardiops neopilchardus) and any uneaten food was removed the following morning.

The temperature in the tank closely followed that of ambient seawater as heating facilities were not available and fresh seawater from the harbour was exchanged daily. A screen of 70% shade cloth was placed over the tank to prevent excessive algal blooms.

2: Induction of Spawning

Methods used to induce female crabs to spawn (extrude eggs) included bilateral and unilateral eyestalk ablation (Heasman and Fielder, 1983) and environmental stimulation. Table 1 shows the effect of the three husbandry techniques on induction of spawning.

Both physical eyestalk removal techniques induced crabs to spawn (60% and 70% for bilateral and unilateral ablation respectively) however bilateral ablation caused high mortality (22.5%) of crabs in the 24 hours following eyestalk removal. This was most likely due to excessive loss of haemolymph and other stress related factors.

Table 1. The number of mature female mud crabs, Scylla serrata which extruded eggs when subjected to three (3) spawn induction techniques.

Spawn Induction Method	No. Crabs Subjected	No. Crabs Spawning	Mean No. Days to Spawn ± sd	No. Died
Bilateral Eyestalk Ablation	40	24 (60%)	12.4 ± 4.4	9
Unilateral Eyestalk Ablation	10	7 (70%)	21.9 ± 13	1
Eyestalks Intact Tank Environment	38	7 (18.4%)	27.4 ± 29	4

On the other hand, crabs subjected to unilateral eyestalk ablation showed a low mortality level (10%) equivalent to that of intact crabs held communally. Similar results have been reported for Penaeus monodon (Liao and Chen, 1982) where mortality for bilaterally ablated prawns was higher than for those unilaterally ablated and bilateral ablation was therefore not considered a practical procedure for induction of spawning in this species.

The mean time taken for intact crabs, held in the broodstock tank, to spawn naturally was 27.4 ± 29 days (n = 7). Eyestalk ablation markedly reduced this time and increased the percentage of crabs which extruded eggs. Plate 2 shows a berried female mud crab holding approximately 1 million eggs.

3: Hatching

Although broods of eggs were obtained in a shorter period of time when crabs were subjected to eyestalk ablation, the quality of first stage zoea larvae (Z_1) obtained at hatch was variable. Broods extruded after bilateral ablation produced very poor Z_1 with only 25% of the hatches providing larvae suitable for culture i.e. vigorous and feeding at the water surface. Hatching was often extended over a 24 hour period resulting in prezoea or Z_1 larvae which lacked vigour and fell out of the water column. Total mortaltiy occured within 24 hours of hatch.

In contrast, broods extruded after unilateral ablation or natural spawning showed strong hatching synchrony (0600-0800 hrs) at 29 ± 1°C and produced good quality larvae in 71% of the cases. Samples of larvae from these hatches were used in larval rearing trials.

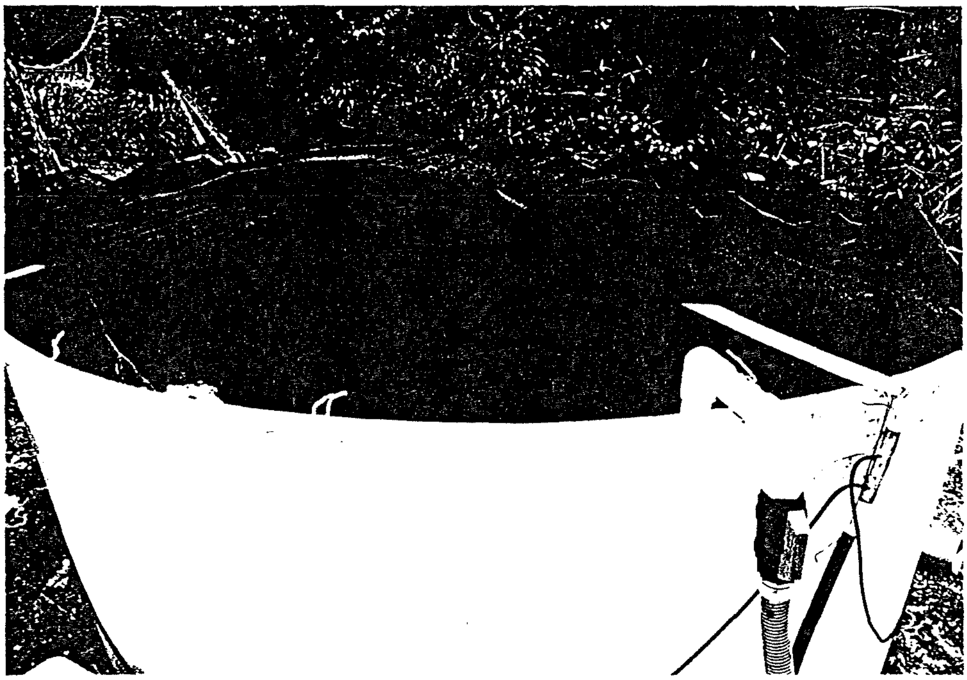


Plate 1. Fibreglass broodstock holding tank. The tank is 4.5 sq.m and has afalse bottom covered in 20 cm depth of calcareous sand.

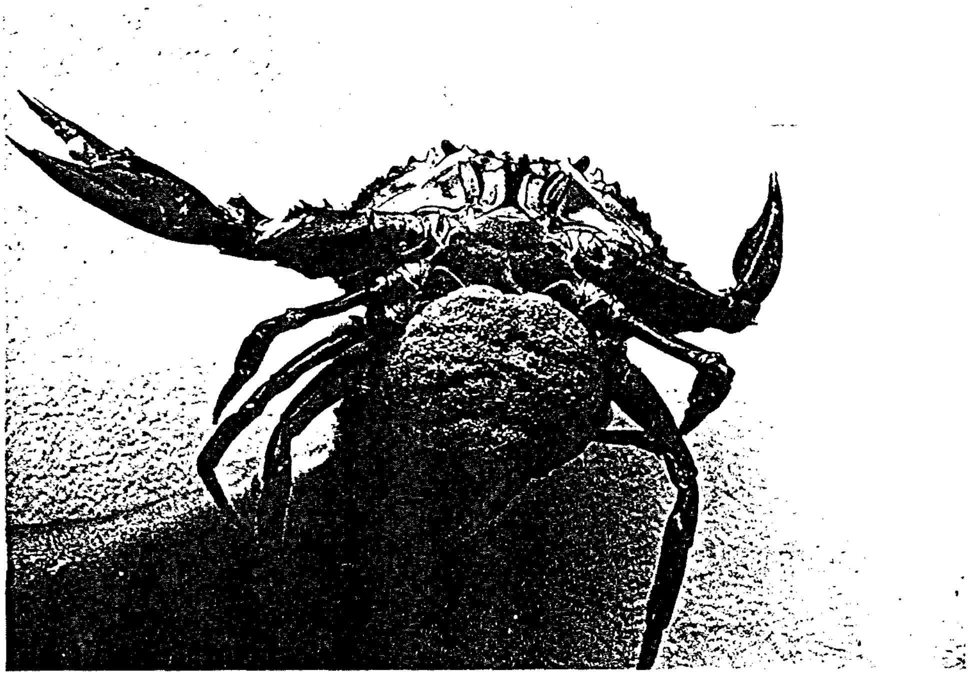


Plate 2. A 'berried' female mud crab <u>Scylla serrata.</u> The brood contains approximately 1 million eggs.

4. Larval Rearing

Thirteen (13) attempts at rearing mud crab larvae to first stage crab (C_1) were carried out however only the final three (3) were successful in producing large numbers (1000 total) of juvenile crabs for projected observational studies.

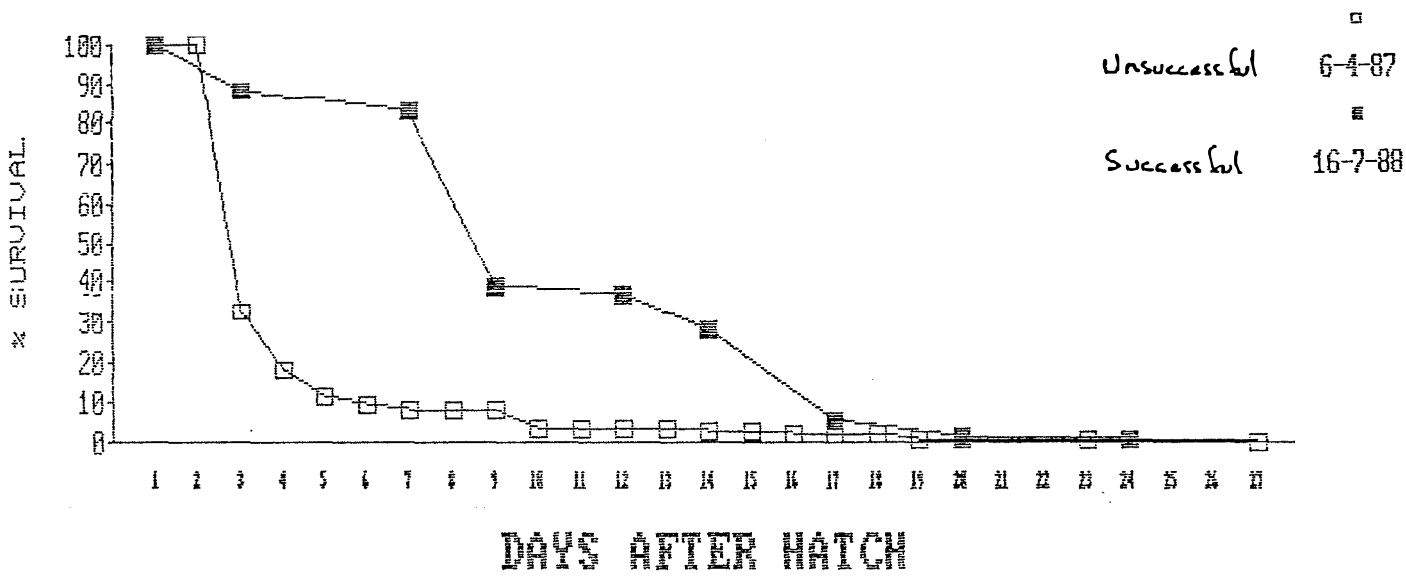
Figure 4 shows a typical larval survival curve for the successful and unsuccessful attempts. The first ten larval runs were carried out using experimental rearing tanks situated inside the main hatchery building. Sea water was drawn from the main rearing system and was pretreated by sterilization followed by reconditioning through ultra-violet and biological filters.

Unfortunately continued water quality problems were experienced (as seen by mass mortality of commercial numbers of Barramundi larvae) and after major mortality at Z_1 a steady decline in larval numbers occurred. Similar mortality patterns have been reported for S.serrata and Portunus trituberculatus larvae cultured in Japan (Cowan, 1984). The major causes were attributed to poor quality of the newly hatched Z_1; deteriorating water conditions with time and inadequate larval nutrition.

Because satisfactory numbers of juvenile mud crabs had not been obtained by October, 1987 a decision was made to postpone the project while a new larval rearing system was established. A modified system based on a design by Heasman and Fielder (1983) was constucted.

This overcame the water quality problems previously experienced and larval survival, particularly during the early zoeal stages, was greatly increased. Larval nutrition for the early stages (Z_1, Z_2 and Z_3) was also improved however mortality

Figure 4. Typical survival of mud crab Scylla serrata larvae in the "successful" and "unsuccessful" larval rearing attempts.



persisted during the latter larval stages (Z_4, Z_5).

Exuvia entrapment at the first metamorphosis from Z_5 - Megalopa caused excessive mortality. Affected animals died during ecdysis after being unable to free their appendages and eyes from the exuvia or alternatively some individuals shed their exuvia but lacked vigour and died soon after. Similar symptoms have been experienced for larvae of Macrobrachium rosenbergii and Palaemon serratus larvae and juvenile lobsters, Homarus sp. (Brock, 1982). It is thought that this is largely due to inadequate larval nutrition.

The survival rate from Z_1 to C_1 was very low and averaged approximately 0.5%. This is in the order of survival rates (4-9%) claimed by Japanese technicians for culture of Scylla (Cowan, 1984) but is much lower than the 26% survival recorded by Heasman and Fielder, (1983) indicating that site variation may contribute significantly to the success of mud crab larval rearing.

Improvement of larval nutrition needs further investigation before commercial numbers of juvenile mud crabs will be reared.

CLEARWATER LABORATORY OBSERVATIONS

Observations of moult associated cannibalism were carried out under clearwater conditions in tanks contained in a controlled environment room (29 $\pm$ 1^{o}C; 14/10 hr Day/Night; salinity 30 $\pm$ 2 $^{o}/_{oo}$).

Investigations included a series of replicated trials determining the effect of substrate, food quality and quantity and stocking density on survival of juvenile mud crabs. In addition, non-replicated continual surveillance trials which utilized time-lapse video recording, enhanced data obtained for the above trials with crab behavioural observations.

1. Simulated Tidal Trial

Introduction

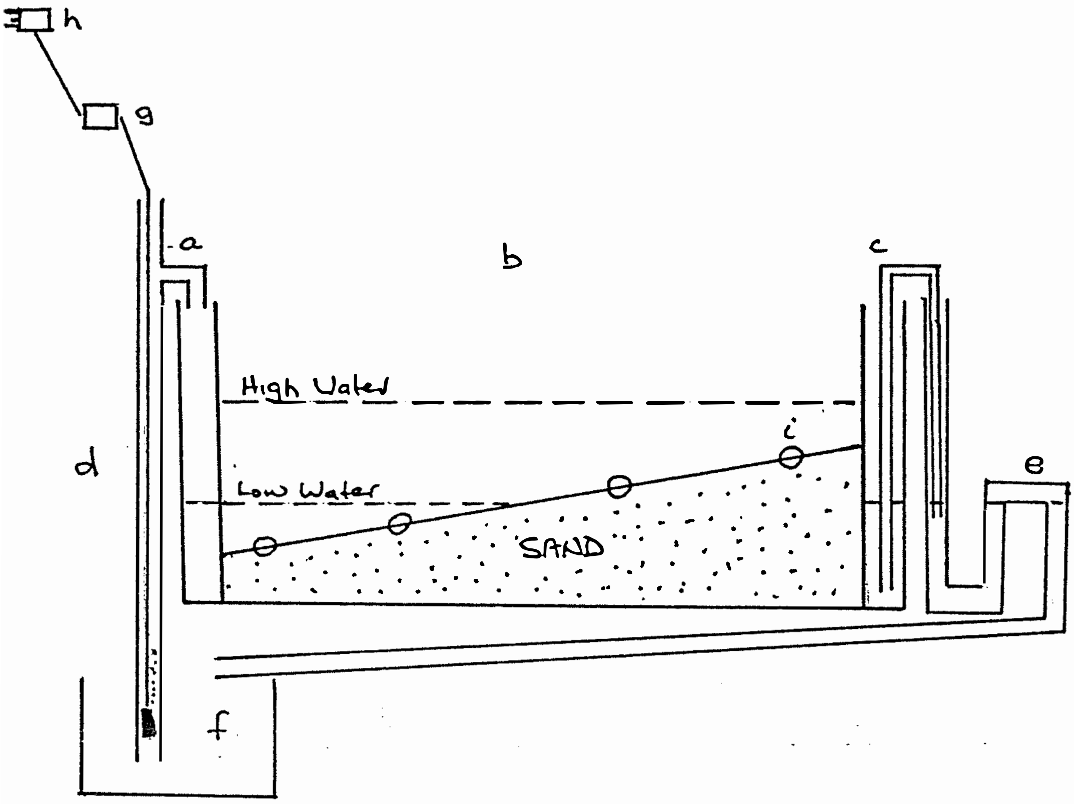
Heasman (1980) observed that juvenile mud crabs commonly moulted (shed exuvia) in seclusion under rocks and root systems in the intertidal zone of mangrove flats. Evidence for this was the discovery of exuvia and occasionally newly moulted, softshelled crabs when rocks or leaves were lifted at low tide. Hill et.al. (1982) also recorded that juvenile mud crabs (20-80 mm carapace width) remained in the mangrove zone at both high and low tide.

It was thought therefore that secluded intertidal sites may be essential for ecdysis of juvenile mud crabs and a trial was established to simulate this in the laboratory.

Materials and Methods and Results

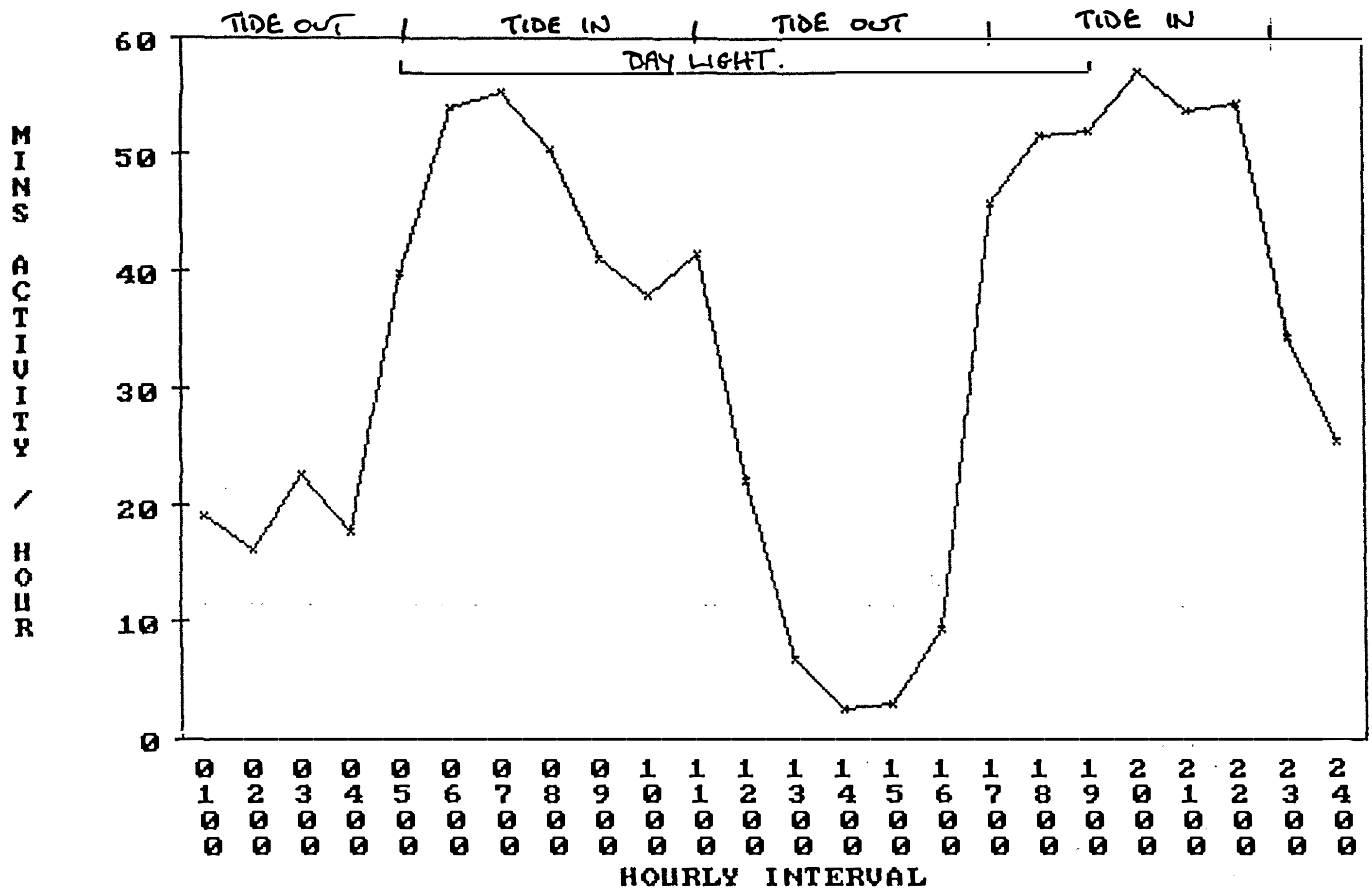
A simulated tidal system based on principles developed by Quinn and Fielder (1978) was established in a glass aquarium (fig. 5). In this, an intertidal zone, comprising half of the bottom substrate, was exposed and flooded at six (6) hourly intervals. Four (4) shelters, made from offcuts of 40 mm pvc pipe, were provided with two (2) shelters positioned in the intertidal and subtidal zone respectively. Both of the intertidal shelters were capable of holding water when emersed, thus

Figure 5. A simulated beach system (based on a design by Quinn and Fielder, 1978).



a & c, perforated false walls; b, sand compartment; d, airlift controlled by time switch (h) and aquarium air pump (g); e, constant level siphon; f, 30 litre reservior; i, artificial shelters.

Figure 6. The mean hourly activity of 2 juvenile mud crabs <u>Scylla serrata</u> held in a simulated tidal system for 5 days.



emmulating a pool of water typically found beneath a rock or leaf in the mangrove zone at low tide.

Two (2) wild caught C_6 mud crabs (av.C.W.= 21 $\pm$ 1.45mm) were used in each trial and were fed twice daily on minced crab (Portunid sp.). The trial was repeated three (3) times and each trial was run until one of the crabs moulted (5-6 days). Closed-circuit television and time-lapse video recording were used to continually observe crab behaviour.

The state of the water level appeared to have a marked effect on juvenile mud crab behaviour (fig. 6). The number of antagonistic contacts and time spent actually moving over the bottom and foraging for food was much greater at "high tide". At "low tide" the crabs were mostly inactive i.e. either buried in the sand in both subtidal and intertidal zones or occupying an artificial shelter.

Three (3) crabs were observed to moult. Two (2) of these crabs moulted at high tide between 0507 and 0607 hrs. whereas the third crab moulted at low tide at 1500 hrs.

All crabs moulted in the subtidal zone and were positioned on the sand substrate. They did not occupy the artificial shelters which were large enough to accomodate a moulting crab.

All of the newly moulted (softshelled) crabs were attacked and consumed by their hardshelled conspecifics, almost immediately following ecdysis. It appeared that the hardshelled crabs were able to detect the presence of a moulted crab by a chemical stimulus. On several occasions the hardshelled crab, which had been buried and had the sight path blocked by a shelter, became active and made its way directly to the softshelled crab. The chemical involved was most likely moulting hormone (Fielder, pers. comm.).

From these results obtained by small-scale tank trials, it appears that the imposition of a simulated tidal system is not an effective method for reducing cannibalism of softshelled juvenile mud crabs.

Other factors against this system of management include:

(a) subadult (70-150 mm C.W.) and adult (150-200 mm C.W.) crabs, which represent the marketable product, migrate into the intertidal zone at high tide but mostly retreat back to the subtidal zone with the falling tide (Hill et.al.,1982). Therefore stocking density would increase at low tide and hardshelled as well as softshelled cannibalism could account for major mortality.

(b) good quality brackish/sea water would be necessary constantly for water replacement

(c) High pumping costs.

2. Substrate Preference Trial

Introduction

The above tank trial had shown that juvenile mud crabs had essentially occupied a different habitat for hardshelled (intermoult) and softshelled (moulted) behaviour. The intermoult crabs spent their inactive periods either buried in the sand or secluded in the artificial shelters whereas moulting occured on top of the sand substrate.

It was postulated therefore that the mud crabs may prefer to moult in open spaces to facilitate escape from potential predators. Heasman (1980) showed that recently moulted crabs are able to flee from or repel (by threat postures) other hardshelled crabs within several hours (1 - 2% of the intermoult duration) of moulting.

This trial was set up to determine if juvenile mud crabs had preferred intermoult and moulting sites when provided with naturally occurring substrates.

Materials and Methods

The substrates used in the trial were coral rubble, detritus (leaf litter found in the crabs natural habitat) and calcareous sand. The coral rubble and detritus provided darkened cavities for seclusion and the sand a fluidised substrate for either burying or open space for moulting.

Two (2) substrates were provided in equal proportions in each of three treatment substrate combinations. The combinations were coral rubble/sand, detritus/sand and sand/sand (control). Each treatment combination was replicated three (3) times in a completely randomized design. Tanks were 0.11 m^2 and each tank was stocked with 3 C_5 or C_6 wild caught mud crabs (stocking density = 27 m^{-2}).

Observations of intermoult crab and exuvia position were noted every 2 hours from 0800 to 1800 hrs for seven (7) days.

Results

Hardshelled crabs significantly ($P < 0.001$) preferred coral rubble and detritus substrates to sand as sites for normal intermoult behaviour during the period of observation (tables 2 & 3).

Table 2. Total number of juvenile mud crabs found occupying the coral rubble or sand for 6 observations during 0800 and 1800 for 7 days. Three (3) treatment replicates with 3 crabs per rep.

	TREATMENT					
DAYS	RUBBLE (total number crabs)			SAND (total number crabs)		
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
1	18	17	18	0	1	0
2	17	13	18	1	5	0
3	17	12	17	1	6	1
4	15	7	9	3	11	9
5	13	13	10	5	5	8
6	14	13	8	4	5	10
7	9	13	11	9	5	7
Subtotal	103	88	91	23	38	35
TOTAL		282 ***			96	

*** Significant at 0.1% level

Table 3. Total number of juvenile mud crabs found occupying the detritus or sand for 6 observations during 0800 and 1800 for 7 days. Three (3) treatment replicates with 3 crabs per rep.

	TREATMENT					
DAYS	DETRITUS (total number crabs)			SAND (total number crabs)		
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
1	17	16	17	1	2	1
2	15	13	16	3	5	2
3	16	18	13	2	0	5
4	15	17	13	3	1	5
5	17	17	17	1	1	1
6	16	18	13	2	0	5
7	15	14	15	3	4	3
Subtotal	111	113	104	15	13	22
TOTAL		328 ***			50	

*** Significant at 0.1% level

When crabs moulted in the coral/sand treatment 83.3% (n=12) of the exuvia were found on the sand surface. Thus there appeared to be a distinct preference for different sites to carry out intermoult and moulting activity. This was a very desirable attribute because by simple preference for a substrate the vulnerable softshelled stage had removed itself from the vicinity of the predatory hardshelled crabs.

There did not appear to be any preference for the sand substrate as a moulting site when combined with detritus. Only 56% (n=9) of the exuvia were found on the sand.

A possible reason for the difference between detritus and coral rubble may concern the type of cavity available for seclusion. Although the coral had interstitial cavities suitable for hardshelled seclusion they may not have been large enough for ecdysis, thus forcing the crab to leave the coral. On the other hand, the nature of the detritus (organic debris) was such that the cavity size was undefined i.e. the substrate could be easily moved by both hard and softshelled crabs to create larger cavities if desired.

Although the treatment combinations caused different behavioural patterns there was no effect on cannibalism at this stocking density as survival for all treatments was 100%. Further trials investigating the treatment effect at higher stocking density were not carried out for the following reasons.

If a rubble system were to be established in a pond situation several problems could arise.

(a) The rubble would have to provide intersticies large enough to accomodate subadult and possibly adult crabs. This would only be accomplished with large rocks/bricks which in most cases would have to be trucked onto site. This would be a costly procedure.

(b) Siltation, which would reduce the efficiency of the system by reduction of cavity volume, could be a major problem. Desilting would require removal, at least in part, of the rubble which would be labour intensive and therefore expensive. The frequency of this procedure would depend largely on the quality (amount of suspended solids) of the incoming exchange water.

(c) Harvesting could present problems as seine netting would be impossible and ineffective over the rocky bottom; drain harvesting would again require the removal of the rubble to capture secluded crabs. Trapping would be the only other alternative and this can lead to bias sampling as well as incomplete population harvest.

(d) By providing a wide range of cavity sizes the smaller crabs may remain within the rubble to moult, thus becoming vulnerable to larger intermoult crabs also occupying this zone.

The use of organic detritus in a pond situation would not be possible due to the potential water quality problems, however it would be possible to provide inert artificial materials which created a similar environment.

The following trials were based on development of this idea.

Artificial Substrate Trials

Introduction

Preliminary observations of large numbers of C_1 - C_4 mud crabs held in tanks supplied with two (2) types of artificial material, namely fibreglass flywire and nylon onion bags, had shown that both materials provided highly desired habitats.

Juvenile mud crabs spent most of their time secluded underneath or within folds of the mesh and only left to forage for food. Antagonism between conspecifics was reduced and this appeared to be related to the amount of artificial material present.

A large proportion of the exuviae were found on the mesh and it seemed that the moulting crabs required a substrate which they could grasp to facilitate extraction from the exuviae. Many of the exuviae were firmly attached with the dactyl of their perieopods (walking legs) wrapped around the matrix of the mesh.

When C_4 crabs were observed in the process of moulting it also appeared that extraction from the exuvia was accomplished faster on a mesh substrate than on a bare tank surface.

Although both artificial materials provided similar substrate qualities the onion bag was chosen for further investigations for the following reasons.

(a) Onion bags were much cheaper than comparitive areas of flymesh and they were

(b) readily available.

(c) The open weave of the bags allowed better water circulation and did not accumulate detritus as quickly as flymesh.

(d) The bags were purchased in a form suitable for establishment in a pond situation whereas the flywire required work such as cutting and folding/stitching to create darkened cavities.

Artificial Shelter/Depth Trial

Due to the above observations a trial was set up to establish quantitatively if provision of increased amounts of artificial shelter affected survival of juvenile mud crabs.

Of particular interest was whether the typically benthic juvenile crabs would utilise artificial substrate positioned in the water column as Heasman (1980) observed that threatened C_1 - C_3 mud crabs commonly swam vertically upwards and remained in the water column for several minutes.

Materials and Methods and Results

The trial consisted of four (4) non-replicated shelter treatments and was carried out in the experimental tank system as described in figure 7.

Horizontal layers of onion bag were provided at intervals of 112 mm depth and treatments 1,2,3 and 4 each had 1,2,3 and 4 layers of mesh respectively.

Each tank was stocked with 9 C_5 (C.W.= 15.5mm) and 9 C_6 (C.W.= 20.6mm) crabs which represented a stocking density of 65 crabs/m^2. The crabs were fed to satiation three times daily (0800, 1700 and 2300 hrs) on a diet of minced crab (Portinid sp.) and prawn (Penaeus sp.).

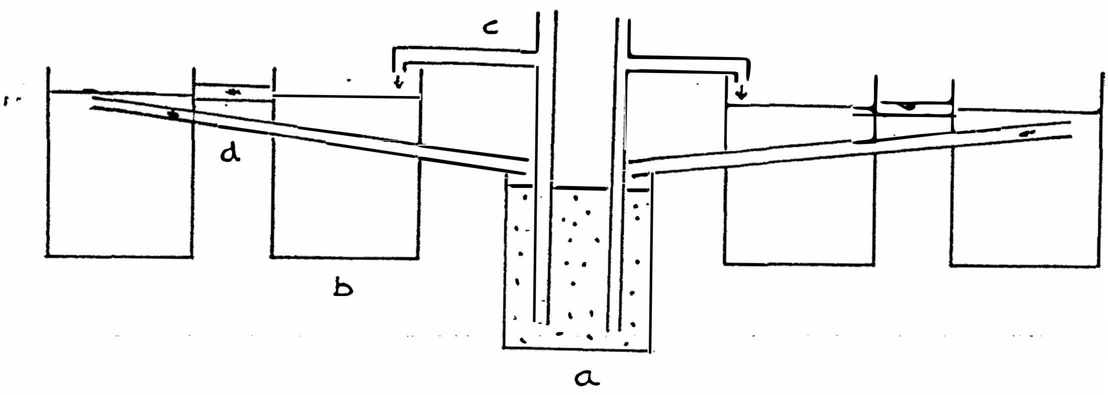
The tanks were checked twice daily for any exuviae and the position in which they were found was recorded. The number of surviving crabs was recorded every 2-3 days. The trial was conducted for 31 days.

The amount of available shelter had a marked effect on survival of the crabs (table 4). On the whole, the number of surviving crabs was related to the number of layers of shelter. Survival was lowest (22%) in the treatment with 1 shelter and highest (61%) in the treatments with 2 and 4 layers. The number of mortalities was closely related to the number of moults which occurred on the bottom level (figure 8). Food was placed onto this level so it is likely that most of the crabs present there were foraging and were therefore potential cannibals.

This may explain why survival in treatment 2 was the same as treatment 4. 71% and 77% of the moults occured above the bottom layer for treatments 2 and 4 respectively whereas only 55% occurred above the bottom layer in treatment 3. This may indicate that the position where moulting occurred was largely opportunistic. The treatments were not replicated so no real conclusions about site preference can be drawn.

The data does show however that juvenile crabs occupied artificial shelter which was present at varying depths throughout the water column.

Figure 7. Experimental tank system used for observation of the effect of artificial shelter on survival of juvenile mud crabs.

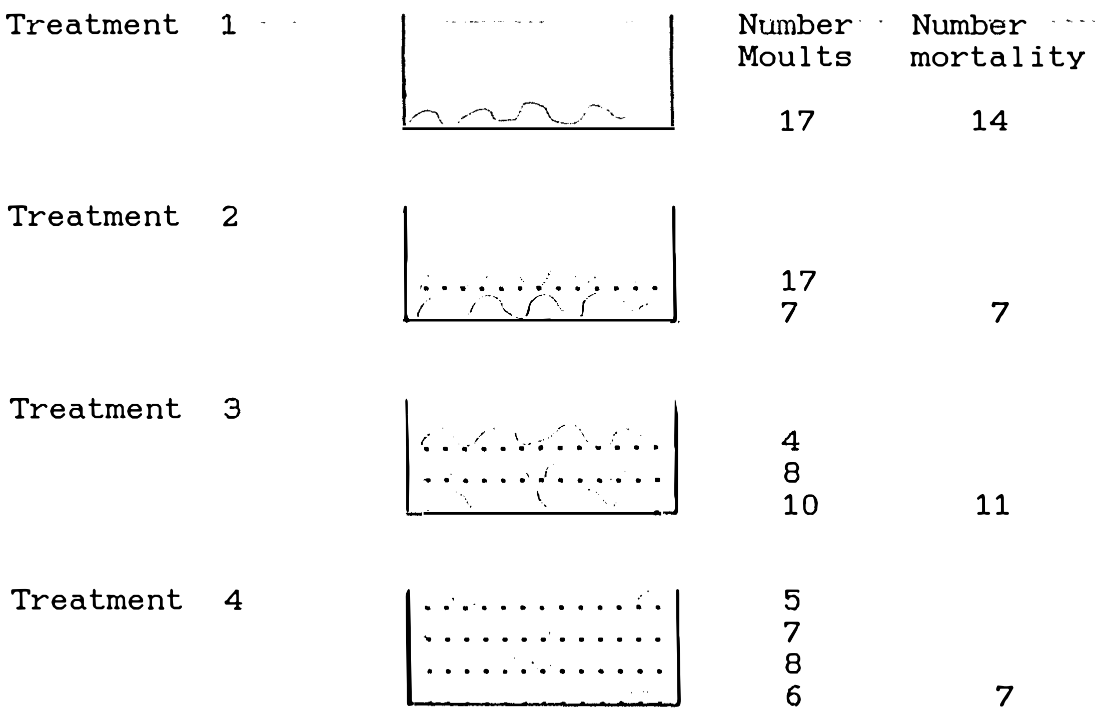


a, coralline biofilter; b, 100 litre circular experimental tank; c, airlift pump; d, overflow return line.

Table 4. The number of moults and mortalities experienced in tanks which had horizontal layers of artificial substrate provided at depth intervals of 112.0mm. Tanks were initially stocked with 9 C_5 and 9 C_6 crabs.

Number of Shelter Layers	Number of Moults	Number of Mortality	No.Mortality / No. Moults %	% Surv.
1	17	14	82	22
2	24	7	29	61
3	22	11	50	39
4	26	7	27	61

Figure 8. The position, number of moults and mortality that took place in 4 treatments of varying levels of artificial shelter. Tanks were stocked with 9 C_5 and 9 C_6 mud crabs initially.



Artificial Shelter/Sand Trial

Introduction

The above trial had shown that crabs would utilise artificial shelter for both intermoult and moulting behaviour however the shelter was not tested in conjunction with a natural substrate.

It was thought that the mud crabs may have had a greater preference for a natural fluid substrate in which they could bury, and therefore the inclusion of artificial shelter in a pond would be pointless if the crabs did not use it.

Two trials were run in concert to determine the effect of artificial shelter with a sand substrate on crab behaviour and survival.

Continual Surveillance Trial

Materials and Methods

This trial utilised continuous video observation and was carried out in a single 100 litre (Nally Pty Ltd) container, which was established with two levels of artificial shelter (225 and 337 mm depth) and a bottom level of calcareous sand. Each layer of substrate occupied 1/3 of the container surface area (plates 3 & 4).

The artificial layers were constructed from plastic cardboard covered in nylon mesh bag. Excess onion bag was bunched to create folds in which the crabs could hide. The sand layer was positioned centrally and was approximately 5 cm deep.

Water was air-lifted from the tank into a coralline biofilter and reconditioned water was returned to the tank below the sand layer. This prevented turbulence and allowed undisturbed

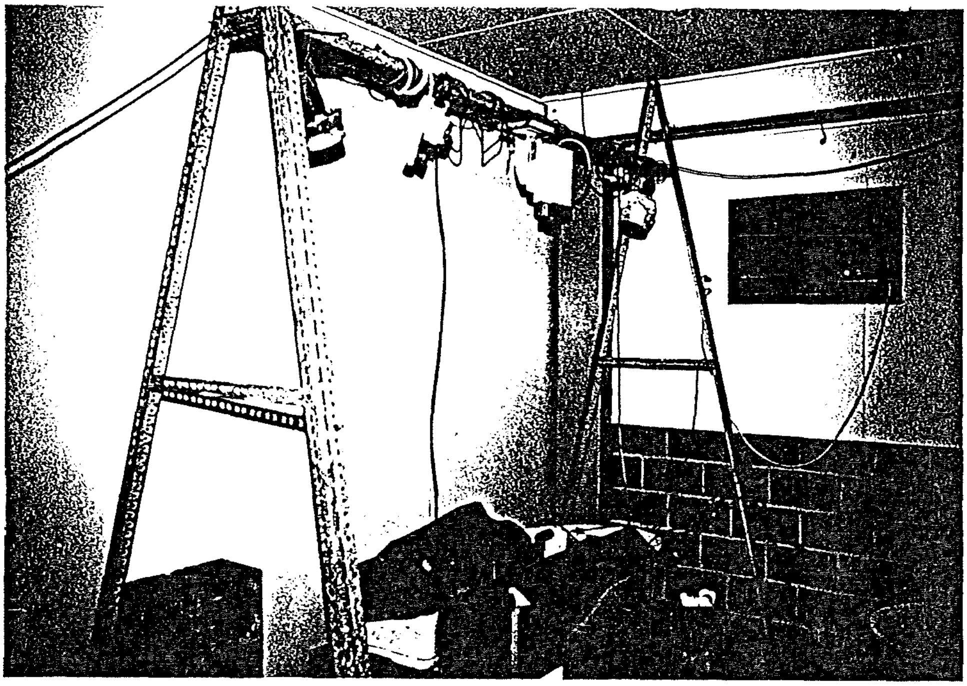


Plate 3. Surveillance camera used in conjunction with time-lapse video recorder for observation of juvenile mud crab behaviour.

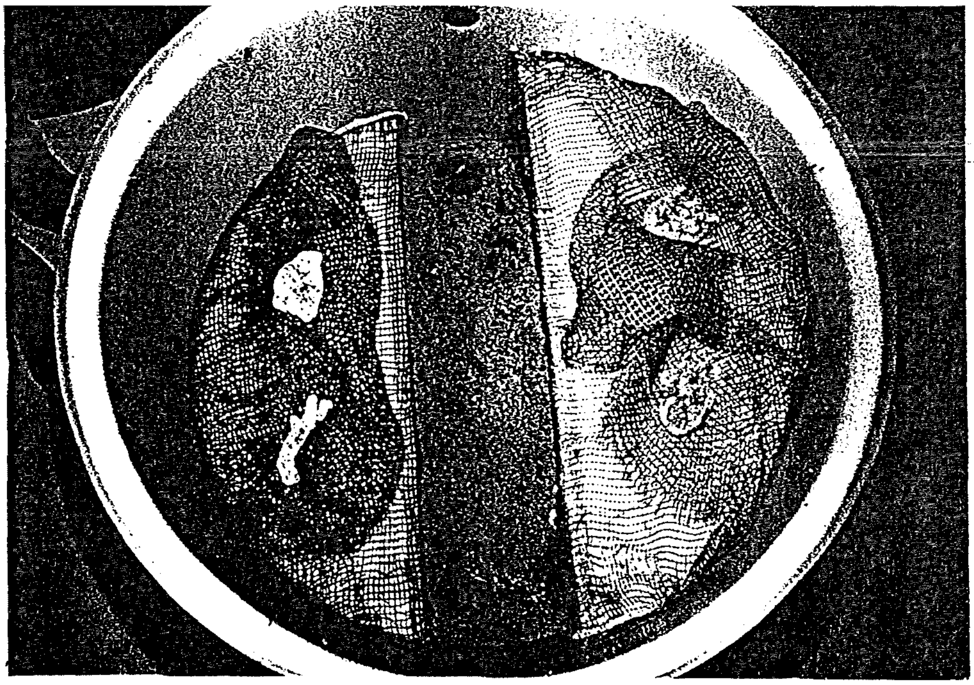


Plate 4. 100 litre experimental container. High and Low levels of artificial shelter and a bottom sand layer.

observation with the video equipment.

The tank was stocked with 9 C_6 mud crabs (32 crabs/m^2) which were fed 3 times daily on minced crab and prawn. The food was placed on the sand substrate.

Video records were taken for 5 days after a 7 day acclimation period. Analysis of the video consisted of observation of crab position at 15 minute intervals. Data was analysed for significance using ANOVA.

Results

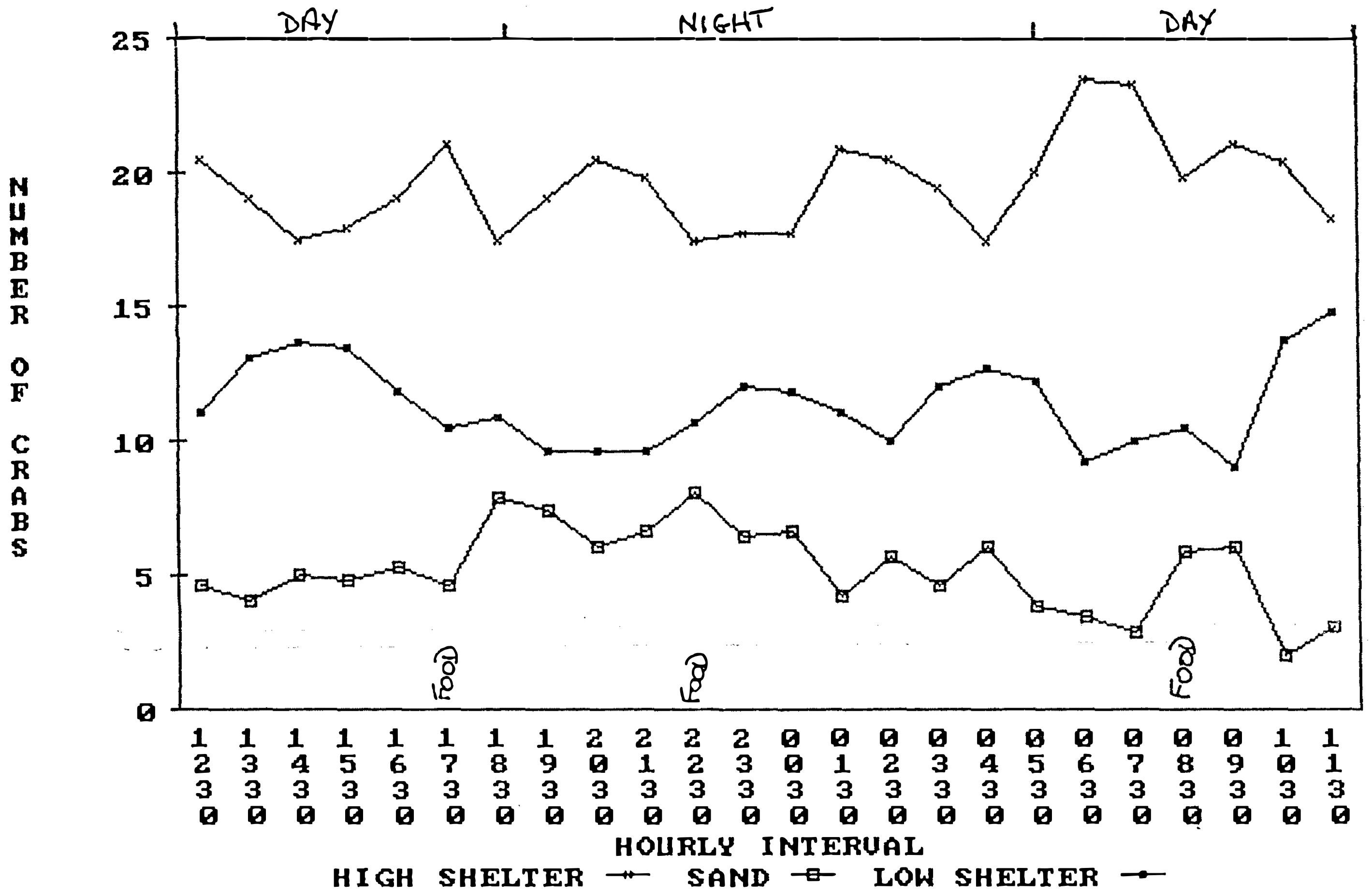
Results showed that over the 5 day period of observation the juvenile crabs significantly ($P<0.001$) preferred the artificial substrate for intermoult activities and that more crabs spent their time secluded on the higher bag shelter than the lower (figure 9).

Crabs were noted to be absent from the sand on 24.8% of the observations ($n = 464$), however the mean for total hourly observations over 5 days showed that there were always some crabs present on the sand. On only 2 occasions were crabs observed to be buried. The rest of the time they were exposed and actively moving (foraging) over the sand surface.

Although the crabs were not individually identified it appeared that they underwent a feeding rotation. There were no apparent peaks of activity (increased number of crabs) at feeding time. Crabs would leave the shelter of the bags and move onto the sand where they consumed food or on occasion retreated back to the bags holding food. A maximum of 4 crabs were observed on the sand at any one time.

Moulting did not occur during the 5 day observation period

Figure 9. The mean number of juvenile mud crabs found occupying the substrate layers per hour (total of 4 by 15 minute observations). Substrate consisted of 2 layers of onion bag at 225 (LOW) and 337mm (HIGH) depth respectively and a bottom sand layer. The tank was stocked with 9 C_6 mud crabs initially and the trial ran for 5 days.



however 8 exuvia were found during the 7 day acclimation period. Five (5) moults occurred on the 337 mm depth shelter, 1 on the 225 mm depth layer and 2 on the sand. Mortality did not occur over the course of the trial.

The trial indicated that artificial shelter was actually preferred for seclusion over the natural fluid sand substrate. Inactive crabs also preferred to be as far away as possible from the feeding site.

Artificial Shelter/Sand Survival Trial

Materials and Methods

This trial was established to determine if the presence of vertical bag shelter affected mud crab growth and survival.

The trial consisted of 2 treatments with 2 replicates per treatment and was carried out in the tank system as in figure 7. The first treatment (control) provided a calcareous sand substrate only while the second treatment provided both sand and vertically suspended artificial bag substrate. Two (2) onion bags were cut in half and placed into each of the 2 treatment tanks. This represented 14.5 bags/m^2. To ensure that the bags were suspended vertically in the water column a piece (10 cm^3) of polystyrene was tied to one end while the other end was weighted down with a piece of coral. The sand substrate was placed on top of a false bottom and water was circulated (by an air-lift pump) through the sand to prevent anoxia. The depth of each tank was approximately 450 mm (plate 5).

Each tank was stocked with 25 crabs (S.D. = 92.5 crabs/m^2) ranging in size from C_4 to C_7. An equivalent ratio of each stage

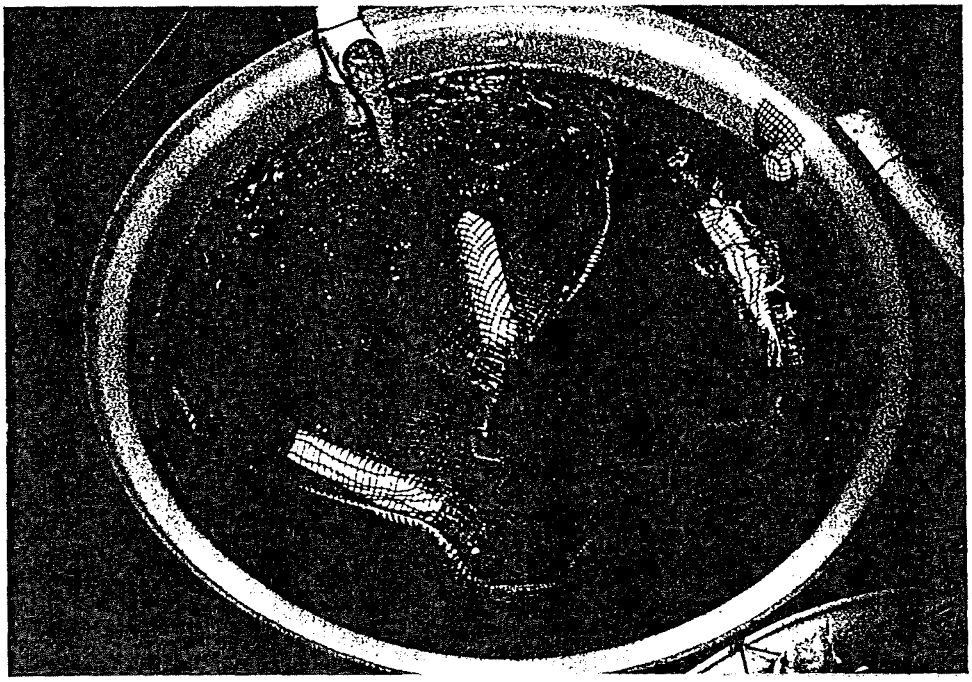


Plate 5. Experimental 100 litre tank. Substrate provided consisted of vertically suspended artificial onion bags and a bottom sand substrate.

crabs were placed into each tank. Crabs were fed as in the previous trial.

Observations of any exuvia and their position were noted twice daily. A population census was taken approximately every third day. The trial was run for 23 days.

Results

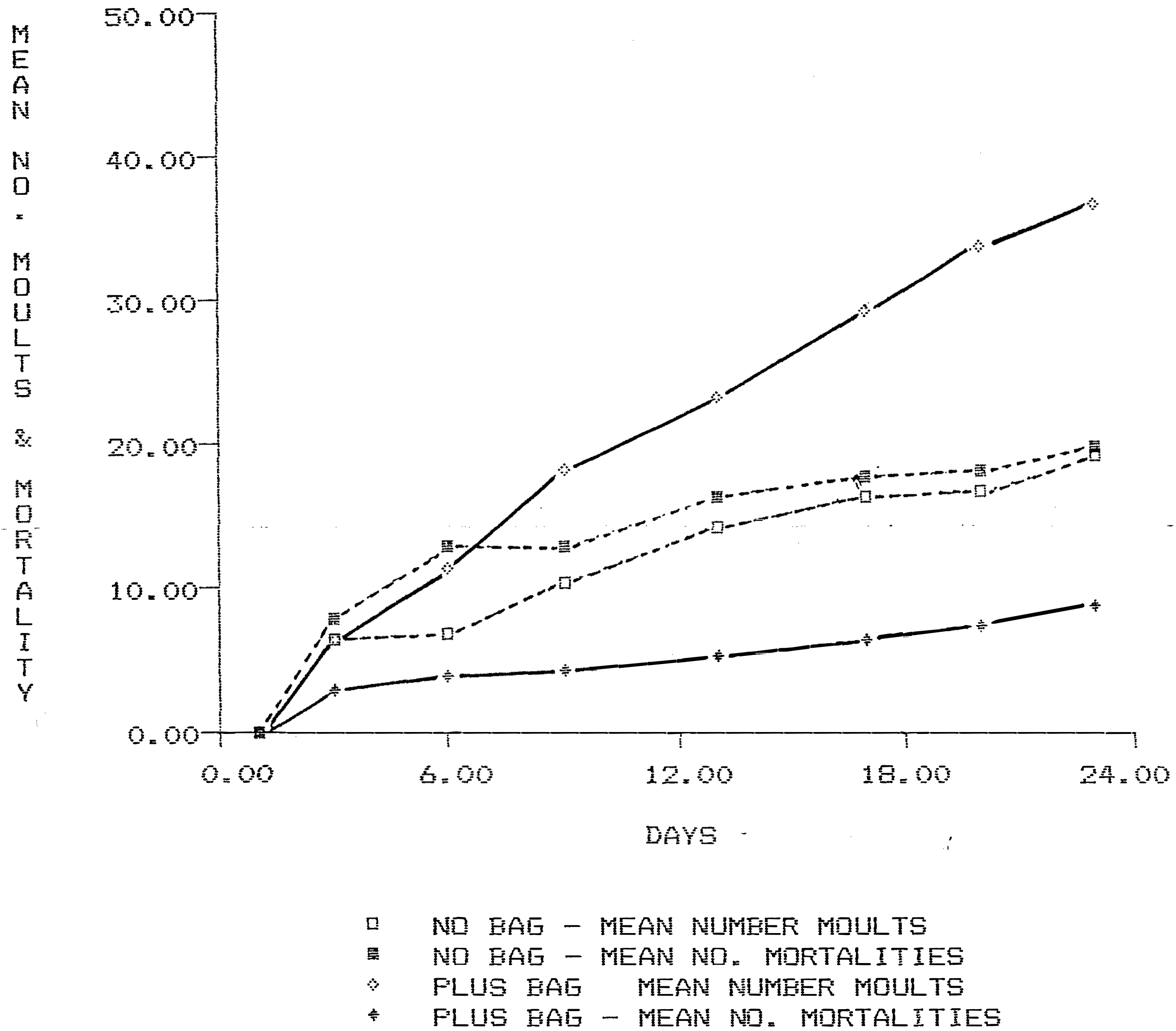
The results showed that addition of the vertically suspended bags significantly ($P<0.001$) increased survival of the juvenile mud crabs (table 5).

As a consequence of increased survival, the biomass after 23 days was also significantly ($P<0.01$) greater in the plus bag treatment. There was no difference between the mean weight of individual surviving crabs however the range in the plus bag treatment was larger and both replicates of this treatment comprised C_9 crabs. There were no C_9 crabs present in the sand only treatment as that these larger crabs were consumed, as they attempted to moult, by smaller conspecifics.

This is contrary to the result obtained by Holland et.al. (1971) when blue crabs, Callinectes sapidus were held communally in a tank with a sand bottom only. They found that crabs became larger as the population became smaller (due to cannibalism) and their trial was terminated when the population was comprised of one large crab.

These authors did report however that a lessening of cannibalism (as was expected) was not observed as the population in each aquarium was diminished. This was also observed in our trial (figure 10).

Figure 10. The effect of the presence of vertically suspended bag shelter on growth (success of moulting) and survival of juvenile mud crabs. 25 mud crabs ranging from C_4 to C_7 were stocked initially. The trial ran for 23 days.



Cannibalism of hardshelled crabs accounted for a major proportion of mortality in the sand only treatment, as indicated by a greater number of mortalities than moults.

Aggression between the few remaining crabs in the sand only treatment was significantly (P<0.05) high as 50% of the crabs were missing appendages. In the plus bag treatment however a mean of 24.7% of a larger population of crabs were missing appendages.

Approximately equal numbers of exuviae were found in the bag treatment replicates and about half of the exuviae were positioned either in or on the mesh bags (table 6). The other half were lying on top of the sand. This data suggests that there was no strong preference to moult on the bags however the observations included only the position of exuviae after the crabs had moulted. Because the bags were suspended vertically through the water column it is highly likely that some exuviae had fallen off onto the sand.

Table 6. The number of exuviae found on the sand and the mesh bags in treatment 2.

	SAND	MESH	TOTAL
Rep1	20	19	39
Rep2	20	15	35
TOTAL	40	34	

Discussion

Results of the above 2 trials show conclusively that the addition of vertically suspended artificial shelter greatly increases juvenile mud crab growth and survival.

Figure 11. The mean total amount of food consumed (%BWt.) by 15 juvenile mud crabs during 4 hourly periods for 7 days.

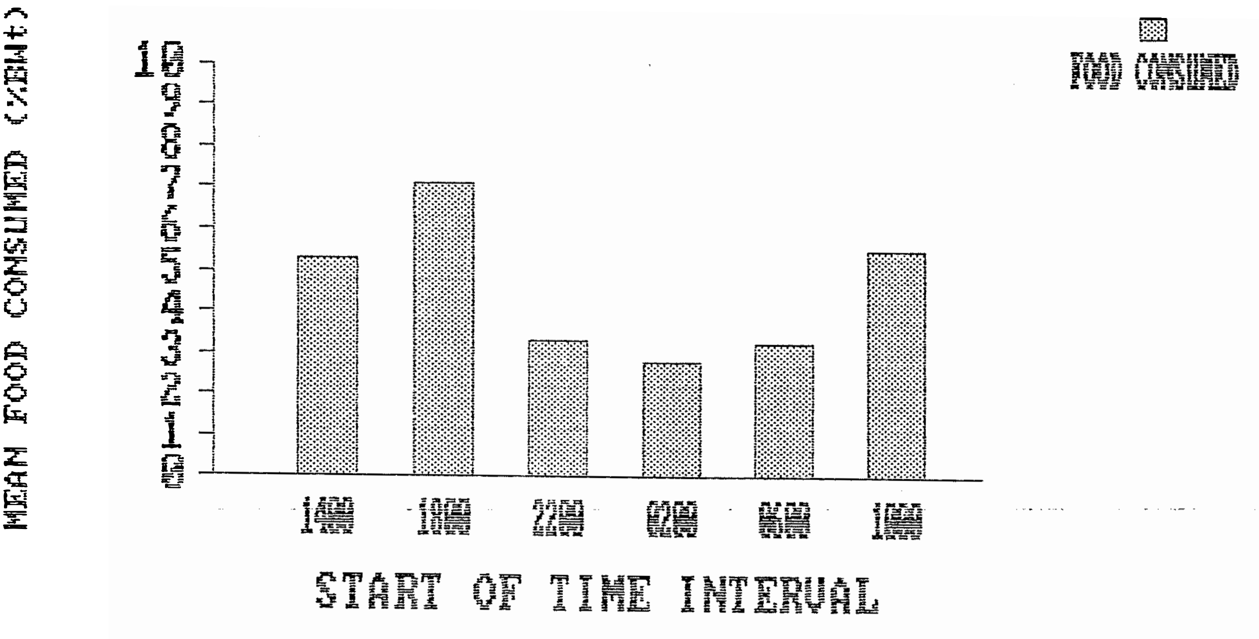
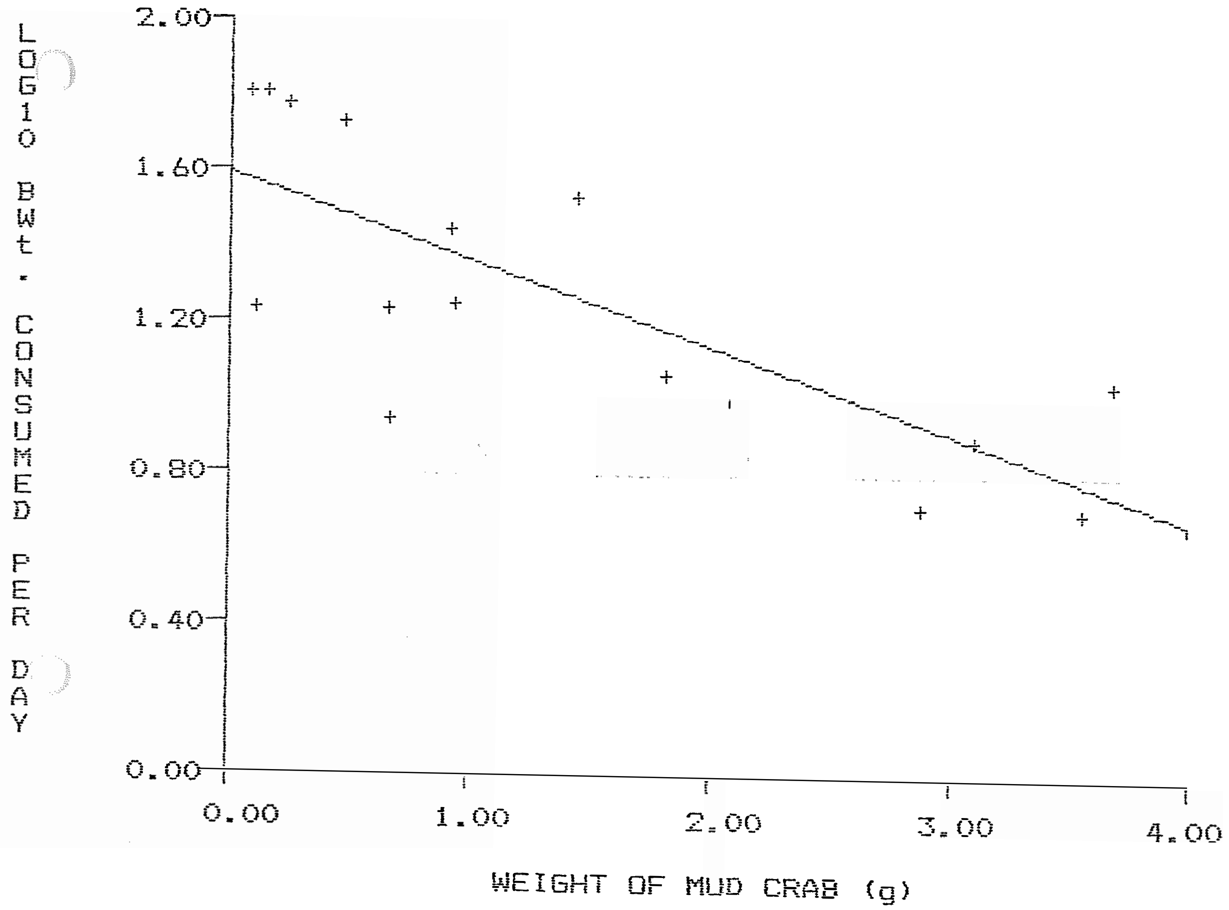


Figure 12. The mean amount of food consumed (%BWt.) per day by crabs of varying weight. Observations were taken daily for 7 days.



The crabs showed a strong preference for the artificial shelter, especially in the shallower regions, for normal intermoult activity.

Both hardshelled and softshelled cannibalism was significantly reduced by providing sites (cavities) for seclusion in which crabs could either carry out moulting or escape to after having already moulted. The crabs were able to remain here until their new shell hardened and they could continue normal intermoult activity.

Provision of the artificial shelter markedly reduced contact and therefore antagonism between conspecifics which resulted in fewer crabs losing limbs. This is very beneficial as generally loss of appendages results in smaller increments of moult (smaller sized animals) and may prolong intermoult duration depending on the number of limbs requiring regeneration (Hartnoll, 1982).

Therefore by suspending artificial shelter through the water column, another dimension (depth) which is otherwise unoccupied by the mud crabs can successfully be utilised to increase intensity of production.

Feeding Trials

Several trials were set up to determine the quantity of food consumed by juvenile crabs and the effect of feeding frequency on survival.

1. Individually contained crabs

The first trial investigated food consumption of individual juvenile crabs. Fifteen (15) wild caught juvenile mud crabs ranging in size from 0.007 - 3.679g were held individually in 1 litre containers of sea water (salinity = 31.5ppt; Temp =25 °C). Each crab was presented a known quantity of 20% agar bound prawn pellet at 4 hourly intervals. The food was placed on a 53 um mesh screen to facilitate retrieval. After 4 hours any remaining pellet was removed from the container, drained for 1 minute on blotting paper and weighed (Mettler AE 166 balance). The amount of food consumed was calculated by difference. Preliminary trials had shown that pellet weight did not change after 4 hours immersion.

The feeding trays were cleaned and a new cube of food placed into the crab container. Water was exchanged daily and the trial ran for 6 days after a 7 day acclimation period.

Results

More food was consumed during 1000 - 2200 hrs however some food was consumed during all 4 hourly observations (figure 11). Food consumption (dry wt. food/wet wt.crab * 100) was highly variable from day to day and between crabs. The mean amount of food consumed by 15 crabs over the 6 day period was 27.2 $\pm$ 22.6 %Biomass/day.

There was a distinct reduction in the quantity of food consumed as the crabs became larger (figure 12). Smaller mud crabs (C_2 - C_5) usually moult every 5 - 6 days (at 29 - 30 °C) whereas the larger crabs in the trial (C_7) moult approximately every 14 days. Therefore the demand for food by the smaller crabs may be greater due to the shorter intermoult duration.

An optimal feeding strategy would be to supply food constantly because although a feeding peak was observed, some food was consumed during every 4 hour period. Also because the amount of food consumed varied daily, a strict feeding regime could not be set. Better management would involve constant observation of the amount of food present in a pond and altering the quantities supplied accordingly.

2. Feeding Frequency Trial

The quality of food available can significantly influence the growth (intermoult duration and moult increment) of crustaceans (Hartnoll, 1982). Food quality can vary for reasons such as leaching of water soluble nutrients and the rate at which fats/oils become rancid. This trial was established to determine if frequency of feeding affected survival and growth of juvenile mud crabs.

Materials and Methods

The trial consisted of 2 feeding frequencies of 2 times/day and 6 times/day in which food was provided at 0800 and 1700 hrs and 0800,1030,1300,1530,1730 and 2200 hrs respectively.

A total of approximately 60% (dry wt.food : wet wt.crab*100) of minced crab, Portunid sp. was fed to each tank daily. (30% BWt. was fed initially but it was being consumed rapidly. Increased rearing temperatures of 28 $\pm$ 1 ^{o}C was the probable cause of the higher consumption.) This was a sufficient quantity to allow satiation with little remaining food so that good water quality was maintained. Prior to each feeding session any remaining food and waste was siphoned from the tanks.

The experimental design was completely randomized with 4 replicates of each treatment. Experimental containers were 0.11 m^2 and each received reconditioned water from a central coralline biofilter.

Each tank was stocked with 10 hatchery reared C_5 (C.W.=15.9mm) mud crabs. An equal amount of bunched artificial material was provided for shelter.

Daily observations of the number of remaining crabs and any newly moulted crabs were carried out. The weight of the newly moulted crabs was determined and the amount of food given to each tank was adjusted accordingly. The trial ran for 28 days. Results of the trial were subjected to ANOVA to determine any treatment significance.

Results

Table 7 shows that frequency of feeding had no effect on survival or growth of the mud crabs. This indicates that the minced crab had a similar quality after 2.5 and 9 hours immersion. The food was usually noticed to be present but in diminishing quantities as the day progressed.

Table 7. The effect of 2 frequencies of feeding on survival of 10 juvenile (C_5) crabs held in 0.11 m^2 tanks. Each tank was fed a total of 60% biomass per day for 28 days.

	Frequency of Feeding							
	2 times/day				6 times/day			
	R1	R2	R3	R4	R1	R2	R3	R4
Survivors	9	3	4	8	8	5	4	6
	mean = 6.0 n.s				mean = 5.0			
Tot. Wt(g) crabs	31.5	12.4	17.8	30.2	25.6	22.2	17.1	28.9
	mean = 23.0 n.s				mean = 23.5			
Mean C.W. (mm)	29.3	30.5	32.2	30.0	28.7	32.0	31.9	32.9
	mean = 30.5 n.s				mean = 31.4			

Whether the food quality was good or bad (due to leaching etc) was not determined chemically. However it was highly palatable and produced excellent growth rates which implies that it had remained in good condition.

Pelletized, formulated feeds were not tested as Portunid crab specific feeds do not currently exist in Australia. It is likely however that retention of quality after immersion will pose major problems to the development of suitable formulated feeds. Bordner et.al. (1986) found while testing synthetic feeds for the clawed lobster Homarus americanus, that the degree to which soluble nutrients leached was highly variable. This was dependent on the composition of the pellets and was more related to the quantity of fish and shrimp meal present rather than the amount of binder.

Therefore in order to overcome potential quality problems with pelletised foods the most practical feeding scheme would be one of frequent application of small quantities of food.

3. SMALL-SCALE GROWOUT TRIALS

Introduction

As a continuation of the previous experiments a larger-scale trial, incorporating the tank design and management systems deemed most suitable for intensive mud crab culture, was set up. Unfortunately only one tank was available in which to carry out the trial, however it has provided excellent information on the potential production of mud crab culture.

Materials and Methods

A 5000 litre circular (2.4 m diameter) fibreglass tank was used as the rearing vessel. Eight (8) reefs each consisting of 5 onion bags were provided for shelter. In order to suspend the bags vertically a piece of polystyrene was placed in the closed end of each bag (plate 6). The tank bottom was left bare (no sand was provided) to enable easy removal of waste and uneaten food. Thirty-three (33) sibling mud crabs ranging in size from C_8 (C.W.=36.5mm) to C_{10} (C.W.=63.7mm) were placed into the tank. This represented an initial stocking density of 7.2 crabs/m^2. The food type varied but on the whole consisted of minced crab *Portunid sp.* and formulated fish pellet. This was mixed together to form a moist dough. Records of food consumption were kept to determine conversion rates. The amount of food present in the tank was observed regularly (every 1-2 hours) and provided when necessary. Feeding commenced at 0730-0800 and continued to 2400 hrs.

The tank water was aerated continually and at least 100% of the volume was exchanged daily. Four (4) 200 Watt aquarium heaters were used during the cooler winter months in an attempt to raise the water temperature. Temperature ranged from 21.5 to 29.5 ^{o}C.

At 3-4 day intervals the tank bottom was siphoned to remove waste. At approximately 14 day intervals the tank was completely drained and the crabs were measured (C.W.mm) and weighed to determine biomass increase. The tank was checked twice daily for any exuviae. The trial ran for 123 days.

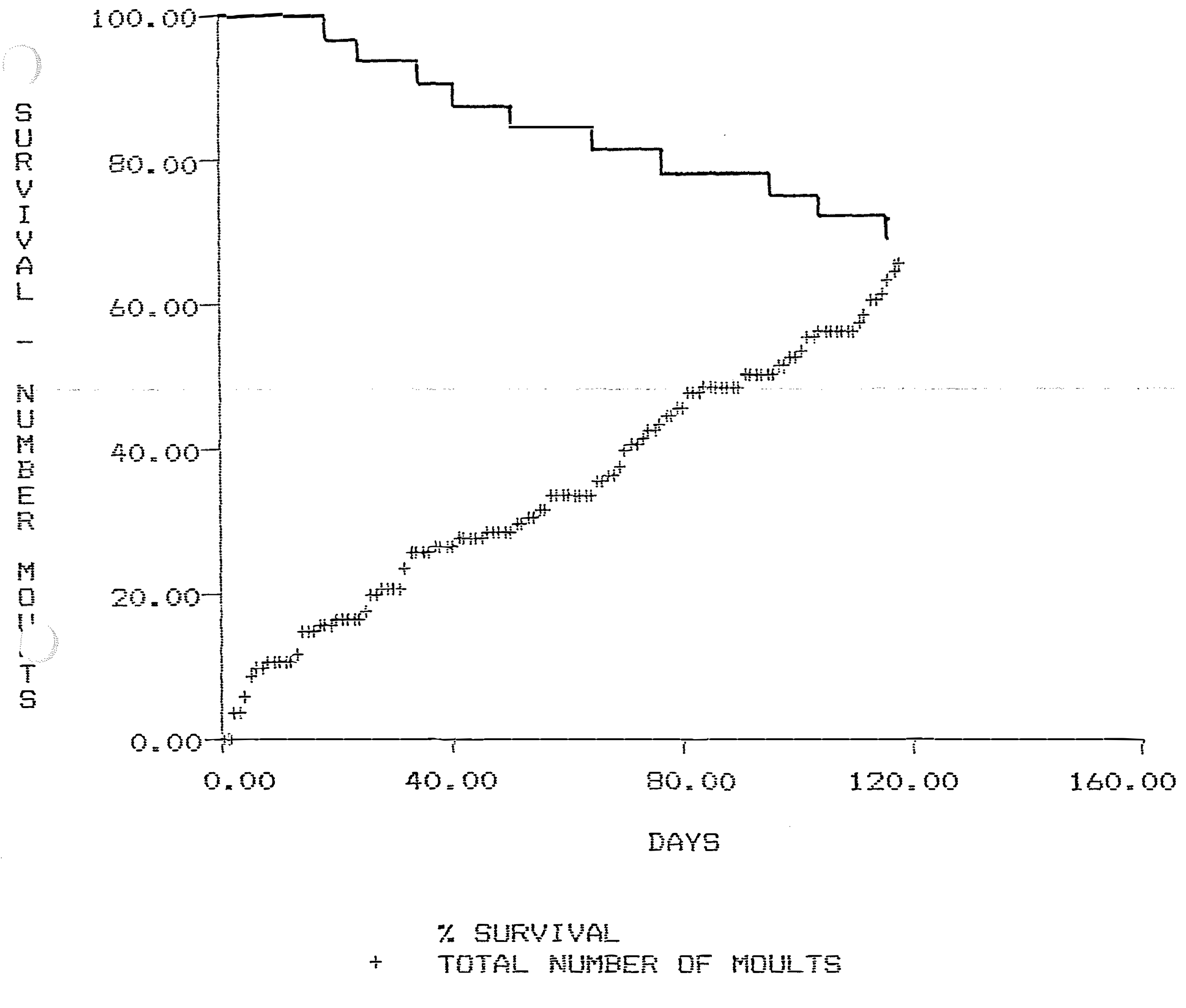
Results and Discussion

Figure 13 shows the percent survival and number of moults recorded over the 123 day growout period. Sixty-six (66) moults and therefore instances in which the crabs were softshelled and highly vulnerable to cannibalism were observed. Twelve (i.e.36.4%) mortalities were recorded during the trial and reduced the stocking density from an initial 7.2 crab/m^2 to a final 4.6 crab/m^2.

Many of the exuviae and newly moulted crabs were found inside folds of the bags demonstrating that the larger mud crabs continued to use the artificial shelter for moulting and seclusion.

Growth of the mud crabs was exceptional with the first C_{12} crabs of 100mm C.W. (200g) obtained in 77 days (137 days from

Figure 13. The percent survival and number of moults observed by juvenile mud crabs grown for 123 days in a 4.5 m^2 fibreglass tank. Vertically suspended artificial substrate was provided as substrate. 33 crabs (C_8 to C_{10}) were stocked initially representing 7.2 crabs/m^2.



metamorphosis). This size crab represents the marketable Asian product (Baliao et.al.,1981). An example of this sized crab is shown in plate 7. The first C_{13} crab of 120mm (300g) was obtained in 118 days (182 days from metamorphosis).

Figure 14 shows the growth rate of hatchery reared crabs in this study was greater than that recorded by Heasman (1980). The mean temperature experienced in both trials was similar i.e. 26.4 $\pm$ 2.1 and 27.0 $\pm$ 0.5 ^{o}C respectively.

The intermoult duration for successive instars was similar in both trials however the moult increment in the present study was larger in the later stages (C_9 - C_{12}). In fact the carapace width of a C_{12} crab in this trial was equivalent to that of a C_{13} crab in Heasmans trial.

The high sustained moult increments (30%) of the latter stages in the present trial may be explained by differences in feeding strategy and amount of food consumed. In our trial food was supplied ad libitum in small quantities from 0800 to 2400 each day. The food was generally consumed within 1 - 2 hours after which time more fresh food was provided. An average of 10% (wet wt. food : total biomass) was consumed each day.

In Heasmans trial however food was provided in excess once daily and uneaten food was removed about 12 hours later. The mean amount of food consumed per day was 3.3% total body weight. This 3-fold reduction in consumption when fed once daily to excess (in this case prawn, fish and mussel) may indicate that the quality of the food had deteriorated rapidly leading to smaller consumtion rates. A deficiency in either quality or quantity of food depresses the rate of crustacean growth by

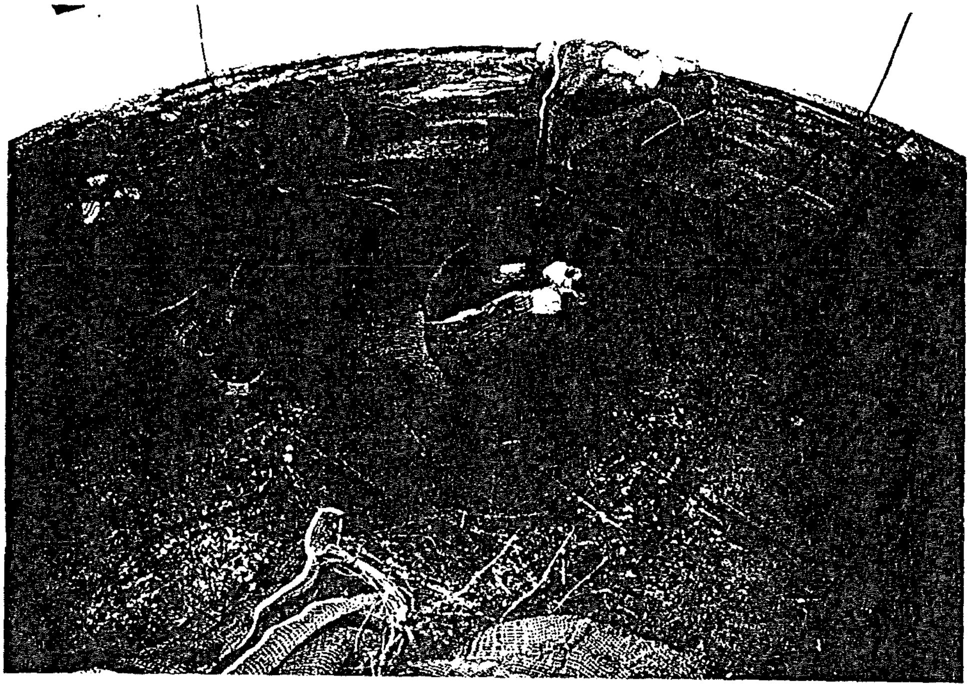


Plate 6. Small-scale growout tank (4.5 sq.m). 40 onion bags were suspended vertically through the water column.

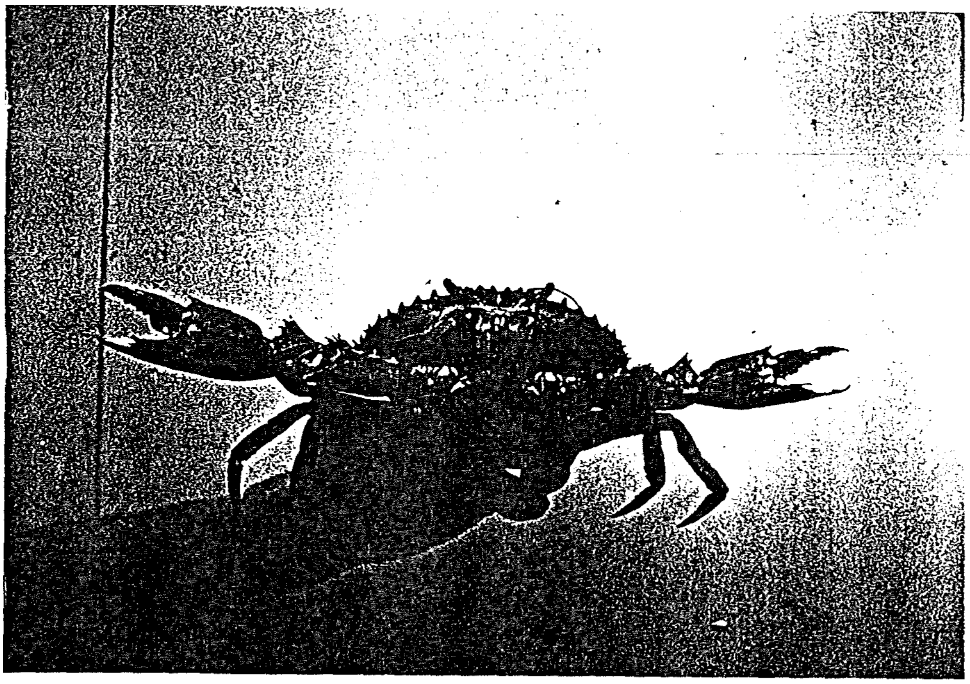
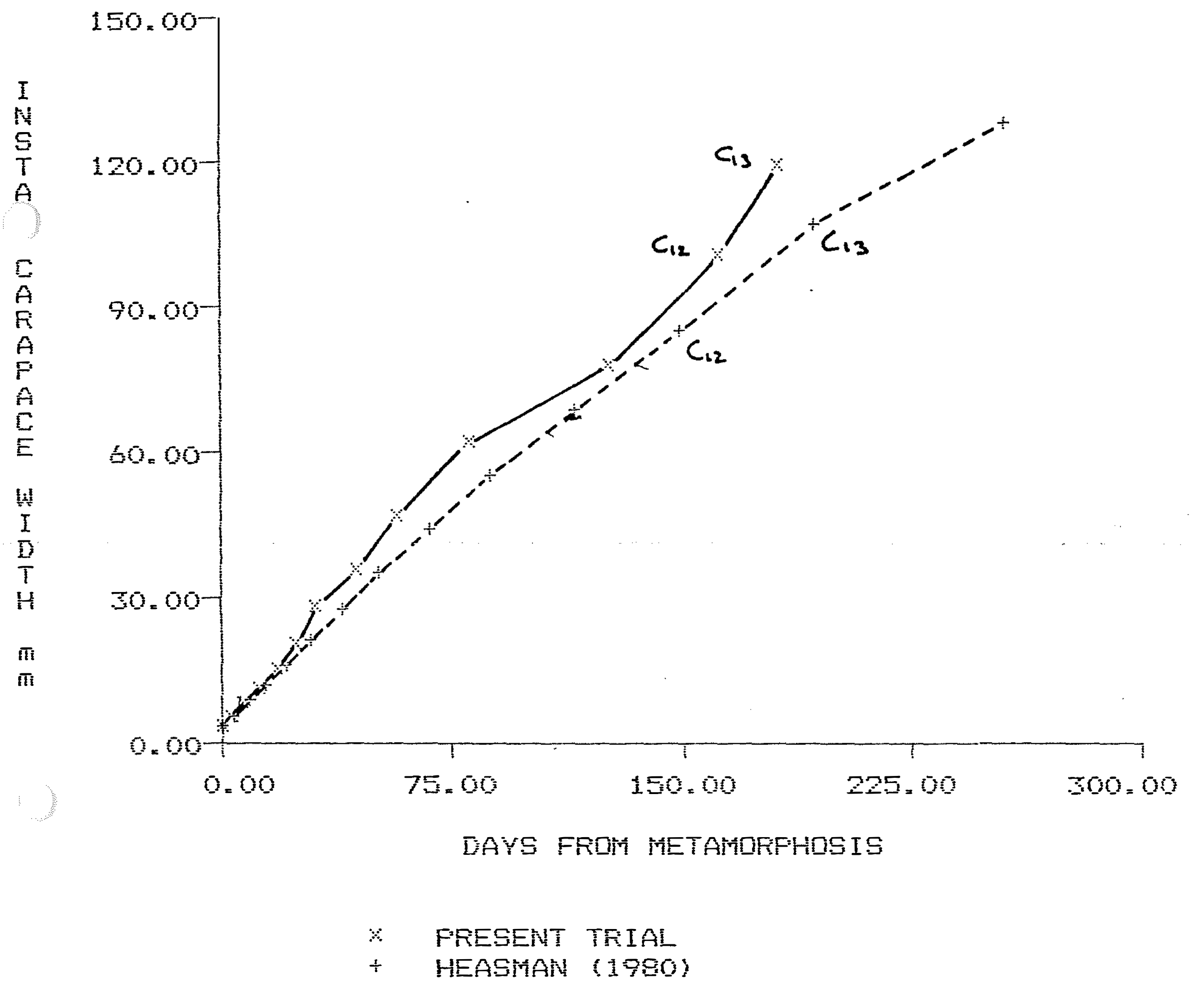


Plate 7. Stage 12 (C.W.- 100mm) hatchery reared female mud crab <u>Scylla serrata</u>. This is a marketable sized crab in Asia (Balioa et.al.1981)

Figure 14. The growth rate of hatchery reared juvenile mud crabs (present study and Heasman, 1980) conditions. Crabs were reared at approximately 27°C



either reducing the increment or lengthening the intermoult (Hartnoll, 1982). In this case with mud crabs it appeared that only moult increment was affected.

Therefore by providing high quality food constantly, consumption and consequently growth rates can be increased.

Table 8 shows that production (5580 kg/ha) in the present trial was approximately 6 times greater than that of mud crabs grown in experimental earthern ponds at SEAFDEC (Baliao et.al., 1981). Crabs were able to be held at much higher initial stocking density (7.2 crabs/m^2) with relatively low mortality (36.4%) when provided with artificial shelter whereas crabs grown in earthern ponds at 2 crabs/m^2 sustained major mortality (69%) with subsequent low net production (948 kg/ha).

The relative growth increment (g/day) of the SEAFDEC crabs was greater than that of crabs grown in our trial. It is most likely that the higher temperatures experienced in the earthern ponds (25 - 34 ^oC) contributed to this by shortening the intermoult duration.

Autotomy (the sacrificial loss of limbs during antagonistic encounters) was experienced throughout the growout period and increased as crabs became larger (figure 15). Walking and swimming legs were autotomized more often than chelipeds. At the termination of the trial 14.3% of the crabs were missing one cheliped and 29.0% were missing other limbs.

The 14.3% missing chelipeds would not be suitable for market as approximately 60% of the edible flesh is contained within the claws. These crabs would have to be on grown to the next instar when the claws would be regenerated (smaller than the original)

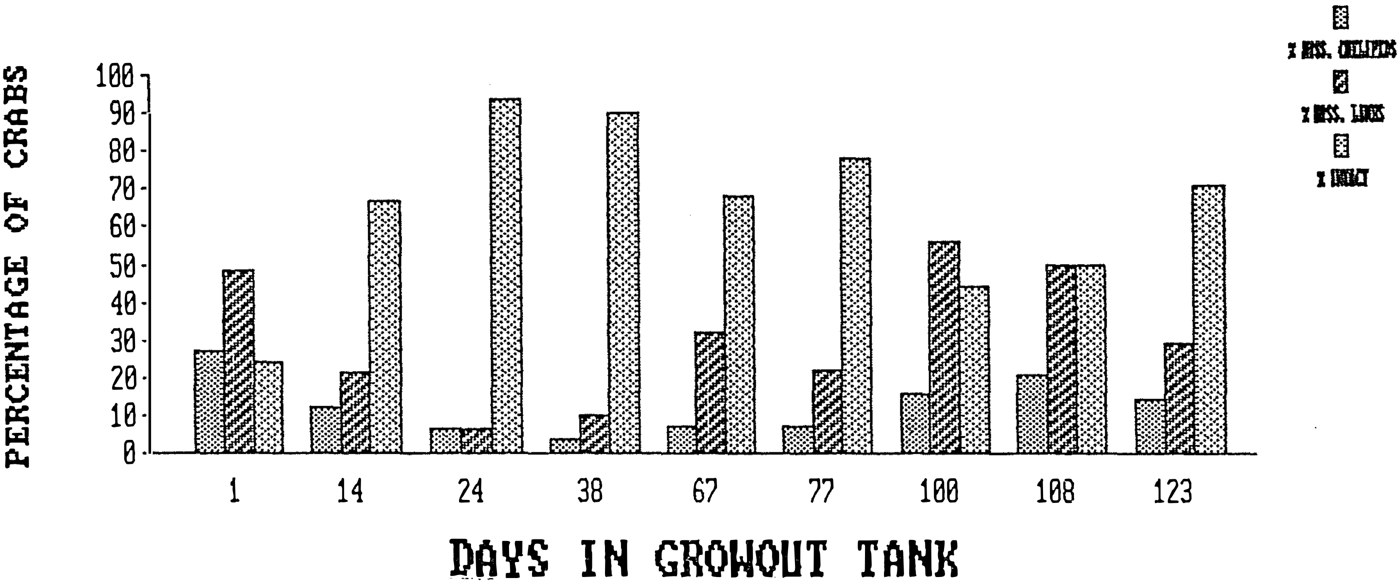
Table 8. Growth and productivity of mud crabs grown in tanks with artificial substrate (present study) and in experimental earthern ponds at SEAFDEC (Baliao et.al., 1981).

Trial	S.D. /ha.	% surv.	Mean C.W.mm in.	fin.	Growout Period days	Relative growth inc. g/day	Feed conv.	Product. kg/ha
A	72000	64	45	89	119	0.82	6.1	5580
B	20000	31	52	97	90	1.69	4.04	948
C	5000	88	52	107	90	2.28	1.72	908

A Present study
B & C - Treatments at SEAFDEC

S.D. - Stocking Density (crabs/ha.)

Figure 15. The number(%) of juvenile mud crabs missing appendages during 123 days of continued growout in a 4.5 m^2 fibreglass tank supplied with artificial shelter. Crabs were stocked initially at 7.2 crabs/m^2.



or discarded if this was not economically viable.

At the end of the growout trial the population consisted of crabs ranging in size (C.W.) from 67.8 - 120.0 mm or C_{10} - C_{13}. Therefore a proportion of the population had not reached a marketable size. Recent research by Aiken and Waddy (1988) on lobsters Homarus americanus has shown that they also display a wide variation in growth rate when held communally in tanks.

When the lobsters were sorted into size groups and restocked at $25/m^2$ at 60 day intervals the results showed that each group reflected the growth pattern of the original population. That is some of the lobsters in each group grew very rapidly while others continued to grow slowly. This resulted in the faster growing lobsters of the smaller group surpassing the slower growers of the larger lobster group. This growth pattern was caused by social pressure. That is, "growth rate for any individual is determined by genetic potential and the relative size of other individuals in the tank."

The size variability of the mud crabs may have been caused by similar social pressure. Therefore the potential to increase growth rates, by regular grading and restocking of ponds may exist. This must be investigated further.

CONCLUSIONS

(1) The provision of vertically suspended artificial shelter (onion bag) significantly increased survival and productivity of mud crabs in experimental tanks by reducing moult related cannibalism.

(2) The mud crabs preferred the artificial material to sand for both intermoult and moulting behaviour.

(3) The onion bags occupied depth and therefore increased available pond substrate surface area. This allowed mud crabs to be held at high stocking density ($7/m^2$) with minimal mortality.

(4) The floating onion bag system is easily established and managed and does not interfere with harvesting. On the contrary, extraction of bags could aid harvesting and sampling by capturing inhabitant crabs.

(5) Growth rates were excellent with commercial sized crabs (by Asian standards) obtained in 5 months from metamorphosis. There is potential to increase this growth rate by regular grading of crabs into size groups and growout at high (30 ^{o}C) sustained temperatures.

(6) Juvenile mud crabs consumed food during both day and night and food should therefore be provided continually each day.

(7) Quality of food can have a major effect on growth of mud crabs. In order to overcome potential problems with deterioration of food quality a feeding strategy of frequent, small quantities should be adopted.

(8) The amount of food consumed by individual crabs each day was variable and therefore regular observation of consumption rate (using retrievable food trays) should be carried out and adjustments made accordingly.

(9) It may be possible to achieve greater productivity in an earthen pond with suspended artificial substrate. In the present growout trial a sand or mud substrate was not provided. In a pond situation this substrate would provide a further dimension for seclusion as well as promote generation of natural benthic flora and fauna. Supplementation of a formulated diet with naturally occurring prey organisms may enhance overall nutrition which could lead to faster growth rates.

Results of this study have shown the potential of mud crab Scylla serrata culture in Northern Australia. Before any large-scale production can be realized however, a commercial formulated feed must be available. Sea Hatcheries Ltd. will be undertaking further research into development of such a product as well as continuing development of pond design and management techniques for mud crab culture.

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Table 5. The effect of vertically suspended artificial bag shelter on survival and growth of juvenile mud crabs. Two replicates per treatment. An initial stocking density of 25 crabs. The trial was run for 23 days.

	No. Surv. Crabs	Total Biomass (g)	Mean Crab Weight (g)	Crab Size Range (g)	Cumm. Number Moults	% Crabs Missing Limbs
NO BAGS						
REP 1	4	24.3	6.07 ±2.0	3.2–7.4 C_7–C_8	16	50
REP 2	6	23.0	3.83 ±1.4	2.2–5.9 C_6–C_8	23	50
MEAN	5.0	23.7	4.95	–	19.5	50
PLUS BAGS						
REP 1	15	76.0	5.07 ±2.6	2.1–11.1 C_7–C_9	39	20
REP 2	17	85.9	5.05 ±4.0	0.7–13.6 C_6–C_9	35	29.4
MEAN	16.0 ***	81.0 **	5.06 n.s	–	37.0 *	24.7 *

*** – significant at 0.1% level
** – " 1.0% "
* – " 5.0% "