3.0 Methods and methods evaluation

3.1 Introduction

This section sets out the basic sampling methods that were used. It also describes manipulative experiments to validate the trapping (Section 3.6) and tagging (Section 3.7) procedures.

3.2 Crab handling procedure

Upon capture, a fixed procedure was followed by the same person for the 4 y study.
When the traps were lifted, the contents of the trap were emptied into a padded tub to prevent injury to the crabs. Each crab was measured for carapace width and length, and sexed. The identification tag was inserted and each crab was released at the site of capture. The trap was rebaited and returned to the same position.

3.3 Size class

The size class of each crab was determined by measuring the carapace width and length to the nearest mm (Figure 3.1).
Carapace Width: The minimum distance between the points of the ninth anterior lateral spines.
Carapace Length: The minimum distance along the midline between the posterior margin of the carapace and the nadir of the notch between the central pair of frontal spines (Heasman 1980)

The carapace width and length were measured using a pair of callipers (Matui brand). Each measurement was made twice to reduce the chance of error. The carapace width and length were recorded and then placed into size class groups (e.g., 113 mm carapace width = 110 – 119 mm size category). These data were used to describe the population structure in each habitat.

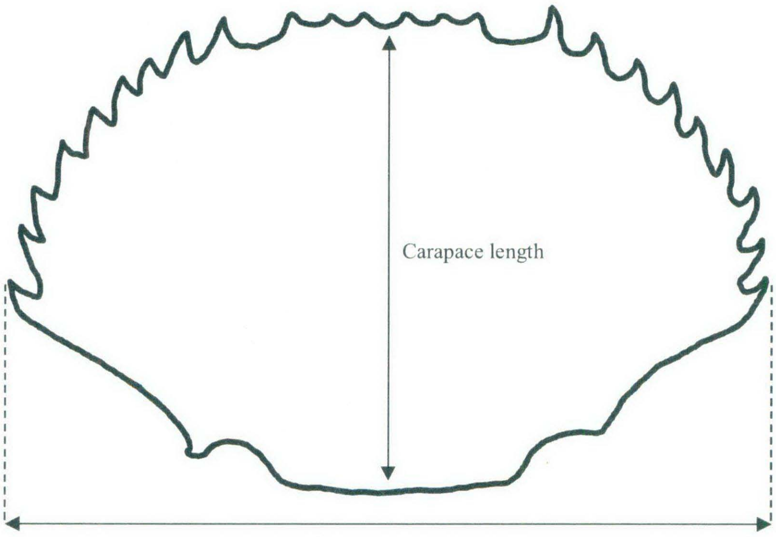
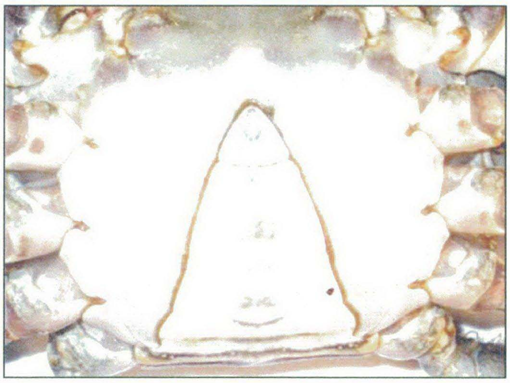


Figure 3.1. The measurement dimensions for carapace length and width for the mud crab (*Scylla serrata*).

3.4 Gender

Gender is clearly recognisable by the shape of the crab's abdomen (Plate 3.1) and the size of the crab's chelae. For the purpose of this study, the abdomen was used as the distinguishing feature. The female's abdomen is triangular or semicircular in shape and consists of feather-like structures that carry fertilized eggs. The male abdomen is narrow or conical.

a



b

Plate 3.1. A female (a) mud crab showing the triangular or semicircular shape of its abdomen and male (b) displaying the narrow conical shape of its abdomen.

3.5 Water quality

Both salinity and temperature were measured at each site. Water temperature were recorded to the nearest 0.1 °C using a TPS WP-81 (TPS, Brisbane) water quality meter at 80% of the water depth. A deep sample was taken, as crabs are mostly bottom-dwelling creatures. During flooding, shallower samples may have given false readings with freshwater over riding saltwater plumes.

Salinity was recorded to the nearest 0.1 parts per thousand (ppt) using a Horiba U/10 and TPS WP-81 water quality meter. Samples were taken at 80% of the depth at low tide, as the ebb tide was more likely to give an indication of flooding in each estuary.

3.6 Trapping

The traps used in the study are those used by professional and amateur fishers. Each trap was 1 m x 0.8 m x 0.5 m (Plate 3.2). These traps are large enough to minimise the agonistic behaviour shown by crabs (unpublished data, P. Butcher *pers. observ.*). The two entrances in each trap were located opposite each other and were 0.3 m x 0.25 m. Each trap was covered in 50 mm wire mesh to target all size classes of crabs.

Bait used was predominantly fleshed skeletons of Silver Perch (*Bidyanus bidyanus*), Snapper (*Pagrus auratus*), Mullet (Family – Mugilidae), various Leatherjackets (Family - Monacanthidae) and Morwong (*Cheilodactylus douglasii*). These species are readily accepted as food by mud crabs. The traps were baited with one of each species to increase the capture if bait preference occurred. Each trap used a plastic mesh bait bag to stop small crabs and fish eating the bait out over the 24 h soak period. Traps were deployed at each site without a buoy to minimise the chance of fishers illegally lifting the traps. Bricks were attached to buoys near the trap with research and permit number attached to simulate that a trap was in the area. This effectively stopped fishers placing traps on top of the sunken research trap. Traps were then recovered each day with a small anchor (grapple) hook. Trapping nights were defined as the number of traps(treatment) x days sampled x months sampled.

Plate 3.2. Traps used for all sampling during the study

Factors that may affect catchability of crabs in traps

There are many factors affecting the catchability of mud crabs. Previous research has suggested that the following influences must be taken into consideration when researching any crab species.

Moult stage: Mud crabs feed less during moulting (Williams and Hill 1982). Moulting peaks during October, November and December, and then in April for late inter-moults.

Temperature: Activity, and particularly feeding, is affected by temperature. At temperatures below 20 °C, both activity and feeding are reduced. This restriction places a seasonal restriction on catchability (Hill 1979, 1980). Large crabs are less affected by temperature than smaller crabs (Williams and Hill 1982).

Sex: The catchability of gender type occurs seasonally with females moving offshore to spawn during October to December (Hill 1994).

Trap and soak time: Gear saturation occurs when the fishing power of the gear reduces as the catch in it increases (Beverton and Holt 1957). The size of a trap may affect saturation. Previous work by Robertson (1989) found that traps that were cleared every two hours caught more crabs over 24 hours than traps which were left for the whole 24-hour period. Larger traps would minimise competition between individuals and possibly reduce this effect.

Time of day: In laboratory trials, crabs would emerge at any time of the day to eat fresh fish but usually emerged at sunset to forage and buried again before sunrise (Hill 1976). Robertson (1989) found that, in the natural environment, there was no difference in catches between day and night.

Bait: Robertson (1989) found no difference between enclosed and open bait sources but suggested that, over longer soak times, enclosed baits would last longer as smaller crabs and fish could not remove the bait.

Tidal movement: During large tidal movements over the full moon period it is possible that bait odours move further (Gunderson 1993). This means that unless all tidal ranges are kept within the same range, traps might be attracting crabs from further away during large tidal ranges than those months with little tidal movements. Synchronising tides each months with similar ranges may standardise for any effect.

Behaviour: Mud crabs show aggressive behaviour towards other crabs. The presence of a crab in a trap may reduce the probability of further crabs entering (Williams and Hill 1982).

Size of mud crabs: Large mud crabs may enter pots more frequently than smaller mud crabs. This suggests that crab traps used for trapping mud crabs may be selective for larger crabs.

To determine if any of the above factors affect catchability in traps used in this trial the following experiment was conducted.

3.7 Activity of the crab (*Scylla serrata*) around baited traps

3.7.1 Introduction

The structure and function of a trap may determine what is caught. Some research has shown that traps give an indication of mud crab stocks but there are interactions concerning gear and the crab itself, which may regulate the composition of the catch (Williams and Hill 1982; Robertson 1989; Smith and Sumpton 1989). Traps used to catch mud crabs by commercial and recreational fishers usually consist of a rectangular frame approximately (1 m x 1 m x 0.5 m) made from galvanised mesh or wire. Each trap has two entrances opposite each other which slope upward into the trap in an attempt to stop crabs from exiting the trap once caught. Any bait source consisting of fish frames are used. Commercial fisherman commonly use whole mullet or oily fish tied to the centre on the bottom or placed in a bait bag to minimise small crabs and fish from eating the bait out of the trap.

Although the fishery depends on wire traps and to a lesser degree netted dillies or witches hats, little is known about the selectivity and catching efficiency or the behaviour of mud crabs in and around a trap. It is important to understand whether traps are sampling the entire population around a trap, and if not, what factors are affecting this (Smith and Sumpton 1989). Some factors which may affect catchability include size, sex and moult stage (Williams and Hill 1982), time of emergence (Hill 1976) or gear variability association with trap soak time, time of day when trapping or bait accessibility (Robertson 1989). These may be some factors affecting catchability in this trial. The aim of this study was to determine the efficiency of these traps for use in population studies.

The main objectives of this sub-project was to determine the efficiency of traps to catch and hold crabs by reviewing the activity of different size classes of male and female crabs at traps. It is predicted as part of the general hypotheses that all crabs will emerge to feed on dusk (i.e.-around 6 pm) and all crabs will enter the trap during the night. There will be aggression between the crab at the bait and crabs trying to enter traps with more aggression from males. Crabs will search around the area of the trap where the bait odour is strongest and there will be no gender or size class dependence for the order that crabs enter traps. No crabs will escape the trap once they have finished foraging.

3.7.2 Materials and methods

Methods for this experiment were derived from work conducted by Smith and Sumpton (1989) on the sand crab (*Portunus pelagicus*).

Collection process

A total of 60 crabs were collected from Coffs Harbour Creek in the southern region of the SIMP using netted dillies and returned after the study. Only crabs that had a full set of appendages and no damage to their body were taken. All crabs were intermoult as indicated by a hard shell free of epizoic organisms. Premoult crabs were not used as they may cease feeding and possibly not enter a baited trap (Williams and Hill 1982). All crabs were sub adults (small adults) (100 –150 mm carapace width) or adults (large adults) (>150 mm carapace width); as these typified the crabs caught as part of ongoing research each month. Crabs were collected as needed and held for no longer than 1 week in holding tanks before being used for each trial. In an attempt to increase capture rates, each crab was starved for three days prior to their use in the trials. However, Haddon and Wear (1987) and Smith and Sumpton (1989) showed that starving crabs for 24 to 48 hours was ineffective for standardising appetite in the portunid *Ovalipes catharus* and *Portunus pelagicus*.

Tank and camera configuration

The observation tank was circular (2 m x 0.9 m deep) (Plate 3.3 - 3.4) and monitored daily for water quality. The tank was covered during the day to minimise light intensity, as it seemed to stress the crabs. During filming the cover was removed to simulate natural lighting conditions. A 200 mm deep level sand bed allowed crabs to bury. A night vision camera (Model – Sony Digital 8 handy cam) was fixed to a tripod 0.5 m above the water level in the centre of the tank. The camera could detect all crab movements with “super nightshot” as a feature of the system.

Plate 3.3. The 2 m diameter tank used for each trial.

Bait dispersion

A steady supply of fresh filtered seawater water at 0.1 L/sec was used for the tank. This movement of water into the tank caused an anticlockwise current. It was important to detect the odour source for the bait when attempting to determine why crabs approached the trap from a certain direction as crabs will follow bait odour (Miller 1979, 1980; Wassenberg and Hill 1987). A dye of potassium permanganate was placed in a porous bag within the bait container. The trap was placed in the same position used for all trials within the tank. The dye was monitored for ten minutes after placement to determine the potential track of the bait odour around the tank.

Crab selection and process

In each experiment, 4 crabs were randomly selected to go into the observation tank. Each trial always had one male and female large adult and one male and female sub adult (small adult), selected from a group of the same size class of crabs. The four crabs were marked with typing correction paint (Pentel multi-purpose quick dry) to enable each crab to be tracked around the tank. All crabs were placed in the tank at 10 00 hours, and this allowed 6 h to habituate to their new environment before the trap was put into the tank.

At 16 00 hours recording commenced after a standard baited commercial trap (Section 3.6) was placed in the middle of the tank directly under the camera. The same trap was used for each trial. At 08 00 hours the following day, crabs were removed from the tank. Crabs that did not attempt to enter the trap during the trial were checked to determine their moult stage and whether there was any problem with the crabs (i.e. carapace damage from interactions in the trap). During October 2003, 15 trials following this procedure were run. While reviewing the tape, observations of behaviour were designated to ten categories for each crab (Figure 3.2; Table 3.1) (derived from Smith and Sumpton 1989).

It was attempted to standardise several factors over the experiment. Foraging in crabs is regulated by moult stage, temperature and reproductive cycle (Hill 1980, 1979; Williams and Hill 1982). While temperature was kept within 21-23 °C for the duration of the trial and some crabs could have been premoult, this may have caused them not to forage as frequently as others. Other factors such as stress caused during capture and living in the tanks may have caused some crabs not to feed.

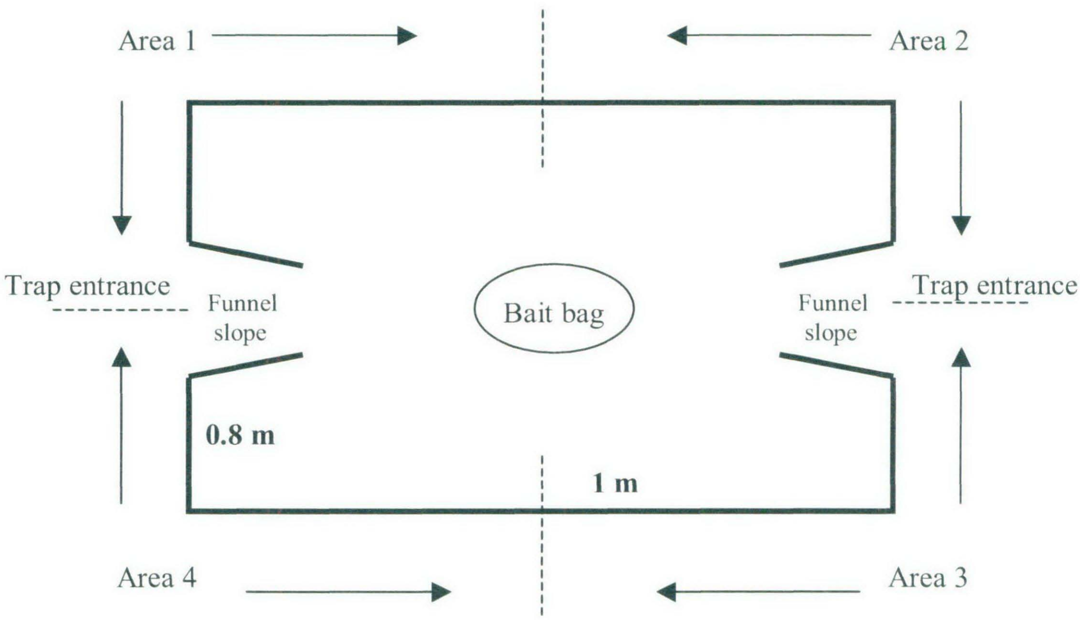


Figure 3.2. Trap design and area layout around each trap

Table 3.1. Categories assigned to crabs during each trial (modified from Smith and Sumpton 1989)

Category	Criteria
Attempt	A forward movement to the trap and contact on the trap wire with any of the crab's chelipeds. An attempt is deemed finished if the crab moves further than 40 cm away from the trap (out of the view of the camera). Reversing against the trap or brushing along the lateral side was not deemed an attempt at entry.
Area searched	The estimated area searched around a trap by the crab.
Point of contact	The area 1 - 4 (Figure 3.2, Plate 3.4) which the crab touches first.
Entry	When a crab enters the body of the trap through one of the entrances and releases its hold of the funnel exit.
Entry order	The order which each crab enters the trap.
Entry type	Which crab was at the bait or funnel as the next crab entered the trap.
Trap top attempt	An attempt by a crab to enter via the top of the trap.
Funnel miss	Moving past an entrance during an attempt or moving up the funnel slope and not entering the body of the trap.
Funnel antagonism	The raising of chelipeds with or without physical contact by a crab in the trap to a crab in the funnel.
Escape	Leaving the trap by a crab that had already been caught.

3.7.3 Results

Bait odour

The dye gave a precise indication of where the bait odour was moving in the current generated by the water inflow pipe. On release, the dye dispersed in all directions around the bait to a distance of approximately 10 cm. The dye plume then travelled in an anti clockwise direction and settled in Area 1 (Plate 3.4). It was therefore assumed the bait odour would be strongest in this area.

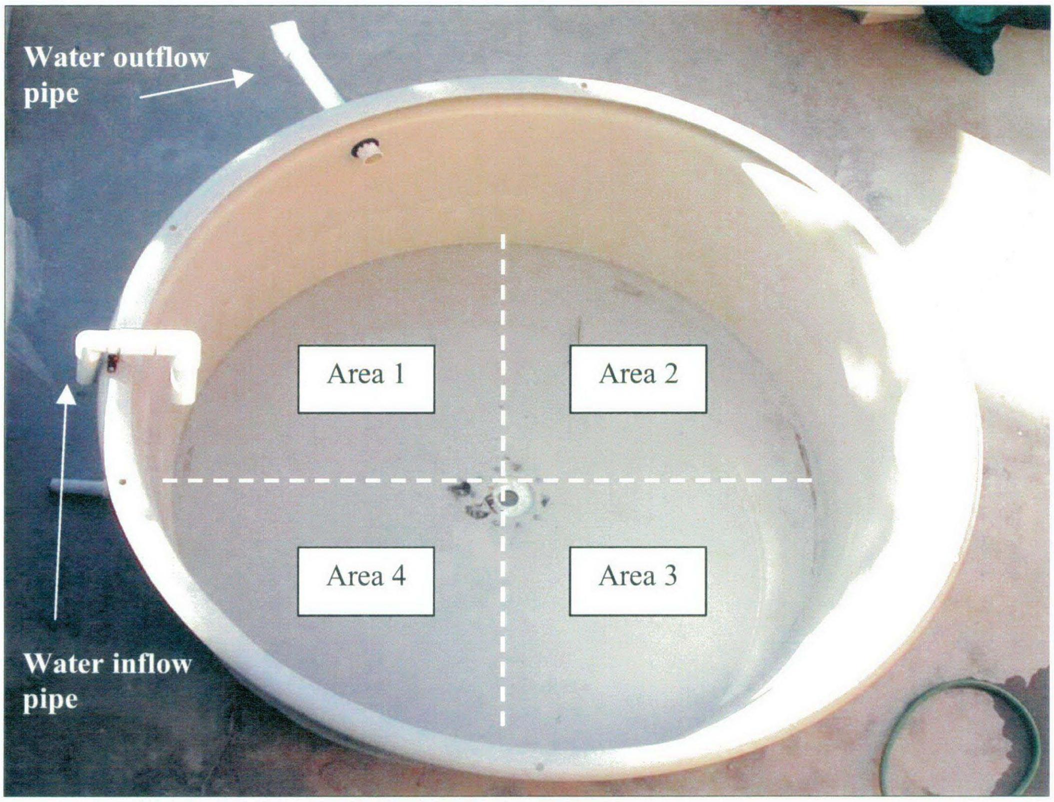


Plate 3.4. Dye plume used to determine where the strongest bait odour concentration occurred was strongest in Area 1 as the water inflow started on the edge of Area 4 and flowed in an anti clockwise direction through Area 3, 2 then 1 where it concentrated. The outflow pipe was located in Area 1.

Attempts

A total of 212 attempts to enter the trap was made during the 15 trials. There was no difference in the number of attempts made between male (96 attempts) and females (116 attempts) (paired t test. $t = 1.19$, $df = 29$, $P = 0.24$). All crabs made an attempt to enter the trap. Most crabs took 3 attempts before they entered the trap successfully, while some crabs took up to a maximum of 12 attempts (Figure 3.3).

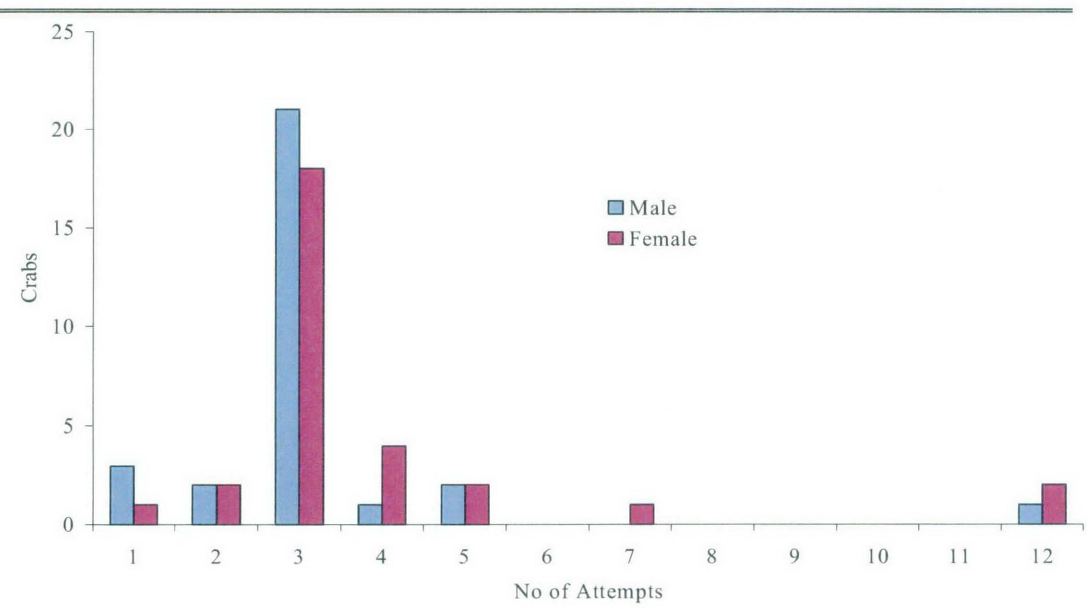


Figure 3.3. The number of attempts made by male and female crabs to enter a trap.

During an attempt, 92% of crabs made initial contact with the trap in Area 1 while 8% were made in Area 4 (Figure 3.4). No crabs made an initial contact with the trap in Area 2 and 3. During attempts 1 and 2, the majority of crabs made initial contact with the trap at Area 1 and 4 while during attempts 3 - 12 all initial contacts with the trap were made in Area 1.

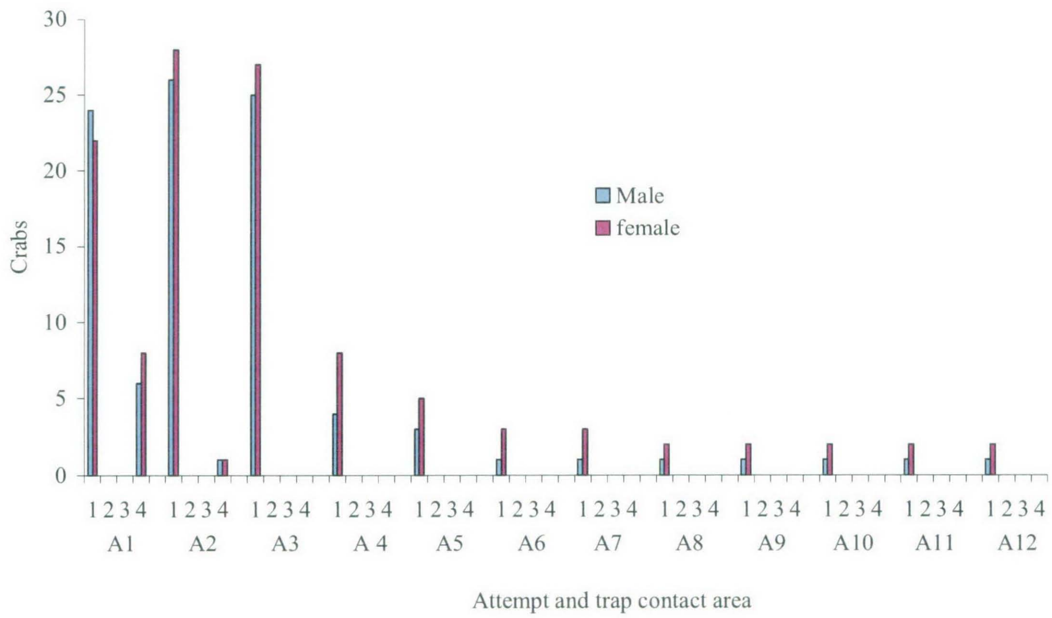


Figure 3.4. Initial trap contact area (1 - 4) during each attempt (A1 – A12).

Area searched

During an attempt, 87% of males and 86% of females searched an area of 90° around the trap while 7% and 8% of males and females searched 91 - 180°. Some crabs searched more widely than this covering 360° during an attempt (Figure 3.5).

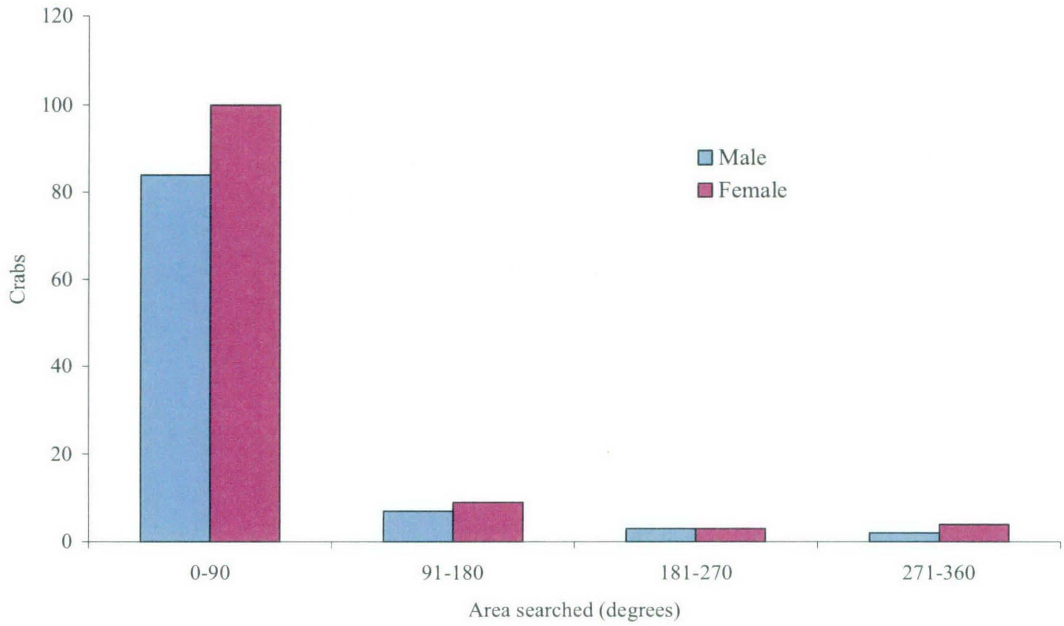


Figure 3.5. The area searched around a trap during a crab's attempt.

Most movement was made during the first attempt where the majority of crabs searched an arc of 90° but others searched further (Figure 3.6). After the second attempt, all crabs searched 90° only and showed little interest moving away from that range. A χ^2 square test showed there was no association between gender category and area-searched (χ^2 0.42, df 3, P = 0.93).

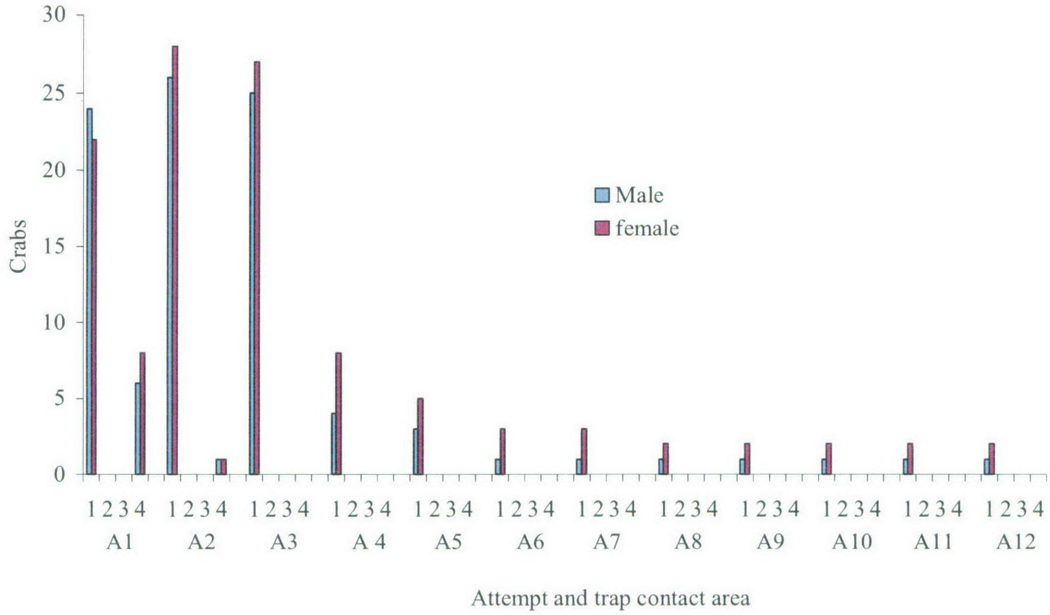


Figure 3.6. The arc searched by crabs at each attempt. A1 = Attempt 1. 1 = 0-90°; 2 = 91-180°; 3 = 181 – 270°; 4 = 271-360°

Funnel misses

A total of 36% of crabs made 1 or 2 funnel misses before entering the trap successfully while 40% of females had 1 funnel miss and 33% had 2 (Figure 3.7). Three crabs had no funnel misses while large females and small males were more likely to have more funnel misses. Small males made the two most attempts with 7 and 8 attempts.

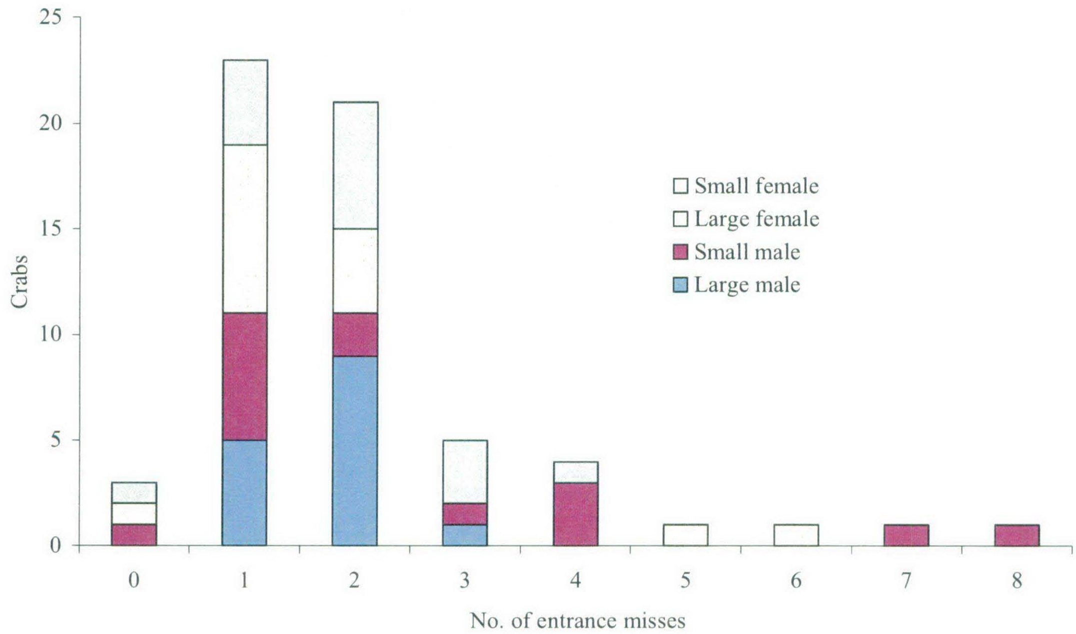


Figure 3.7. Total number of male and female entrance funnel misses before trap entry.

Activity

Daylight did not seem to affect emergence of crabs from the sand. Crabs reacted to the bait odour in the water rapidly with 97% and 83% of males and females respectively making contact with the trap within the first 40 min after the trap was placed in the water (Figure 3.8). Males approached the trap faster than females, with males dominating the trap in the first 15 mins. Females started approaching in larger numbers at 15 mins and peaked at 30-40 mins. It took 15 mins for 50% of male crabs to make initial contact and 30 min for females.

After initial contact was made with the trap, 73% of males entered the trap successfully within 15 mins while females took 30 mins for the same number to enter (Figure 3.9). Most crabs entered during the initial 5-10 minute period with 14 male and 8 female crabs entering during this time. All crabs successfully entered the trap. Males took 1–180 mins and females 2–300 mins after first contact (Figure 3.9)

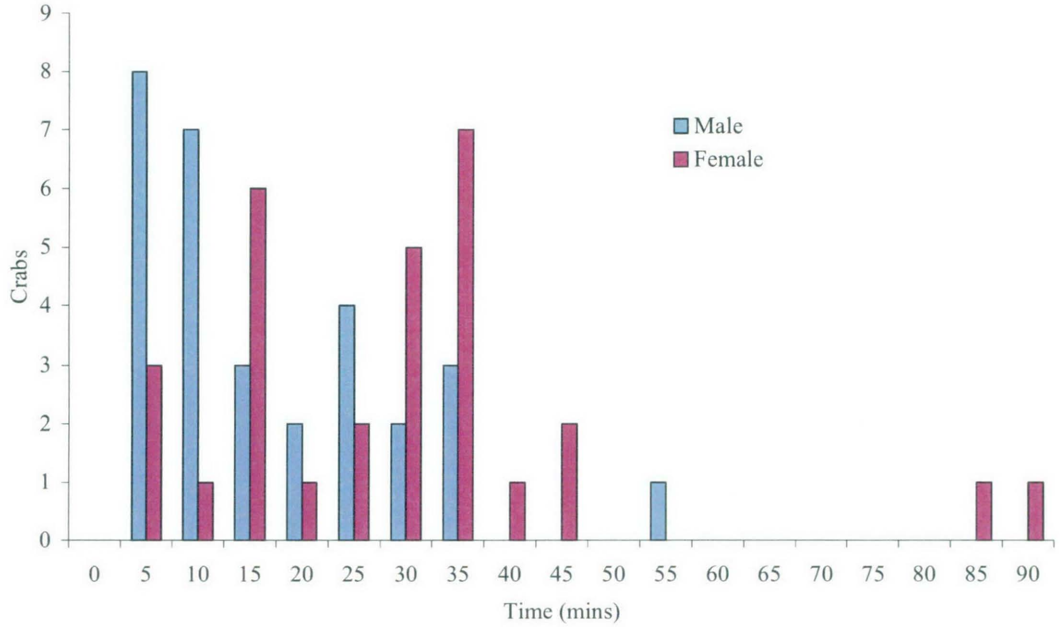


Figure 3.8. Time till initial contact of the trap by a crab once the trap was entered into the water at 14 00hrs

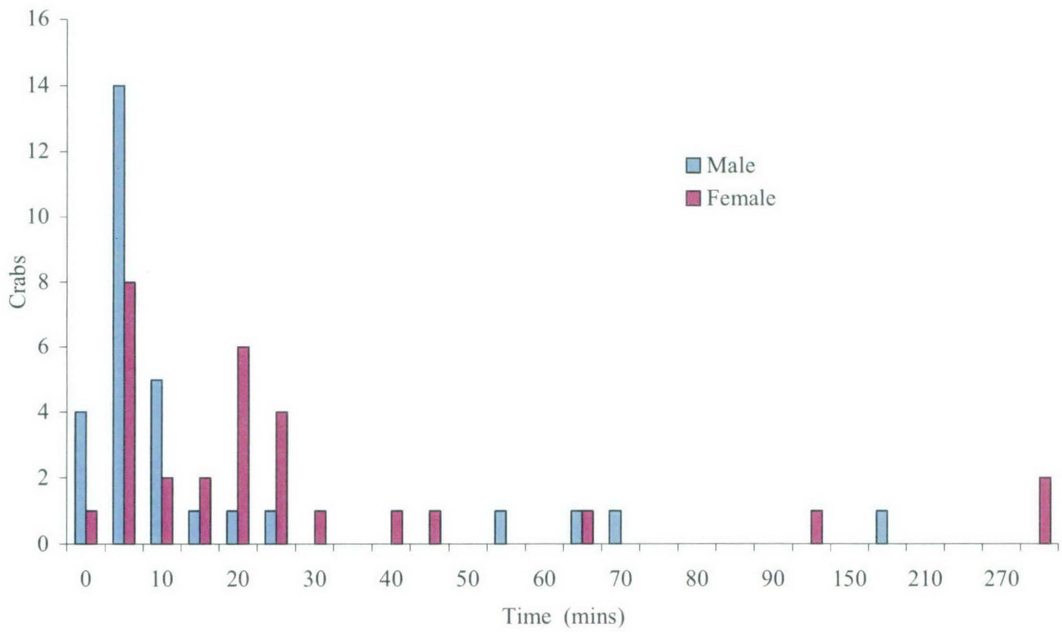


Figure 3.9. Time till successful trap entry after initial contact

All crabs had entered the trap within 6 hr of the trap being placed in the tank. Male crabs took up to 245 min and females 362 min (Figure 3.10). During the study, 86% and 70% of males and females entered the trap within 60 min of the trap being put into the water with the fastest male and female taking 6 and 17 min respectively. There was a relationship for males and females in relation of time to initial contact to time of trap entry but due to three significant outliers (2 male/1 female), R^2 values were low (Figure 3.10). It was thought that these crabs may have had something wrong with them but after examining each crab, they seemed in good health as all crabs eventually entered successfully and ate the bait in the trap.

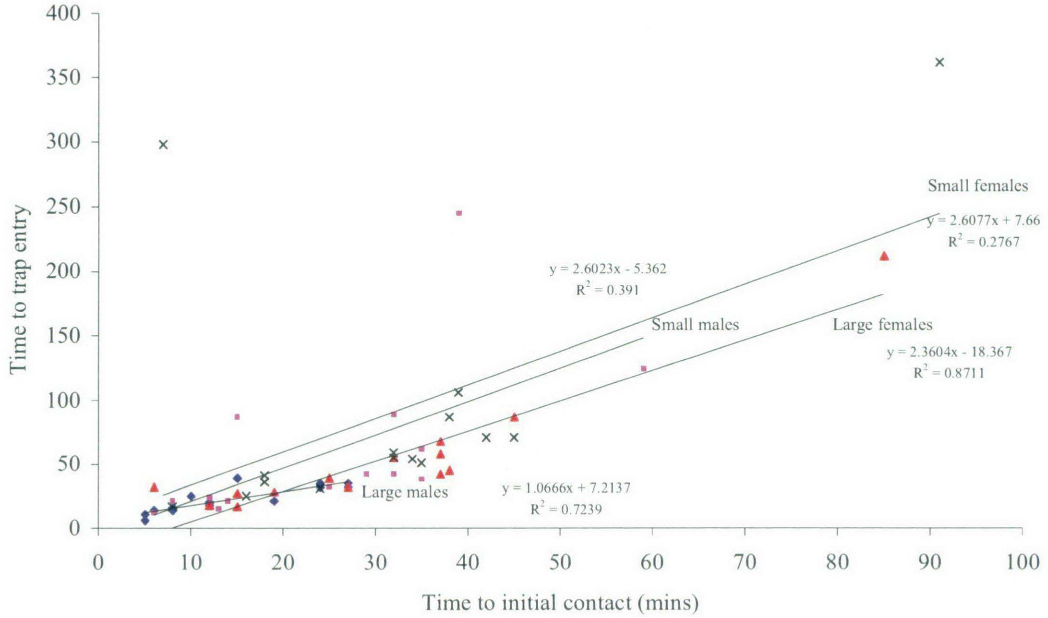


Figure 3.10. Correlation of initial trap contact against time till trap entry for gender and size groups used during the trial

Crab behaviour

Male crabs entered the trap before females on most occasions with 76% of females entering after males were already inside the trap. A chi-square test showed there was an association between size/gender category and entry order category (χ^2 28.53, df 9, $P < 0.01$). Females did not enter the trap as the first crab in any trial. There was little difference in entry order for size classes within male and female groups (Figure 3.11).

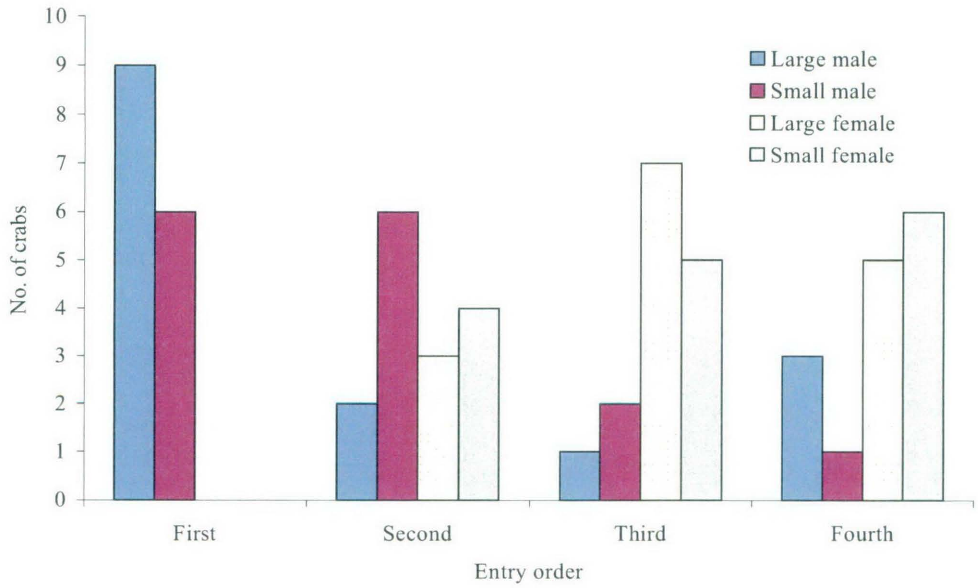


Figure 3.11. The order of entry of each crab used during the study

Females were more likely to make a trap top attempt than males (Figure 3.12). For 11% of all attempts crabs climbed on the trap top. Of these 43% were large females and 30% small females. Large males caused the most funnel antagonism followed by small males and females of any size (Figure 3.12). A χ^2 square test showed there was an association between gender/size category and trap top attempt (χ^2 10.36, df 3, $P < 0.05$).

Of the 15 crabs in each size class, 60% of large males, 33% of small males, and 20% of large and small females showed funnel antagonism as another crab entered the trap. A χ^2 square test showed there was an association between gender category and funnel antagonism (χ^2 4.80, df 1, $P < 0.05$) but no association between size and funnel antagonism (χ^2 7.22, df 3, $P = 0.066$)

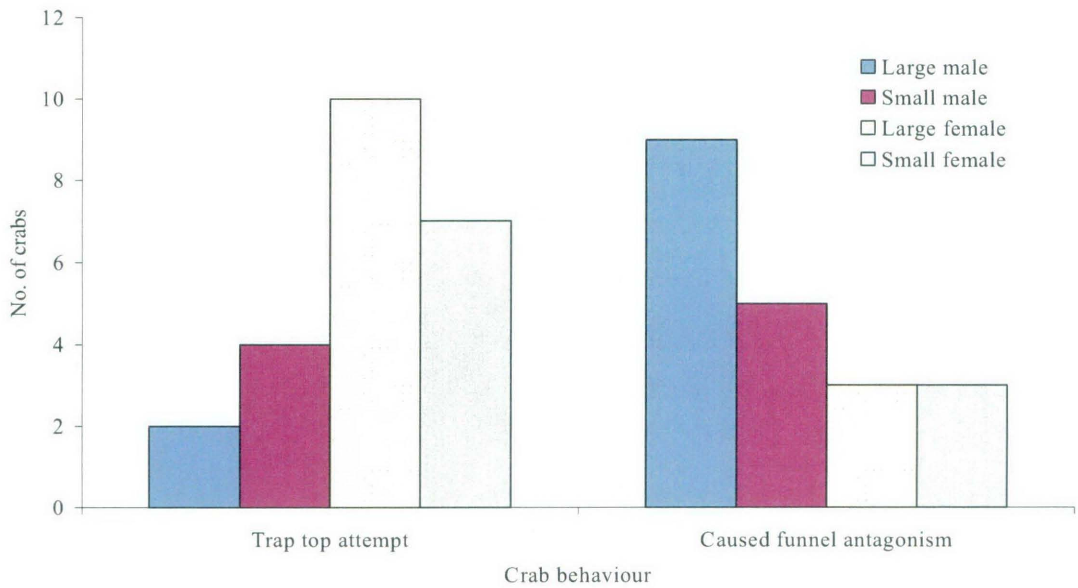


Figure 3.12. Behaviour of crabs around the trap

3.7.4 Discussion

Site of contact

The high number of crabs which made contact with the trap at the site of the bait odour was expected as indicated by the dye and previous tank work on the sand crab (*Portunus pelagicus*) (Smith and Sumpton 1989). Miller (1979) and Wassenberg and Hill (1987) have previously shown that crabs approach a trap from downstream. This implies that they are following the bait odour up a designated trail. Placing traps parallel to the current will increase the chance of a crab approaching the trap where an entrance is located. This is easily achieved in smaller estuaries and rivers where the current runs with the tide but harder in large bays where crabs are also caught. Where a trap was not sitting facing the current the crab would be required to search further for an entrance which may in turn discourage the crab as they will only approach a trap a certain number of times.

Attempts

Males and females were attracted to the baited traps and showed no signs of being 'trap shy'. This supports other work on crabs where males and females had equal attractions to baited traps (Miller 1979; Haddon and Wear 1987; Wassenberg and Hill 1987; Smith and Sumpton 1989). Most crabs only needed three attempts to enter the trap successfully, while three crabs tried a maximum of twelve times before entering the trap. The problem with this in research is that if a crab is unsuccessful after three attempts then it may move away and try a different food source. The crabs in the tank had only one food source available to them but in the wild varying sources may be available around the trap. Therefore, that crab may not be caught as it has exhausted its time trying to enter the trap at that time and may move off to utilise other food sources in the area. It may be beneficial to trap for consecutive days to catch crabs that moved away after unsuccessful attempts.

Males and females were highly successful at entering traps. The position of the entrances may have been a factor yet Miller (1979) found in trap studies with *Cancer productus* that placing entrances perpendicular to the current resulted in a 7% success rate of entry which rose to 65% when entrances were parallel to the current. Each crab had problems finding the entrance to the trap. This may have been because of the swirling currents in the tank. Yet, each crab always searched for several minutes along the first 90 degrees of the area where it first touched the trap. Even if an entrance was located where the crab first touched it did not always move up the slope and into the trap. Smith and Sumpton (1989) found that the percentage of successful entries to total attempts was low for the sand crab (*Portunis pelagicus*) possibly because it moved towards the bait in a zigzag path (Wassenberg and Hill 1987). This meant that the crab crossed and recrossed the probable scent trail, but usually did not attempt wider movements as crabs thought they had found a pathway through to the bait. This is why a small percentage of crabs searched more than 180 degrees around the trap. This was evident in the trial where crabs moved up to the wire outside the trap where they could get the strongest bait odour but did not move and instead tried endlessly to enter the trap at that point. Eventually they would either try again along the trap or move away.

Sex and size determined what order crabs entered traps. The crab that reacted first to the bait odour made it to the trap first, but was not necessarily the first into it. Large males entered first on most occasions followed by small males. These crabs were more aggressive around the trap and seemed more intent on finding a way into the trap. It seemed that starving the crabs before the trial made them hungry as all crabs reacted to the bait quicker than when they were observed being fed, prior to the experiment.

As sampling conditions were similar during this trial, catching crabs in estuarine systems would need to take factors into account such as hunger, antagonism around the trap, strength of bait odour and current, proximity to the trap, crab moult cycle, light and temperature. Crabs that have just fed before trap setting may not forage again for some time period, which may be outside your soak time. It is therefore important to trap over several days to minimise these effects.

Approximately half of all crabs entered the trap within 30 mins of the trap being placed in the tank. Most crabs took extra time because they missed the entrance slope. Even when a crab did come straight to a funnel, it often missed the funnel and continued searching around the sides. This was common in both sexes.

Many crabs, especially females, attempted to enter the trap via the top. In personal observations of the holding tanks, mud crabs frequently hung upside-down on the roof of their cages. This is contrary to work completed on sand crabs by Smith and Sumpton (1989) who found that sand crabs did not attempt to enter the trap from the top. Females searched the top of the trap more frequently, possibly due to male interactions. Females may have been attempting to enter the trap away from aggressive male crabs, which were searching around the sides.

The aggressive nature of mud crabs was evident in the trap interactions. A crab that entered the trap first often defended its catch if any other crabs tried to approach the trap through the funnel. Crabs that were on the outside of the trap may have been deemed too far away to be a threat. On each occasion, the crab in the trap would raise its chelipeds yet keep feeding. This was similar in sand crabs (Smith and Sumpton 1989). Where a crab was entering through the funnel the crab would display these characteristics but never engage in any physical contact. Only when a large male was showing aggression against a small male would the small male retreat from the funnel entrance and try again. Never did this aggression chase the other crab away and eventually it would enter fully into the trap and either eat together or the first crab would move away if it had already eaten enough. Miller (1979, 1980) found that this trap aggression occurred for the crab species *Cancer productus, Cancer irroratus, and Hyas araneus.* These species often approached the trap on the downstream side of the trap where the bait source was and this congregation led to aggression between the crabs. Secondly, Smith and Sumpton (1989) found that there was aggressive behaviour shown from *P. pelagicus* already in the trap towards crabs entering the trap.

Funnel misses were high and the small area searched initially by each crab around the trap suggests that the current design of the traps may be inefficient if soak time is short. Each crab eventually entered the trap during the night and none escaped. While most crab research allows for 24 h soak time, it may be more efficient to set for a 14 h period from 4 pm to 6 am when crabs are most active. This would reduce the chance of bait being eaten out from fish and other crabs, and minimises the chance of fishers illegally lifting gear as setting and lifting would occur when fishers are not normally active. This may not be possible logistically as samples are usually taken across large areas within and among estuaries. However, there is more chance of catching every crab in that area if traps are checked more frequently and the crabs removed. This then gives the opportunity for females to enter the traps, as they seemed to always enter after males. It would also reduce the saturation effect of the trap in high-density areas. Checking traps on a 12 h basis or even 6 h at night would effectively catch most crabs as they reacted to the bait within 6 h in this trial. However, it could also introduce the problem of trap disturbance, which might affect catches. Lifting and setting traps over short time periods may also disturb crabs from normal foraging activities ending in reduced trap catches.

The efficiency of the design of each trap may be improved. It was observed with the rectangular shape of the traps that when crabs approached a trap on the long side they searched along that edge for a period of time before moving around the corner of the trap. Crabs may have been hindered by the trap corner due to them moving further away from the bait when they moved around the corner. A round trap may eliminate this problem, as crabs will be the same distance from the bait at all times and as they search around a trap they will come across a funnel entrance. Smith and Sumpton (1989) suggested that traps for sand crabs should have a continuous entrance around the trap. This would be efficient for sub adult and adult mud crabs as no crabs escaped through the entrances during the experiment. Each trap could be designed to have a continuous funnel around the trap with the addition of one-way entrances that allow crabs in and not out. This would then decrease the number of days that traps would need to be deployed as it is possible for all crabs to be caught on the first night without crabs moving away after several efforts of trying to find an entrance in the current trap design. As the majority of female crabs searched the trap top, trap designs with top entrances may be biased towards female catches. All females eventually entered the trap once males had entered. In a population that is gender biased towards males, females may not have a chance to enter from the side. Top entrances may be added in these circumstances to catch females.

3.3.5 Summary

This experiment was conducted to validate the trapping methods used as part of the main research in each estuary. The results illustrate that the traps efficiently caught sub adult and adult crabs within 6 h. To be effective, the traps need to be set and checked daily for several nights to compensate for when crabs do not enter traps if they could not find an entrance. Alternatively traps can be checked every 12 h to remove crabs when trapping in high-density areas. The size of the traps used in this study did not cause significant interactions between crabs, affect the carrying capacity of atleast four crabs per trap and did not restrict the movement of crabs into the trap. The positioning of each trap with funnel entrances upstream and downstream of the current maximised the catch as crabs tendered to congregate at these ends after following the bait odour up to the trap. It is suggested as part of future research that the trap design may have been more efficient if round traps with continuous one-way entrances were used instead of the traditional rectangular traps with entrances at each end.

While it was possible to use the most appropriate bait, trap size or sample over continuous days because of the findings from this trial it is not always possible to sample the trap every 12 h. All traps during the field-based research were lifted after 24 h soak time, as there was not enough time in a day to sample sites in all three estuaries by continuously lifting traps every 12 h. It was imperative to sample all three estuaries at the same time to ensure comparability and reduce the risk of confounding effects.

3.8 Tagging program

3.8.1 Tag application

Each crab was tagged with plastic t-bar anchor tags using a Dennison tagging gun (Hallprint Pty Ltd). The tags are constructed from a cylindrical marker moulded to the filament of a "T" anchor (Figure 3.13). The type of tag used was a TBA-2 t-bar anchor tag. Tags were yellow and labelled "NSW Fish, Coffs HBR, PB (tag no.)". The filaments were 44 mm in length with the filament kept to its shortest length to reduce the effect of dragging. Tags were inserted into the posterior region of the crab where the carapace and abdomen meet (Plate 3.5; Plate 3.6) because the carapace and abdomen split along this junction during moulting. This reduces the chance of losing tags. The tags were placed to the right of the dorsal abdominal artery to prevent killing the crab.

Crabs were tagged to show successive captures and indicate movement patterns within and among estuaries. A trial was run to determine the efficiency of these tags. To have a successful tagging program we need to know the physical response of crabs to tag insertion. This was achieved by determining the length of time tags were retained for, if moulting affected tag retention and the most effective position for tag insertion (section 3.9).

3.8.2 Collection program

To increase the number of tags returned a program called "Mud crab Lotto" was established under NSW Government Gaming and Racing permit no. TPL03/07787. The study was advertised on television, radio, local papers and posters to let people know that a reward could be won for returning tags (Appendix 4). The reward system seemed to generate interest as people suggested that they may not have returned tags if there was no reward scheme. All people who returned tags were entered into the draw to win $300 at the end of the study. The problem with the reward scheme was that people might have placed extra effort in trying to catch crabs with tags leading to higher than normal trapping effort in the estuaries. With this in mind the prize pool was kept low. Individual rewards for each tag were not practical as this would have meant a large monetary payout on our behalf (e.g. provide $3 for every tag returned, giving a total cost of $720 for the project).

Plate 3.5. A mud crab in the Wooli Estuary and the position of the tag at the junction of the carapace and abdomen.

3.9 The efficiency of t-bar anchor tags for marking the mud crab (*Scylla serrata*)

3.9.1 Introduction

Tagging studies in fisheries provide a tool for population assessment and tracking organisms over time. Methods associated with tagging studies have changed by using different technologies available to track different species. Such changing technologies have had little impact in long-term tagging studies on decapod crustaceans due to their complicated lifecycle (i.e. moulting). It is still being argued what methods are the most efficient and cost effective. Williams and Hill (1982) used Floy FD67 anchor tags to assess pot catches and describe population estimates for the mud crab *Scylla serrata*. They concluded that, due to the cost of tagging, that tagging should not be recommended as a method of assessing populations of mud crabs.

One of the main problems associated with tagging crustaceans is that tags may affect normal activity of the individual, and produce artefacts leading to incorrect interpretation of results. For a tag to be effective, it must not compromise survival potential or recapture probability (Begon 1979). McPherson (2002) reinforced previous work on sand crabs that tags should not have any effect on the animals well being at application, during intermoult and the moulting process. Therefore, tolerances of the individuals to tags must be known. For the mud crab, different tags have been used over the past 20 years. Despite extensive research being conducted on this species, little has been done to evaluate the tagging methods and their effects on crabs.

Hill (1975, 1982) tagged the mud crab *Scylla serrata* with Floy FD67 and Floy FD68B anchor tags. His work looked at various aspects of tagging application but did not assess the success of the tag during or after moult. Tags were positioned slightly off centre at the junction of the carapace and abdomen in an effort to stop tag loss at moult but did not test whether this application site was successful for tag retention after moulting. Knuckey (1999) assessed the site of application of the TB series tags produced by Hallprint Pty Ltd. Knuckey (1999) used two application points and found the carapace tag was most effective. The swimmeret tag caused autotomy and tag loss in some crabs while the carapace tag had no effects until moulting. At this point, it caused crabs to remain connected to their exuvia by the tag which was still inserted through the first abdominal segment. This prevented the completion of ecdysis and the crabs died. This problem was prevented by inserting the tagging gun at more of an angle so it sat over the abdominal segment that had previously caught the tag. Knuckey (1999) completed a further trial with this new method and all crabs moulted successfully.

Once the tagging process has been designed where the crab effectively holds the tag through moulting, the second phase requires the tag to be accessible to fishers. For effective returns during tagging programs, tags must remain visible at all times for easy identification by fishers or there may be reduced identification reports. Tags are often bright colours but because they are small and the site of application is usually hidden, they may be missed. Any information program advising the public about the tags is also essential to the program. This can be improved by providing a reward for tag returns.

The aim of this work was to determine the most effective site for tag insertion and retention for the mud crab (*Scylla serrata*) and to identify a successful tagging procedure for field trials. This is important for long-term population studies where moult cycles occur.

3.9.2 Materials and methods

Collection process

A total of 27 crabs were collected from the Wooli Estuary using wire traps (Section 3.6). Only crabs that were in full body condition were taken. This meant that they had a full set of appendages and no damage to their body. All crabs used were sub adults or adults. On collection, each crab was sexed, weighed to the nearest gram, measured for carapace width and length, and tagged. This procedure was repeated again 5 d after the crab had moulted to detect any change. After moulting, crabs were given 5 d to recover from the moult before handling as their shell was still hardening. Handling of the crab during this period could have caused the new shell to crack. At moult, crabs were assigned a categorical rating depending on their fate at moult (Table 3.2).

Table 3.2. Category assigned to crabs after each moult. (derived from McPherson 2002).

Rating	Fate at moult
A	Perished during the moulting process or within 48 h of moulting
B	Tag in old shell and change in body structure (e.g. loss of limbs or old shell attached to limbs)
C	Tag remained with old shell
D	Tag remained in place and the animal was in similar condition to pre moult but the old shell remained attached to animal via the tag
E	Tag moved or fell out before moult.
F	Moult successful with animal in similar condition to pre moult

Tag design

The plastic "T" bar anchor tags used for the experiment was a TBA-2 tag manufactured by Hallprint Pty Ltd, South Australia (Figure 3.13). The Northern Territory Department of Primary Industry and Fisheries in Australia commonly use these tags for research on mud crabs. The tags are constructed from a cylindrical marker moulded to the filament of a "T" anchor. The tag consisted of an 18 mm leader attached to a 26 mm barrel. The filaments were kept short to reduce the effect of dragging. Tags were yellow and labelled with the words "NSW Fish, Coffs HBR, PB (tag no.)".

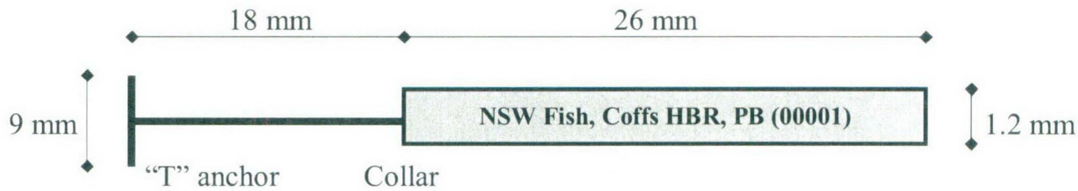


Figure 3.13. Design of TBA-2 anchor tag used during the trial (not to scale).

Tag application

Tags were inserted using a Dennison tagging gun (model- tag-fast III – mark II pistol). The gun was thoroughly washed with distilled water between each application. Two insertion sites were used during the trial to determine if site had any effect on the moult process; i) carapace; and ii) swimmeret (Plate 3.6 and 3.7). Control crabs remained untagged.

Five male and four female crabs were tagged through the carapace (Plate 3.6). Tags were inserted into the posterior suture of the crab where the carapace and abdomen meet because the carapace and abdomen split along this junction during moulting. The tag was positioned in the muscle group associated with the right swimmeret. This reduces the chance of losing tags. The tags were placed to the right of the dorsal abdominal artery to prevent killing the crab.

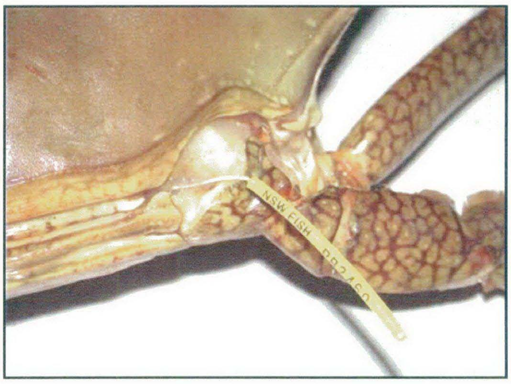
a

b

Plate 3.6. (a) Female mud crab in the holding tank with carapace tag and (b) site of application of carapace tag

Five male and four female crabs were tagged through the dorsal membrane at the junction of the right swimmeret and thorax (Plate 3.7) as described by McPherson (2002). This meant that the anchor section of the tag was located in the same muscle group as the carapace tag.

a



b

Plate 3.7. (a) Male mud crab after successful moult, yet swimmeret tag left behind and (b) site of application of swimmeret tag.

Five male and four female crabs were used to assess natural rates and success of the moulting process or mortality in the tanks during the experiment.

Experimental design

Each crab was kept in an individual cage (900 mm x 40 mm x 70 mm) in three 4000 mm x 900 mm x 900 mm tanks (Plate 3.8). Three crabs from each treatment were randomly placed in 3 cages within each tank. Crabs were separated to stop fighting, as they are vulnerable to attack when soft-shelled after moulting. Each tank was aerated and serviced by a flow through biological filter system of seawater. Temperature and salinity were measured daily and weekly levels of pH, conductivity, DO, NH4, NO_3, NO_2 and PO_4 were taken weekly using a TPS WP-81 (TPS, Brisbane) water quality meter. Each crab was checked daily at 8 am and 5 pm during feeding. Each crab was fed 5% of its body weight consisting of prawns and pilchards. All uneaten food was removed the next morning to eliminate contamination by decaying food.

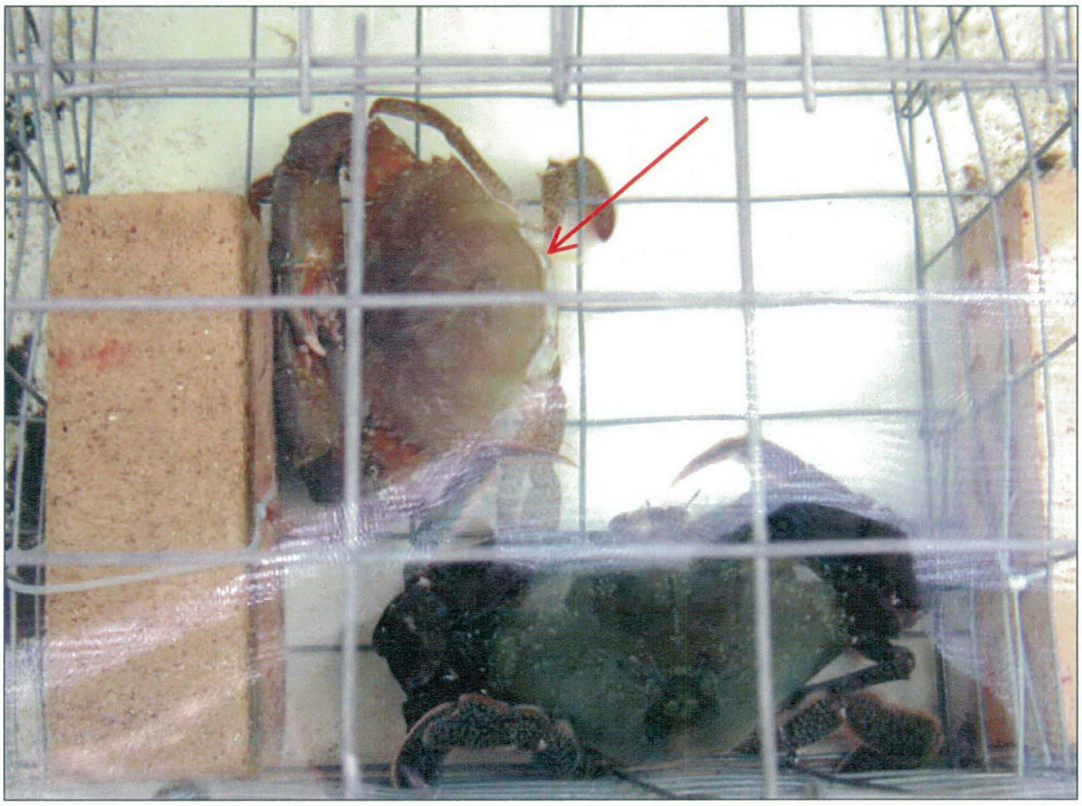


Plate 3.8. Cages used during the trial. In this photo, the crab has recently moulted (bottom of picture) and the tag is still attached to the swimmeret on the discarded carapace (red arrow).

3.9.3 Results

All 27 crabs moulted during the trial with the nine control crabs moulting successfully (Table 3.3). None of the 27 crabs died during the moulting process or within 48 h of the moult taking place and no tags fell out or moved before a moult. The swimmeret tags were least successful with all nine crabs retaining tags in the old carapace (Plate 3.9). Six of these crabs suffered deformities such as limb loss. Eight carapace tagged crabs retained their tags. The one that was not retained successfully still had the old shell attached via the tag. The old shell fell off after 24 hours. There was no difference in the tag retention of male and female crabs. The four males and females with a carapace tag moulted successfully while all swimmeret-tagged crabs of each sex had the same problems with moulting.

Table 3.3. Results of the tagging experiment and criteria for each fate.

	No. of crabs						Percentage			Days to moult
	Carapace		Swimmeret		Control		Carapace	Swimmeret	Control	
Fate	*M*	*F*	*M*	*F*	*M*	*F*				
A	0	0	0	0	0	0	0	0	0	0
B	0	0	**4**	**2**	0	0	0	**67**	0	**21-198**
C	0	0	**1**	**2**	0	0	0	**33**	0	**9-87**
D	**1**	0	0	0	0	0	**11**	0	0	**61**
E	0	0	0	0	0	0	0	0	0	0
F	**4**	**4**	0	0	5	4	**89**	0	**100**	**5-260**
total	**9**		**9**		**9**		**100**	**100**	**100**	

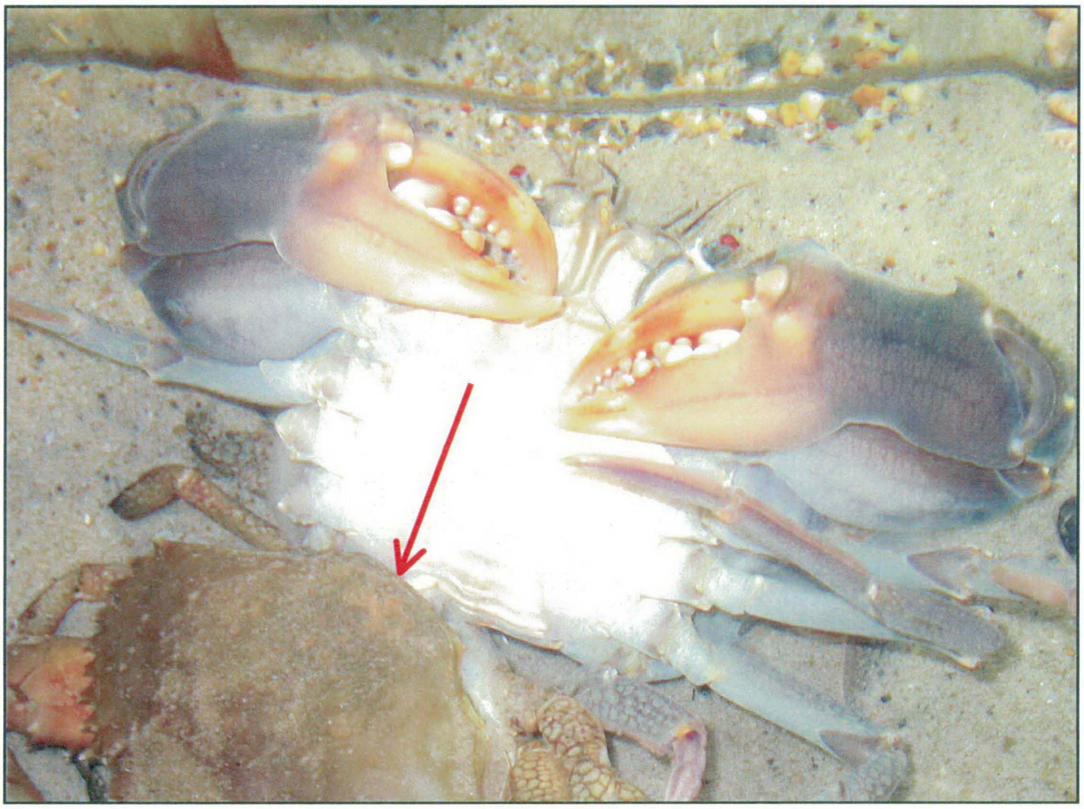


Plate 3.9. Carapace tagged crab during moulting with exuvia being retained via the tag. Arrow indicates location of tag.

3.9.4 Discussion

This study aimed to compare the success of two insertion sites. This will validate the use of t-bar anchor tags in long-term studies and to support that they do not affect the crab during the moult cycle when site of tag application is effective.

Most crabs marked with carapace site t-bar anchor tags moulted successfully and retained their tags. This method of inserting tags into the posterior suture of the crab where the carapace and abdomen joins satisfies all the criteria for short-term and possibly long-term studies on these creatures. Although during this study, only one moult cycle was assessed it is possible that the tags would be successful at a second moult. As no crabs lost their tags and one crab still had its tag intact after 260 days, this gives confidence that all crabs can hold onto their tag until at least that time. The tags did not become brittle during the trial suggesting that they are not susceptible to breaking during moulting when the tags are being pulled through the old carapace.

Swimmeret tags cannot be used as they affect the normal activity of crabs. They do not cause mortality but provide ongoing problems for long-term studies as tags are lost and cause problems during moulting. The problems during moulting raise ethical issues for scientists as the tags cause harm through limb damage. Some tags during the trial caused the exuvia to be retained by the tag, potentially causing stress to the crab by leaving it susceptible to starvation or predation. All crabs still foraged after moulting but the experiment area was in an environment free of predators and other naturally occurring interactions.

No crabs lost, damaged or removed tags from other crabs during the study but cage behaviour by individual crabs suggests that tags could be lost in the wild. Personal observations during the study saw several crabs "handling" tags on crabs in adjacent cages with their chelipeds. It is possible that crabs could pull out tags on other crabs with their chelipeds. This may be further magnified in the field when cages do not separate individuals. Although this is unlikely as the crabs with the tag inserted usually moved away on being touched it is possible that crabs could take hold of other crab's tags and not let go.

3.9.5 Conclusions

The t-bar anchor tag specifications and carapace site insertion used during this trial are appropriate for use in mud crab tagging over a period of at least one moult cycle. It is uncertain if the tag remains in the same position as the original anchor point once one successful moult has occurred and this would need to be determined for crabs over extended time scales. Based on this study, which supported earlier observations by Knuckey (1999), the carapace tag application point was applied to all tagging conducted during the field-based component of this study.

3.10 Fishing Pressure

To assess fishing pressure, monthly counts of traps, boats and people were taken in the Sandon, Wooli and Corindi estuaries. Firstly, counts were taken on each day of sampling each month to determine the amount of fishing effort within the sampled "fished" sites and outside these areas in each estuary (Chapter 4 and 6). To further support the monthly fishing effort results, the Wooli Estuary was divided further into 1 km sections from the estuary mouth (Table 3.4) to determine short term variation in monthly fisher effort and to determine if there was any gradient in fishing effort along the estuary. On each day of sampling, the number of traps, boats and people were counted in each 1 km section to give an approximate daily (section 4.2.5) and monthly (section 6.3.3) count of where fishing effort was concentrated. It would also indicate any change in effort when the new zoning scheme was implemented.

Table 3.4. Upstream latitudes and longitudes of sites used to determine fishing pressure in the Wooli Estuary.

Site	Distance from estuary entrance (km)	Latitude	Longitude	River feature
1	1	29°52.85	153°15.85	Main boat ramp
2	2	29°52.30	153°15.83	Sandslide (natural feature)
3	3	29°51.78	153°15.78	2 x boat ramp/caravan park/wharf
4	4	29°51.29	153°15.67	2 x boat ramp
5	5	29°50.96	153°15.14	Boat ramp/caravan park
6	6	29°50.44	153°15.13	Boat ramp
7	7	29°50.38	153°14.52	
8	8	29°50.48	153°13.95	Wooli River "forkes"
9	9	29°50.81	153°14.19	
10	10	29°51.27	153°13.90	
11	11	29°51.64	153°13.60	"Collets crossing" rockbar
12	12	29°51.77	153°13.11	
13	13	29°52.18	153°12.85	
14	14	29°52.68	153°12.73	
15	>15	29°52.95	153°12.38	