5.0 Using ultrasonic telemetry to track short-term movement patterns of the mud crab (*Scylla serrata*) in the Corindi Estuary, Solitary Islands Marine Park, NSW.

5.1 Introduction

As conductivity of salt water obstructs the transmission of radio signals and frequently visual observation is impossible, telemetry has been commonly used in marine habitats to assess habitat and resource utilisation, movement, feeding, moulting and mating behaviour (Hill 1978; Wolcott and Hines 1989; Wolcott and Hines 1990; Shirley and Wolcott 1991; O'Dor *et al.* 1993). For example, mud crabs were tracked in the Kowie Estuary, South Africa to establish movement patterns over 24 hours (Hill 1978). Crabs were tracked in 30 min intervals to determine speed and distance. Crabs were active on average for 13 hours per day, with most activity being nocturnal. Crabs did not stay in the same position but only moved over small distances along the estuary. The maximum distance moved was 800 m over the 24 h while the average daily movement was 461 m. Speed of crabs was slow with modal speed being 10 to 19 m per hour. Some movements were made at 70 m per hour and were commonly against the current, suggesting that crabs were foraging during these periods. These limited movements suggest that crabs would be protected if fishing was removed as crabs are unlikely to move outside of protective areas within a 24 h period.

The goal of Marine Parks is to protect critical habitat and biodiversity while maintaining or increasing fisheries resources, leading to spill-over into adjacent fished areas (Section 1.2). Identifying if these goals are met may be easily reached using telemetry as a tool. An enhanced understanding of the species being protected helps design zoning schemes to incorporate their lifecycle. This would in turn maximise spill-over for fishers while providing protection and increases in abundance and size of species within these areas.

As Marine Parks in NSW are relatively new, the selection of these areas has been constructed on very limited information (Breen *et al.* 2003). The zoning schemes within these marine parks are revised every 5 years to meet the changing needs of the environment and society. This allows zoning schemes to be modelled on new information not available at the last evaluation period. Ultrasonic telemetry may aid as a tool in identifying movement patterns of fisher targeted species and assist the development and design of new zoning schemes.

Estuarine and fisher targeted species such as the mud crab (*Scylla serrata*) inhabit estuaries of the SIMP that are commonly turbid, restricting direct visual census of mud crabs. Previously, tagging programs were the only method to determine whether crabs spill-over from protected to adjacent fished areas. Although tagging is effective, it does not reveal the activity of the crab between recaptures. Telemetry can be used to track and position crabs at any temporal scale. This method is more effective than tagging individual crabs, as it does not rely on fishers to collect and return tags before movement patterns are traced.

As mud crabs are capable of moving significant distances (Hyland *et al.* 1984), they are susceptible to capture by commercial and recreational anglers, leaving them vulnerable to stock depletion in estuaries that have adjacent protected and fished zones. In turn, large movement patterns may allow areas that have been overfished to restock after depletion. In habitats such as mangroves where little crab movement occurs (Perrine 1978), stock recovery may be slow if fishing occurs, while the number of crabs spilling over into the fished area may be smaller than what would occur in channel areas where crabs move further.

This study is a preliminary study aiming to assess the potential for telemetry and detail for further short-term movement studies of the mud crab (*Scylla serrata*). This may provide an indication of the most effective protective site where spill-over occurs to fishers. I predicted the movement of crabs released in the main channels (fished - Site 1) will be greater than movement in the shallow vegetation dominated area (unfished - Site 2). Therefore, there will be no spill-over of crabs from the current unfished site into the fished zone within the tracking period.

5.2 Study site

The study was undertaken in the Corindi Estuary, NSW (Figure 5.1). The estuary is described in Section 4.2.4. Two sites were chosen with five release points within each site (Figure 5.1). Release points were randomly selected within the sites used for the main manipulative estuarine experiment (Section 4.2)

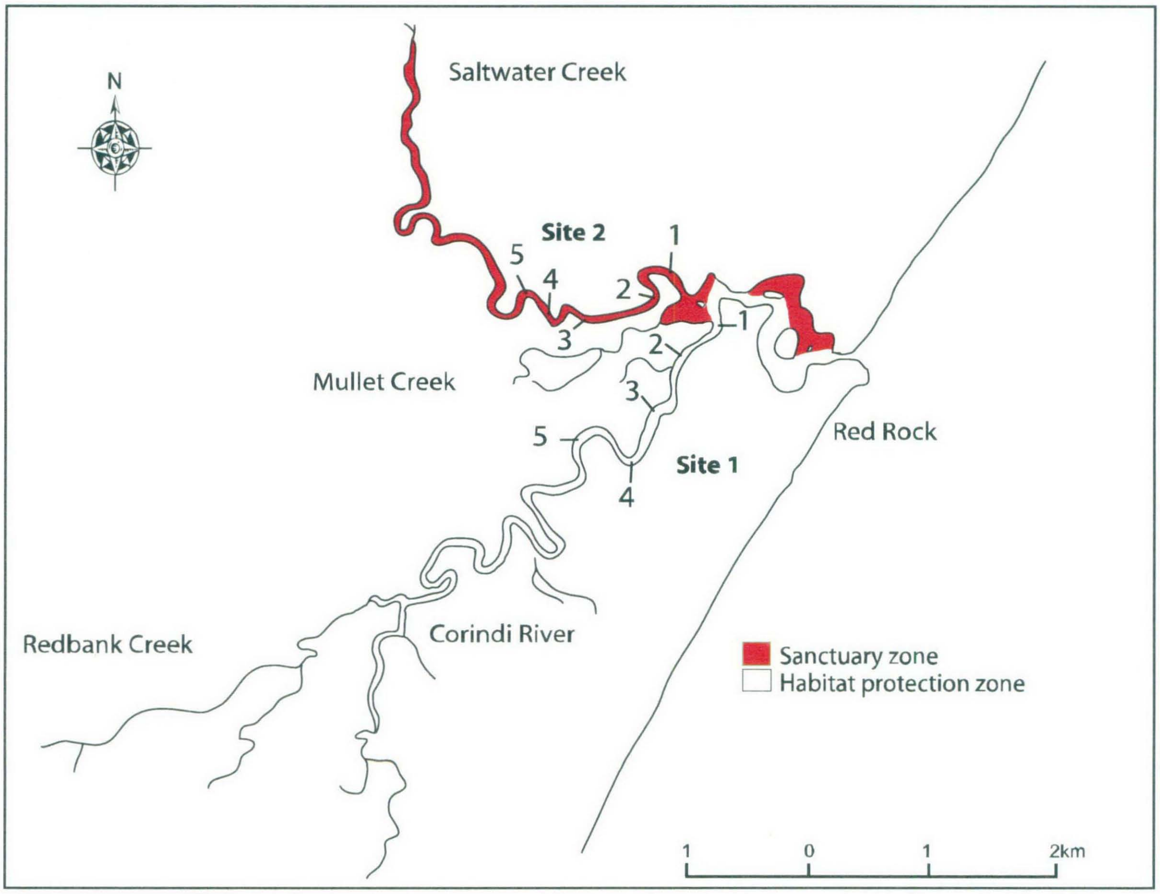

Figure 5.1. Location of study site (1 and 2) and release point for each crab (1 - 5).

5.3 Methods

5.3.1 Experimental design

Only short-term movements were observed due to financial and time restrictions. It was only feasible to purchase five tracking tags due to their high cost (A$200/tag). To determine different movement patterns across two different release sites, the optimal design would be to use 10 tags with 5 tags released at each site. With only 5 tags, concurrent tracking sessions of each site was not possible. Without concurrent tracking sessions in both sites environmental factors such as tidal range, salinity and water temperature could vary between the periods causing changes in activity patterns. Although this is unlikely to make a huge impact as previous work by Hill (1978) suggested that crab movement is independent of current direction and most probably a response to foraging. Two tracking periods were used, as the purpose was to track crabs released at different sites to determine movement within and between two different habitat types (deep channel and shallow channel). Each trial was conducted in two seven-day blocks from late January 2002 to minimise temporal variation. The activity of crabs during both of these periods would be similar as all crabs had usually finished moulting by January minimising the chance of losing a tag and crabs were likely to be still actively feeding and moving during this period while water temperatures were between 20 - 25 ^{o}C (Hill 1980). Fishing pressure was also at its highest during January each year (Chapter 4 and 6) providing high fishing effort in the estuary and a mosaic of traps for crabs to move through if crabs moved into the fished zone.

Crabs were caught using commercial wire traps (Section 3.6). Each crab was measured for carapace width and length and sexed (Section 3.2 - 3.4). Adult (< 150 mm carapace width) and sub adult (100 – 150 mm carapace width) crabs were used (Table 5.1). Juveniles (> 100 mm carapace width) were eliminated, as the ultrasonic tag appeared to inhibit movement of juveniles when observed in laboratory tanks. Five crabs were tagged (Section 5.3.2) and released at random points within Site 1 and tracked (Section 5.3.3) for 7 days (30th January 2002) then recaptured by trap. Each crab was released again (8th February 2002) at random points in Site 2 and tracked for a further 7 days. The same crab was used for each site to determine if movement patterns were the same for each crab after being released at two different release sites (Plate 5.3).

Table 5.1. Characteristics of the crabs used for tracking.

		Crab characteristics				Tag characteristics		
Tag	Release date(s)	Width (mm)	Length (mm)	Gender	Weight (g)	Frequency	Code	Interval
1	30th Jan/ 8th Feb 2003	134	90	M	488	72	3,4,5	882
2	30th Jan/ 8th Feb 2003	119	80	M	307	73	3,3,6	919
3	30th Jan/ 8th Feb 2003	162	112	F	653	74	2,4,6	942
4	30th Jan/ 8th Feb 2003	145	95	M	466	75	5,5,5	956
5	30th Jan/ 8th Feb 2003	157	105	F	543	76	4,5,6	977

5.3.2 Tagging

Transmitters (Type CT-82-3, battery type 2/3AA, ring type –4, Sonotronics, Tucson, USA) were attached to crabs. Each tag was 67 x 18 mm, weighed 10 grams with 24 months battery life, externally mounted, and cylindrical in shape (Plate 5.1). Each tag was attached to the centre of the carapace with (Magic brand) super strength epoxy glue. This contained a mixture of liquid epoxy resin and amine. During placement, the carapace was dried and enough epoxy used to create a strong robust joint. It was ensured that no epoxy was put on any other part of the crab's body. Each crab was kept for one week in external tanks before being released to establish if the tag had any effect on the crab or if the crab had been injured during capture.

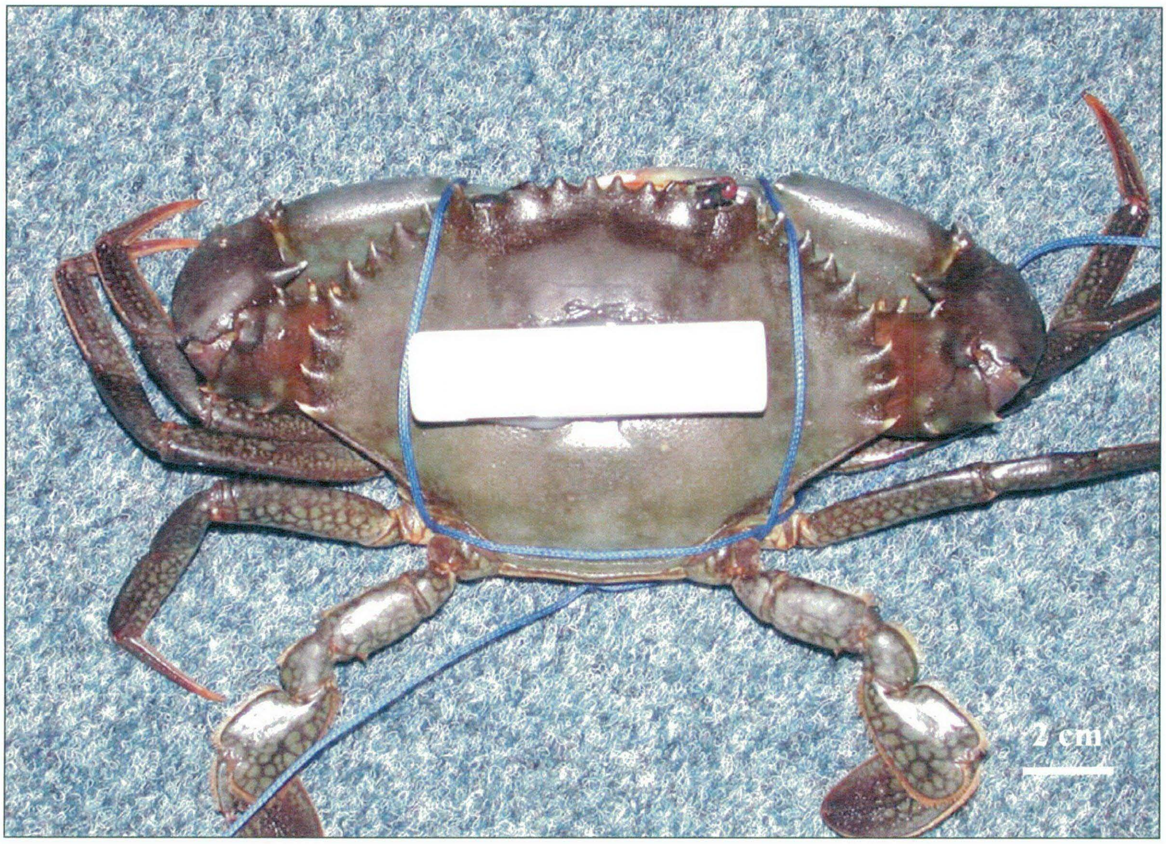

Plate 5.1. Transmitter attached to a crab. Blue string was removed after epoxy was dry.

5.3.3 Tracking

Crabs were tracked from a 3.6 m aluminium boat using a USR-96 Narrow-band Receiver (Sonotronics, USA). The receiver was operated with a DH-4 Directional Hydrophone (Plate 5.2). The signal strength is determined by the relative condition of the water. This means that the signal strength of the transmitter can be reduced by particulate matter in the water and whether the tag is obstructed by debris such as a log or seagrass. To determine the signal strength of tags in the study area, trial releases were used at each site to confirm that each tag could be detected when released on each crab. Crabs were released with a tag and attached to a tether of fine fishing line so that movements were not restricted. A small float was attached to the end of the tether and released. I then proceeded to move away from the crab until no signal could be detected. The crab was released with transmitter only on confirming that the signal could be detected up to 100 m from the crab. This ensured that locating the crab could be done fast and efficiently each day and long periods were not spent searching for the crab.

Crabs were tracked at 06.00 h each day to detect whether there was any change in location over 24 h. Each tag was detected by setting the receiver to scan the 5 tag frequencies automatically with the hydrophone pointing in one direction (Table 5.1). Once a tag was found, the receiver was set to manual and the tag detected within a few metres. As the water was deep at Site 1 (> 2 m), the tag was not seen while Site 2 was shallow and on most occasions, the tag could be seen sitting above the substrate while the crab was buried. After detection, the location was noted with a GPS.

All tracking points were recorded on aerial photos generated in Arcview supplied by Orthophotos, Roger Dwyer & Associates, Coffs Harbour through the NSW Marine Parks Authority, Solitary Islands Marine Park.

Plate 5.2. Receiver and hydrophone used to track crabs

5.3.4 Environmental measurements

The initial movements by each crab over the first day may be a crab response to release or the direction of the water flow as crab released with the tethers (Section 5.3.3) seemed to move away from the boat and did not bury into the substrate. To lessen the likelihood of crabs moving large distances on release due to a "shock" response to being released or from the high water flow, each crab was released at 06.00 h each morning just before sunrise (6.18 am) and to coincide with when the water flow was at its smallest flow during the change of the tide. On the first release date at Site 1, the tide was low (0.21 m) at 04.20 h with the water movement heading downstream towards the mouth of the estuary. The maximum and minimum tidal movement during this period was 2.03 m and 0.21 m on the release date. At the second release date (Site 2) a high tide (1.58 m) occurred at 06.31 h with the water movement heading upstream. The maximum and minimum tidal movement was 1.81 m and 0.34 m on Day 5.

Temperature and salinity was measured each day at all release locations (Section 3.5) while the substrate was sampled with a benthic grab to gain an estimate of substrate type that crabs are living in at each location point (1- sand/silt, 2- seagrass or 3- other). The location across the estuary of where each crab was caught was noted (1- left, 2- middle or 3-right) and water depth was taken at every tracking point.

5.3.5 Statistical analysis

A univariate general linear model of "distance" versus "Site" (fixed), Day (fixed), Tag(Day) (Random) was used to test the null hypotheses of no difference in the average daily movement between the two release sites.

Paired t-tests were used as the same crabs were released in both sites to firstly, test the hypothesis of no difference in the total distance moved over the 7 days between sites and secondly, the hypotheses of no difference in the total distance from the initial release site at the end of the 7 days tracking.

Water quality variables of temperature and salinity were compared to support the null hypothesis of no difference in water temperatures and salinity between sites within and among days. The water quality was analysed by "Areas" nested within "Sites" and "Sites" nested within "Days". Significant effects were then investigated using *post hoc* Tukey's (HSD) tests to compare means among sites to determine whether there was a significant difference between sites or days.

To test the null hypothesis that there is no association between "Site" and "Substrate" (seagrass, sand) and secondly "Site" and "Position captured" (left, middle, right) within and between sites a χ^2 square analysis was conducted. Firstly, I wanted to know if there was a difference in the number of crabs recaptured between seagrass and sand habitats in the same site and whether this trend continued between sites (i.e. were more crabs caught in sand habitats at Site 1 or seagrass habitats at Site 2). Secondly, I wanted to determine if there was a difference in the location where crabs were caught across the estuary within and between sites (i.e., crabs at Site 2 were more likely to be found at any site across the estuary while crabs at Site 1 were more likely to be located along the left side of the estuary.

5.4 Results

5.4.1 Water quality.

During the study, there was a significant (site x day) interaction for temperature ($F_{7,47} = 7.824$, $P < 0.0001$). Comparison of means tests showed that temperatures were higher at Site 2 in days 1 - 2 and 6 - 8. There was no significant difference in salinity between sites each day ($F_{7,47} = 2.281$, $P < 0.0528$). The average temperature was 24.6 °C (Site 1) and 25.7 °C (Site 2) while the average salinity concentration was 32.5 ppt (Site 1) and 33.0 ppt (Site 2) (Figure 5.2).

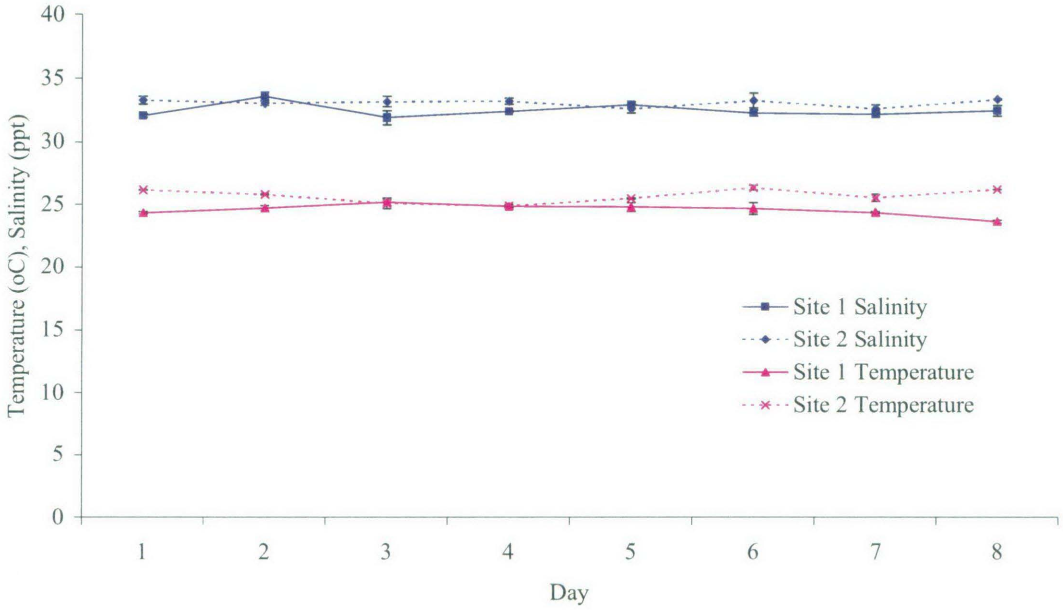

Figure 5.2. Average (± SE) salinity (ppt) and temperature (°C) readings recorded at 80% water depth at each site over the 7 day tracking period.

5.4.2 Tag retention

Each crab collected showed no visible signs of stress during their one week hold over period in tanks before release. All crabs ate daily and no food remained the following morning. All crabs moved around the tank freely although when they buried in the sand substrate the tag remained visible. No tags were lost during the hold over.

5.4.3 Crab activity

Daily movement

All crabs on release settled in the substrate within 10 m of the release point. The average daily movement of crabs was significantly further at Site 1 (114 m) than Site 2 (34 m) ($F_{1,69} = 18.97$, $P < 0.0001$, Plate 5.4; Figure 5.3, Figure 5.5). There was no significant difference in daily distance moved within sites between crabs ($F_{28,69} = 1.19$, $P = 0.314$). Trends indicated that crabs moved increasingly shorter distances over time after release in Site 1 while the average distance did not vary between days at Site 2 (Figure 5.4). The maximum distance travelled in 24 h was 500 m at Site 1 and 125 m at Site 2 while the minimum distances at each site were 10 m (Site 1) and 0 m (Site 2). No crabs returned to the same position as the previous day at Site 1 while Crab 2 (days 3 - 4 and 5 - 6) and Crab 4 (days 0 - 1) at Site 2 remained in the same position for two consecutive days. All crabs at Site 1 moved large distances before settling within an area with consecutive small movements while at Site 2, crabs moved relatively small distances compared to Site 1 (Plate 5.4).

Total distance

The average total distance travelled during the 7 days was significantly greater at Site 1 (558 m) than Site 2 (135 m) ($t_4 = 7.44$, $P = 0.0017$). The greatest distance travelled in 7 d was by Crab 5 at both sites which moved 1260m (Site 1) and 375 m (Site 2) and minimum distance was by Crab 4 which moved 600 m (Site 1) and Crab 2 which moved 60 m (Site 2) (Figure 5.6)

Plate 5.3. The location of release points and sites for each crab in the Corindi Estuary. Boxed areas indicated sections located in Plate 5.4

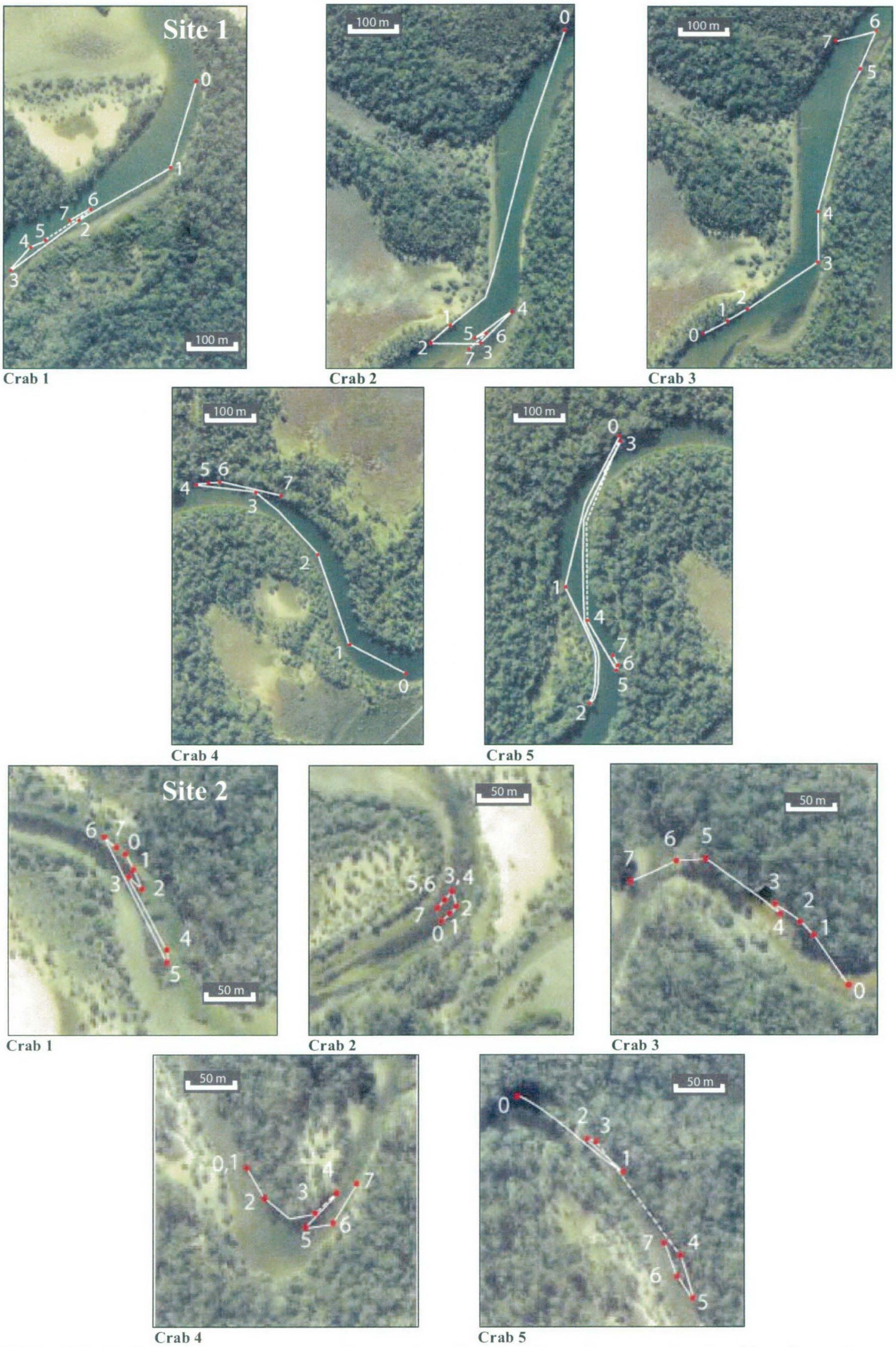

Plate 5.4. Daily crab movement patterns at each site. (0 = release point, 1 = Day 1, etc.)

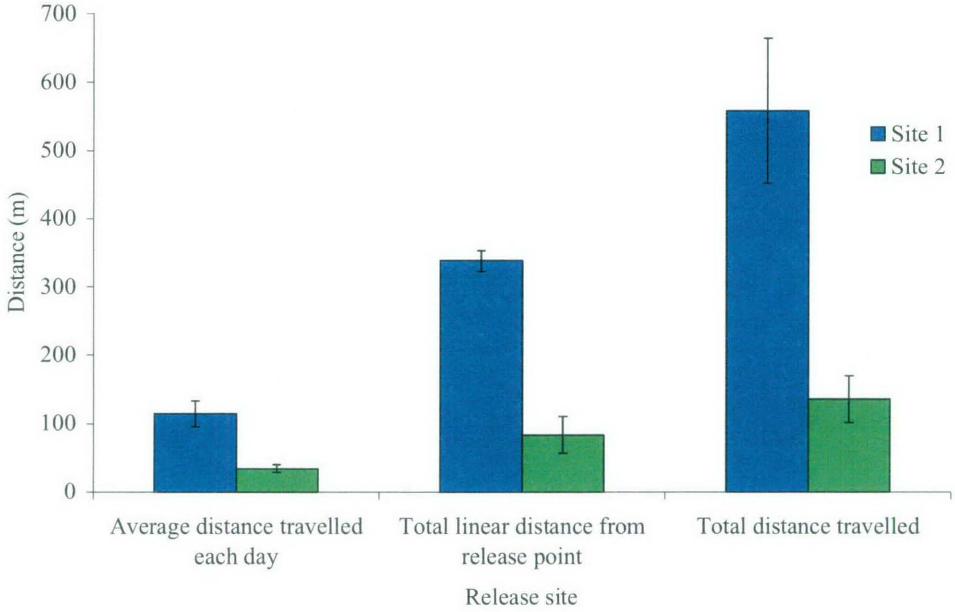

Figure 5.3. Difference in movement (± SE) (daily, total distance from release site and total distance) characteristics of crabs released at each site.

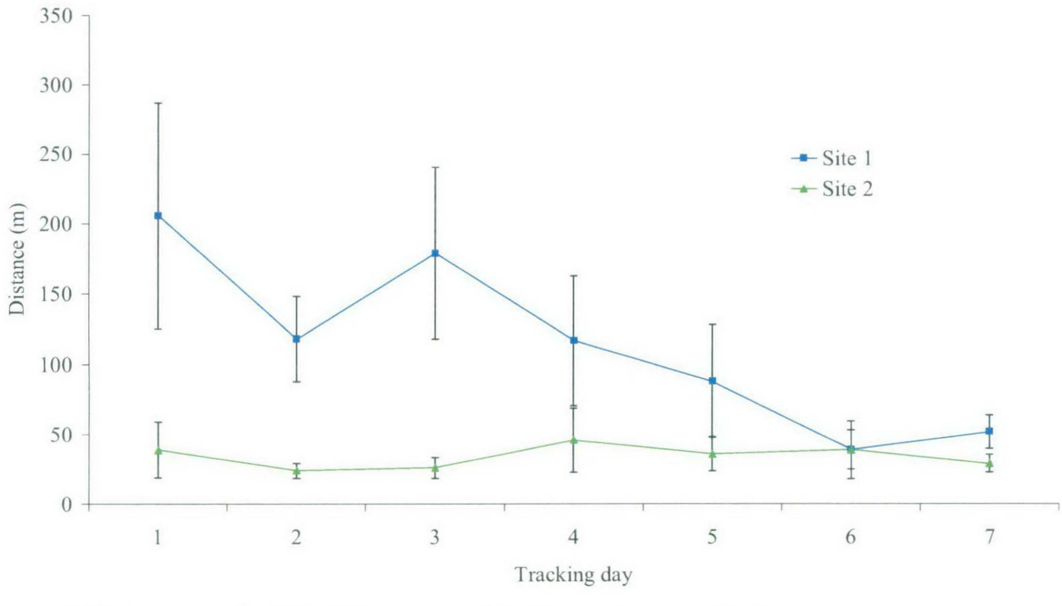

Figure 5.4. Average (± SE) distance travelled by crabs at each site.

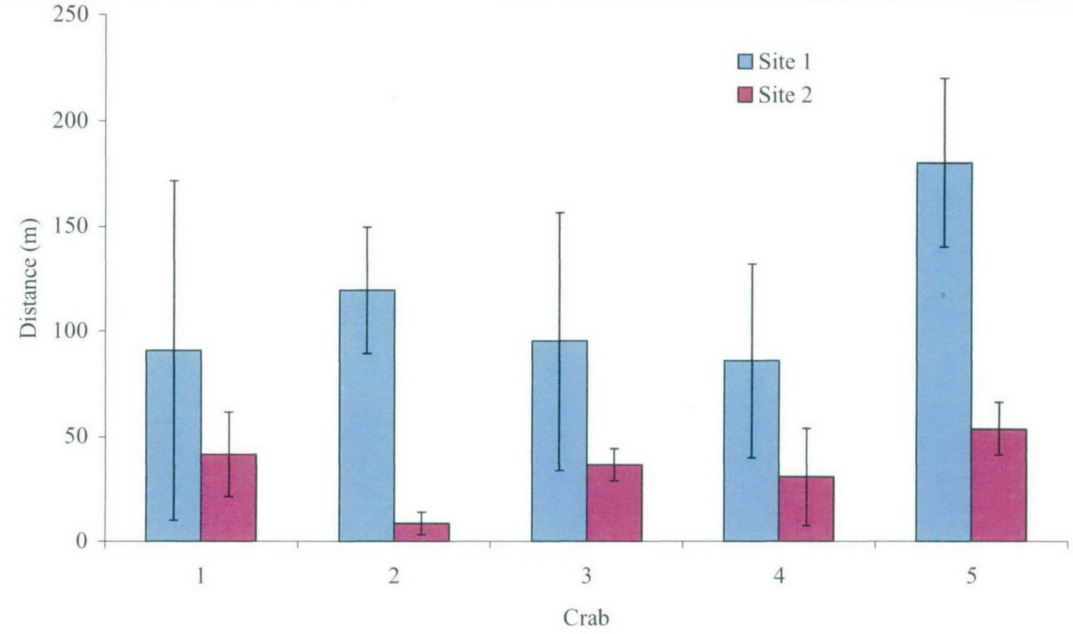

Figure 5.5. Average (±SE) distance travelled daily by each crab over 7 days.

5.4.4 Dispersal from release site

The average distance from the release site over 7 days at Site 1 (338 m) was significantly larger than Site 2 (83 m) ($t_4 = 5$ $P = 0.0075$) (Figure 5.6). The maximum distance from the release site was travelled by Crab 3 at Site 1 (535 m) and Site 2 (235 m) while the minimum distance from the release Site was travelled by Crab 1 at both sites (325 m - Site 1, 10 m - Site 2) (Figure 5.6).

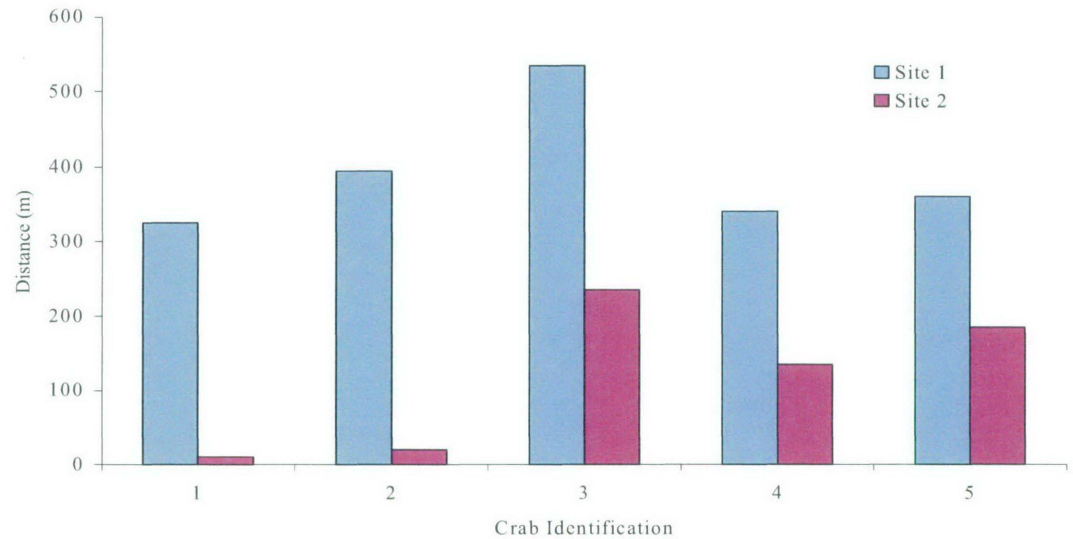

Figure 5.6. Total distance moved by crabs from their release site after 7 days.

5.4.5 Location

No crabs were found in the middle section of the estuary at Site 1 (Plate 5.4, Figure 5.7). Crabs moved across the estuary at some period, as four of the five crabs at Site 1 were located on the adjacent bank at least once during the seven days. Crabs at Site 2 were more likely to be found in the middle (10 days) or right hand side (21 days) of the estuary. χ^2 square analysis suggested that there is an association between site and location across the estuary each day (χ^2 25.82, df 2, P = 0.0000). It was more likely that crabs would be found on the left side but never in the middle at Site 1 and on the right hand side and the middle at Site 2.

Crabs may have individual-specific preferences where they forage as Crabs 1, 2 and 3 were found in *Zostera* beds while Crabs 4 and 5 were found in sandy substrates at both sites. χ^2 square analysis suggested that there is an association between site and substrate (χ^2 13.03, df 1, P = 0.0003). It was likely that crabs would be found in sand habitats at Site 1 and seagrass at Site 2.

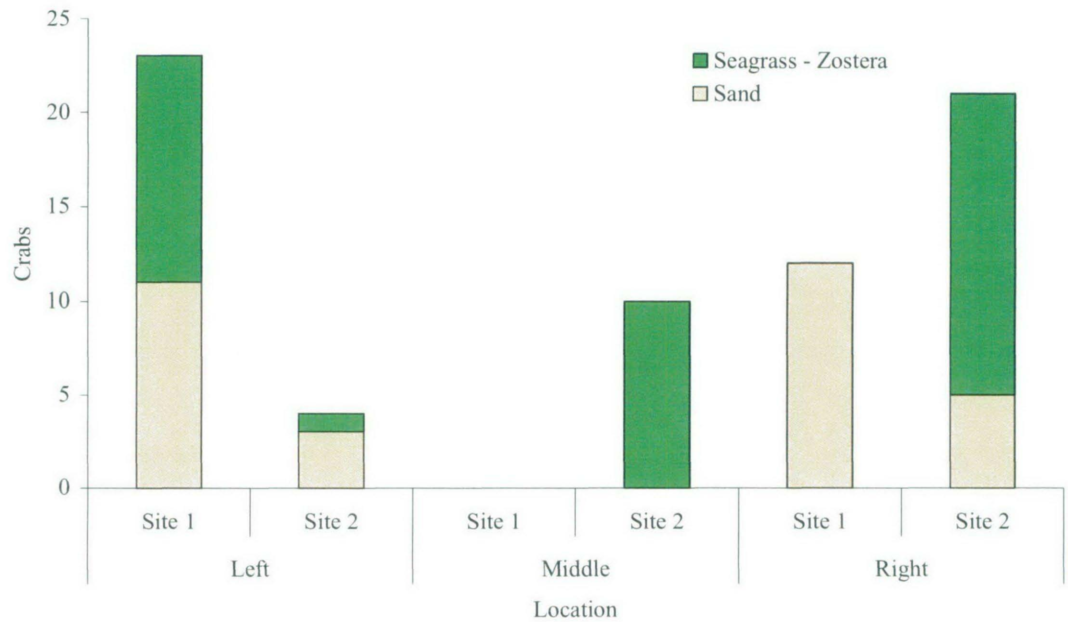

Figure 5.7. Location of where crabs where caught in each site (left, middle or right bank of estuary) and the substrate type crabs were located in (sand, seagrass).

5.5 Discussion

5.5.1 Maximizing fisher benefit

Local area depletion and slow replenishment is likely to occur if fishing were permitted in the current Sanctuary Zone at Site 2. The small short-term movement patterns of mud crabs suggests that the current zoning scheme may not be as effective as it could be in terms of creating spill-over of crabs from the Sanctuary Zone. As I only monitored five crabs for 1 week, this is very much a preliminary conclusion. However, each crab released in the Sanctuary Zone (Site 2) did not move large distances. In a study of mud crabs in a South African estuary, Hill (1978) found similar small movement patterns of crabs where the maximum distance moved was 800 m over 24 hours while the average daily movement was 461 m. Hyland *et al.* (1984) also found that crabs in a small creek leading into Moreton Bay, Queensland, Australia, moved on average 151 m after 5 days, which was similar to this study for Site 2. Movement patterns in this study may have been different if external forces such as floods (Section 4.4.4) or migrating females (Hill 1994) were occurring. These external forces cause crabs to move downstream towards the mouth of the estuary. This suggests that if intensive fishing pressure occurred in these fished areas, local depletion of stocks may occur, as there are limited numbers of crabs moving large distances from the protective areas to replenish fished ones.

The current Sanctuary Zone border minimises fisher benefit because of the small movement within this site. As a large sandbar is located at the Sanctuary Zone border (Figure 5.1 and Plate 5.3), it may be unlikely that crabs would leave the shallow seagrass-dominated Sanctuary Zone to move downstream. This may be why there was minimal exchange between Sites 1 and 2 (Chapter 4), as resources in the Sanctuary Zone were optimal and crabs did not need to move across the large sandbar to enter the main channel areas. Having the Sanctuary Zone as part of the main channel system would be more affective for fishers as crabs in this site moved further. It would also be more likely to provide spill-over across a Sanctuary Zone border into a fished area and it would link the downstream Sanctuary Zone site at the mouth of the Corindi Estuary. More importantly due to the potentially small movement of crabs into the fished area from the current Sanctuary Zone, the acceptance and tolerance by fishers to not catching crabs will drop leading to compliance problems.

As crabs in the deep channel area of Site 1 moved further they would be more susceptible to capture than those found in the shallow areas of the Sanctuary Zone if both areas were open to fishing. As crabs at Site 1 moved further each day, were the furthest away from their release site and travelled the furthest over the 7 days, they are more likely to encounter a trap and be caught by fishers.

5.5.2 Foraging behaviour and habitat utilisation

Large daily movements by crabs may be in response to resource allocation and food availability (Hill 1978). Movement seemed to alternate between brief long journeys followed by several days of small movements. Crabs may have been foraging during these small movements before moving onto other food sources. In the Sanctuary Zone, crabs moved less each day and searched small areas. In a study in Chesapeake Bay, USA, Wolcott and Hines (1996) suggested that in areas where food sources are patchy, the blue crab (*Callinectes sapidus*) would move further until a source is found. They found that the blue crab moved rapidly for up to several kilometres and then foraged while moving in small areas, similar to the activity of mud crabs. The attraction of blue crabs to food sources was proven by a field enclosure experiment where areas with and without food sources were used to determine where crabs would forage. The food-rich areas attracted crabs significantly more than areas without food (Wolcott and Hines 1996). As crabs moved long and short distances during this study, this may have been in response to available resources.

As there were few intertidal zones for mud crabs to forage in at each site, individual mud crabs showed discrete habitat preferences. Three of the five crabs were predominantly found in seagrass (*Zostera*) at both sites while the other two crabs were found in sand. Toole (1980) suggested that fish use intertidal areas for protection from predators, for minimising intraspecific competition and for maximum feeding efficiency. There were some large intertidal areas located at the bottom end of the estuary downstream of where crabs were released but each bank predominately consisted of narrow (2 m) intertidal areas. Each crab had the opportunity to move downstream to these intertidal areas but none were ever found adjacent to these banks when located each morning. Further research tracking crabs at night and day may indicate that there is variation in habitat preference between day and night. It would be evident if these crabs were using the intertidal areas as they may settle adjacent to them during the day before entering these areas again at night.

The structure of the intertidal zone (e.g. vegetation density) is a limiting factor determining the extent to which mud crabs move in an area (Perrine 1978). This may have been why mud crabs moved smaller distances at Site 2 which was dominated by *Zostera* across the channel. In a study on mud crabs on the Island of Ponape, Perrine (1978) found that mud crabs were restricted in their movement in areas of dense mangrove growth and it was the intertidal flats devoid of mangroves which provided the ideal habitat for foraging. Where extensive intertidal areas existed that were covered by mangroves, crabs were restricted to the channel areas. Only 9 of 233 crabs he caught and recaptured had moved away from their original release point. As no crabs were found in the intertidal zones during this current study, this may have been in response to predation threats as most predators such as fish and birds utilise these types of areas for foraging and predation (Toole 1980). Mud crabs may be targeted by some fish and bird species in these areas as on occasions the Blacknecked Stork *(Ephippiorhynchus asiaticius*) was seen foraging in the intertidal flats and catching juvenile and subadult mud crabs.

Deep channels associated with small intertidal zones restrict mud crabs in their distribution at high tide with limited time in the intertidal zone. However, Hyland *et al.* (1984) found that mud crabs will move large distances to feed on adjacent intertidal flats to compensate for the small intertidal zone. This large movement occurred at Site 1 but was restricted to the channel areas only. As each crab in this site was never found in the middle section of the estuary during the chosen tracking period, the greatest section of the estuary to forage may have been the edges where food sources were being channelled along the edges or being caught in the *Zostera* beds. Alternately, crabs may have different movement patterns during the day where only constant tracking would determine if they spent time in other sections across the estuary.

Different size classes of mud crabs prefer different habitats. While this study was undertaken during mid summer and adult and sub adult crabs were used it was expected that crabs would be found at some point over the 7 days in the intertidal areas. In a study in Deception Bay, Queensland, Australia (Hill *et al.* 1982) found that adult crabs dominated deep-water habitats and invade the shallows in the warm months while sub-adult crabs feed in the shallow intertidal zone most months except in the coldest weather during winter while juveniles inhabit protected areas such as mangroves and seagrass beds. These protected areas such as seagrass are dominant in the Sanctuary Zone and may aid in the development of juvenile crabs while protecting larger individuals. All crabs were found in the channel areas during the study suggesting that either crabs do not frequent these intertidal areas in the Corindi Estuary or they have moved out of these areas once tracking has started during morning tracking periods.

5.5.3 Threat from fishers

There were no visible signs of other traps within Site 1 during the sampling, but that is not to say that trapping did not occur at other times. As some traps were located about 1 km further upstream from the Crab 5 release site, the bait odour from these traps may not have been strong enough to carry in the current to entice the tagged crabs to move up towards them even though the crab did move in that direction for the first two days. No fishers reported catching a tagged crab.

All crabs that were released were caught in traps or scooped with a net if crabs were visible at the end of the 7 days' sampling within 1 hour of detecting the crab. This suggests that if areas are reopened to fishing any crab that is near a trap is susceptible to capture and stocks may become depleted quickly. This has design implications for marine park managers. If protected areas are opened too frequently, most crabs may be removed as they are faced with an excessive amount of traps to pass by. In a study on Bramble Reef, Great Barrier Reef Marine Park, Coral Trout (*Plectropomus leopardus*) populations were protected and then opened to fishing. After 12 weeks of fishing 80% of legal sized coral trout had been removed (Russell 1998). This type of scenario may occur with mud crabs if areas previously protected were open to fishing (Section 4.4.2). It may take some time for stocks to build back up after depletion and longer for spill-over to occur. A design that does not have periodically opened and closed seasons would be most effective at preventing crab stocks from being depleted. This outcome increases the chance of maintaining a stock size while providing regular spill-over of individuals if the sanctuary area is selected in an area which provides spill-over.

5.5.4 Problems of tracking

The data collected provided a small pilot study analysis of movement patterns across two sites used in the main trapping experiment (chapter 4) and support where the main sources of recruitment for the fished zone may come from. This primarily only gives a preliminary indication of what crabs do at that time of the month only and this could be different each month of the year when food, temperature or salinity may affect movement.

Telemetry provides a useful tool to detect short-term movements of mud crabs in estuaries of the SIMP. It enabled detection of fine scale movement patterns that would have been impossible to detect with catch and release tagging studies. While the information gathered is beneficial, the cost of setting up the project (A$5000) and potential loss of telemetric tags in a fishery places restrictions on where tagging could occur. If tagging occurs where fishing is active, there is the potential for tags to be taken by fishers. This highlights the importance of good public relations between fishers and authorities conducting the research to prevent tag loss.

Future studies should look at replicating this design across estuaries. It would also be beneficial to use for specific events such as the movement of female crabs and movement after a flooding event.