4.4 Discussion

4.4.1 Sanctuary zones a panacea?

Support for future management

The main aim of this research was to assess the use of protective zones in management of the SIMP by detecting differences in CPUE and size classes of mud crabs caught in fished and unfished areas within the Wooli and Corindi estuaries. As there were significantly more crabs of all size classes in the Sanctuary/Refuge Zone (unfished) than the fished Recreation Zone in most months in the Wooli and Corindi estuaries prior to the zoning change, the results support the use of protective zoning schemes as a management tool. These schemes appear to be protecting mud crabs from exploitation. This type of information will help justify and guide future management decisions (Agardy 1995; Kelleher 1999), especially for estuaries within the SIMP and other NSW marine parks. As each estuary is relatively small and sites were close to each other, it supports the hypothesis that zoning schemes seem to be the main factor affecting the abundance and size class levels.

Similar results have occurred across the world where marine protected areas restricting fisher access have led to increases in abundance and size of targeted species (Cole *et al.* 1990, Johnson *et al.* 1999). In a study conducted in the Daintree and Moresby estuaries in northern Australia, the abundance of large male mud crabs (*Scylla serrata*) was higher in the Moresby no-take reserve than the surrounding fished area (Rudkin *et al.* 2003). It would be expected that similar female abundances between sites would occur as females are protected from being taken in the State of Queensland. Although they found differences between fisher-targeted species, Rudkin *et al.* (2003) did not sample before the area became a no-take reserve meaning that differences may have occurred between the no-take and fished sites before the protection. Rudkin *et al.* (2003) also only sampled over a two-week period during winter in each estuary, minimising their ability to detect temporal differences.

If estuaries within the SIMP remained open to fishing without any protection, catches would have been low throughout each estuary similar to those regularly found in the fished area. Leaving estuaries open to fishing is thus potentially detrimental to future mud crab stocks leading to even smaller catches in the future. It was the lack of management that led to wild

stock declines of mud crabs in a Philippine Estuary (Cowan 1984), while Kosuge (2001) suggested that zoning with different levels of fishing were required to protect overfishing in the Matang Mangrove Forest, Malaysia. It appears that the early intervention by the NSW MPA through the use and development of protected areas within the SIMP has ensured mud crab stocks have not been overfished to the point of significant population declines.

Natural variation in abundance

Even though protected areas in each estuary had more crabs, there was substantial variation between estuaries. Other studies on mud crabs have also found high temporal and spatial variability among catches (Heasman 1980; Rudkin *et al.* 2003). Catches at Wooli were larger than Corindi possibly due to the location of the Sanctuary Zone borders and the habitat surrounding these areas. As the zone border at Wooli is 7 km further upstream than at Corindi, the greater habitat area in fished and unfished zones at Wooli may support larger quantities of crabs. At Corindi, the fished area is situated in the lower estuary near the mouth. This area is dominated by sand flats with few mangroves lining the bank while the habitat at Wooli consists of mangrove-dominated channels and muddy substrate. Habitat use by mud crabs varies between the different stages of their life cycle (Hill *et al.* 1982; Hyland *et al.* 1984) with most of their lives being spent in mangrove habitats. They only leave these areas for spawning and the developmental stages of their life cycle (Hill 1994).

It would be unlikely that large numbers of crabs would reside in the lower section of the estuary if habitat requirements were not optimum as the distribution of estuarine fish is linked to food availability and habitat preferences (Sheaves 1992). The abundance of available prey in the lower estuary may also influence where mud crabs forage and determine the carrying capacity of regions. For example, the blue crab (*Callinectes sapidus*) occurs in higher abundances where food such as clams is plentiful (Wolcott and Hines 1996). As mud crabs eat slow moving and sessile benthic invertebrates (Hill 1976), these food sources may be more plentiful in the upper estuary in muddy substrates resulting in higher densities in this region (*pers. comm.* Beth Hastie, National Marine Science Centre, Coffs Harbour, 14th June 2002). Juvenile mud crabs eat plankton, slow-moving benthic molluscs and crustaceans while adults primarily feed at night on bivalves and gastropods, small crabs (Grapsidae and Paguridae) and polychaete worms (Hill 1976; Fielder and Heasman 1978; Hill 1979).

Variability in catches among months may have been influenced by water temperature and quality. Temperature, salinity and light are limiting factors affecting mud crabs (Hill 1974, 1980; Bhuiyan & Islam 1981; Davenport & Wong 1987; Parado-Estapa & Quinito *undated*). In tropical environments where temperature fluctuations are small, there is little variation in mud crab activity. However, in temperate climates, the activity of mud crabs is seasonally dependent. Hill (1980) conducted laboratory analyses on mud crabs and found that the duration of emergence, movement and feeding varied at different temperatures. Mud crabs emerged consistently at temperatures between 12 - 25 °C. The proportion emerging at any one time was highest at 20 - 25 °C but this decreased as temperatures fell below 20 °C. At temperatures between 20 - 25 °C, the duration of emergence and feeding time was similar, and thereafter decreased as temperature decreased until feeding ceased at 12 °C. Leffler (1972) found that feeding rates declined in the portunid crab *Callinectes sapidus* where feeding and movement ceased at temperatures below 14 °C. Veerannan (1972) also found that at 16 °C the metabolic rates of mud crabs were 50 - 60% of those tested at 27 °C. This suggests while there was still a difference between fished and unfished areas during periods of cold water temperatures in May to August, differences in CPUE were smaller due to the lower number of actively feeding crabs during this period. This underestimates the total number of crabs in the population at that time period but indicates the number of crabs that are still foraging (Hill 1980). This effect cannot be confused with overfishing. It is likely that only summer sampling periods are required to determine differences in abundance between fished and unfished areas. This would be valuable for long-term monitoring programs to save time and money.

Variation due to fisher activity

Temporal variation from fishing pressure also contributed to the variability in catches within the fished zone, and to some extent, the Sanctuary Zone during the study. As public holidays occurred during late December and January and again in short, two-week periods in April, July and October each year, a significant decline in catches in the fished areas during this period indicates that crabs are being removed by fishers prior to, and during, sampling. I attempted to avoid placing traps within 100m of fishers traps during the survey to minimise the competition between recreational fisher traps and the research traps. This could only be enforced on setting and lifting the traps, yet it was rare that fishers went near the research gear as they knew what was required through the research information sheets and talking directly with them. It was impossible to quantify fishing pressure that had been taking place in the areas prior to

sampling, so any fishing pressure directly before monthly sampling could result in lower catches during sampling.

Size class variation

While protected areas support more crabs, the average size of crabs caught in the Sanctuary Zone and fished areas varied between estuaries. At Wooli, the average size of crabs was significantly higher in the protected sites than the fished area but there was no difference among sites at Corindi before the zoning change. After the zoning change, the average size at the fished Site 3 was significantly higher than Site 1, which had been opened to fishing. The larger sizes at the fished Site 3 (Corindi) before and after the zoning scheme could have occurred for several reasons. A large proportion of crabs caught in the fished zone at Corindi were large females. As catches occurred during the warmer months, these crabs were probably moving down to the estuary mouth on their spawning migration and are vulnerable to capture. Rudkin *et al.* (2003) also captured females of which some were berried in a fished site that leads directly to the sea. They concluded that it might have been the beginning of the spawning migration by gravid crabs to offshore areas, leaving them vulnerable to capture. However, the extent of females migrating at Wooli is masked by the large number of male crabs that are caught within the fished area due to the higher spill-over of male crabs at Wooli than Corindi. The small size of crabs at the fished site is probably due to the selective harvesting of larger individuals by fishers as the average size of crabs that were present in the fished zone were just above the legal size of approximately 130 mm carapace width. This poses the threat that larger crabs, and more importantly large females, are being removed from the population as they move downstream on their way to spawn offshore. A more detailed analysis of problems associated with females moving through fished areas while migrating is in Section 4.4.4.

It was hoped that the size class distributions would provide the best representation of the differences in population structure between fished and not fished areas. In this study, there was no difference in size class distributions between sites within estuaries as all sites peaked at the 125 mm or 135 mm size category. I hypothesised that distributions would be skewed to larger crabs in the unfished sites compared to the fished sites and that there would have been similar numbers of crabs in fished and unfished sites in the size categories below the legal length limit (e.g. size class 105-125 mm) as these are under the legal size limit in NSW. In these smaller size classes in each estuary, there were still significantly more crabs at the unfished sites

suggesting that undersize crabs are being removed from the fished areas. It seems that the exploitation of legal-sized crabs continues until fishing effort outweighs the catch. Fishers are then keeping smaller crabs because they cannot catch legal size crabs. This poses a threat to the fishery. However, at Wooli, the fished area has a large percentage of small crabs that, if they remain and grow in the same area, will sustain the fishery into the future. For crabs to be legally taken by recreational fishers they have to have a carapace length of 85 mm or carapace width of 128 mm (Heasman 1980). With this restriction, it seems that there are currently few crabs that can be taken for harvest by recreational fishers each month. This is especially true for the zoning scheme at Corindi where captures only occurred during summer. Therefore, it is likely that undersize crabs would be retained by fishers as there is less chance of catching legal size crabs and when they did, it was likely to be a large female crab on migration.

I predicted a higher percentage of adults (>150 mm carapace width) in each estuary as Heasman (1980) and Hill *et al.* (1982) found that adults dominated the deep subtidal waters, which were targeted in this study. As the Wooli and Corindi estuaries are dominated by channel, rather than large intertidal areas, there would be less zonation of juveniles, sub-adults and adults. It is possible that the *Zostera* beds which line the channels in each estuary are the important habitat of juveniles in the absence of large intertidal areas. There is only one mangrove swamp flat at Wooli between the two estuaries. This area may be an important part of the ecosystem and has been identified as a priority area for protection because of this study. This area may be a nursery for juveniles and sub adult crabs (Heasman 1980).

4.4.2 Re-opening protective zones - management decisions causing stock declines

The strategy used by NSW Marine Parks Authority to open previously protected areas in the Wooli and Corindi estuaries is not an effective approach of changing zoning schemes. If the original objective of closing these areas was to provide ecologically sustainable use of fish and marine vegetation (MPA 2001) then preventative measures must be put in place to stop the rapid decline of species if areas are reopened in the future. While only the decline in mud crabs was assessed, it is possible the same effect could have cascaded through other recreationally targeted species such as Sand Crabs (*Portunus pelagicus*), Flathead (*Platycephalus fucus*), Whiting (*Sillago ciliata*) and Bream (*Acanthopagrus australi*) once fishing effort was reintroduced.

While BACI analysis showed no significant difference in trends after the change in zoning scheme, it would be misleading to management to suggest that no effect had occurred because the test lacked power (Fairweather 1991) or changes in sites opened to fishing were too sudden to detect changes in trends (Underwood 1991). At Corindi, the F-ratios were close to the critical value for detecting a significant change in trends once the area was opened to fishing and further temporal sampling may have provided a significant result. At Wooli, the limited "before" data resulted in high critical values of F-ratios and little chance the F-ratio was going to be significant. This was the side effect of splitting one of the sites at Wooli in two. NSW MPA must determine the implications of decisions carefully before implementation. If long-term monitoring programs are designed to determine if an impact occurs, then compromising the experimental design will always result in no detectable difference because of the lack of before data. In this case, the NSW MPA compromised the ability to make informed decisions in the future.

This lack of before data was further complicated as the three months prior to the opening were taken during winter. There was high variation among months, leaving it unlikely that a small change would be detected. This occurred because the opening was during winter when few crabs were caught in any site during June and July. Site 4 (UF) continued to catch only low numbers of crabs after the change and differed in its trend to Site 1 (UU) and Site 5 (UU) which increased in abundances as normal during the summer period. There was no interaction between Site 3 (FF) and Site 4 (UF) after the zoning change. Any result was also going to be

masked by the floods that occurred in each estuary seven months after the zoning change. Once floods occurred, all sites in each estuary behaved similarly with similar catches occurring in each of the six months after the flood in February 2003.

The NSW MPA reopened protected areas as part of the 5 year rezoning strategy in August 2002 after they had been closed since the marine reserve was established in 1991. Heavy public lobbying to have these areas reopened to fishing saw it approved as part of the new zoning scheme. In an attempt to minimise the impact of fishing pressure in areas about to be opened, restrictions on crab trapping gear were introduced in the Wooli Estuary. This gear restriction prevented the use of wire crab traps and only allowed netted dillies in a 14 km section of the estuary, of which 13 km had been previously protected as Sanctuary Zone. While this was a positive move by the NSW MPA, it should have been introduced at Corindi to prevent overfishing in the early stages of opening the new area in that estuary. Netted dillies are primarily used during the day as fishers work them for short periods of two hours or so, resulting in potentially fewer crabs being taken. Rarely are they left overnight as crabs can tear the material and escape; several crabs were found during my survey with netted dilly material on them. While the effect of having no wire traps in an area did not seem to slow the fish down effect at Wooli where high fishing effort diluted gear restrictions, it might have had a different result at Corindi. Corindi did not sustain the same fishing pressure at the opening of the new zoning scheme as found at Wooli, with low fishing effort spread evenly throughout the estuary above the old fished area.

The fast removal of crabs at Wooli occurred for several reasons. Firstly, there was higher fishing pressure during this period at Wooli than Corindi meaning a greater chance of crabs being captured. The reopened area at Wooli was 13 km long but access upstream was hindered by a rock bar 3 km upstream from the previous zone border resulting in 10 km of estuary remaining potentially untouched by fishers (Chapter 6). With such higher fishing pressure of up to 45 traps per day over the first 6 months in 3 km of estuary, this increased the chance that the previously protected crabs were caught within months of introducing fishing. At Corindi, there is no structure restricting access upstream and fishers had access to 12 km of estuary once the protected area was opened to fishing. These fishers were in smaller numbers with 25 traps being used during the first month after reopening. Only small numbers of traps (5 - 15 traps) were used from September to November before high fishing pressure (32 - 84 traps), not seen

before in the estuary, occurred during December and January. This effort was spread over the entire 12 km of the new section of the estuary. Even with such low fishing effort after the zone change, mud crab numbers dropped dramatically within months suggesting that crab populations are vulnerable to fast reductions even under low fishing pressure.

The decline of crabs in the sites opened to fishing was similar at Wooli and Corindi where high fishing effort reduced crab numbers and the average size of crabs in opened fished sites immediately after the zoning change in August 2002. This occurred within one month of the area opening to fishing after 12 years of protection. This trend also occurred on Bramble Reef on the Great Barrier Reef where the number of legal sized coral trout (*Plectopomus leopardus*) declined by 60% in eight weeks (Russell 1998) and 100%, two years after reopening an area to fishing (Ayling and Ayling 1997). The timing of the opening helped protect mud crabs to some extent as fewer crabs feed during winter than during summer when all crabs in the area would be active and susceptible to capture (Hill 1980). For this reason it was expected that catch per unit effort (CPUE) would be similar to the protected areas until November and December once crabs had finished moulting and water temperatures were warmer leading to higher numbers of crabs foraging (Hill 1980). This did not occur and one month after the change catches in the previously protected area resembled those from the fished area. High fishing pressure focused on the newly opened area at Wooli and effort continued until 7 months after it reopened, suggesting that resources had diminished (Chapter 4.4.4). In contrast, at Corindi, there was little fisher effort after the area was opened to fishing but the area was still reduced in mud crab numbers within the same period as Wooli (Chapter 4.4.4). However, while catches at Corindi dropped at the newly fished site it also corresponded to an increase in the number of crabs being captured in the old fished site. This increase in catches at the fished Corindi Site 3 (FF) after 2 years of low captures suggests that, because fishing effort targeted upstream, there were fewer crabs being captured from the population that moved downstream. The source of these crabs possibly spill-over from the Sanctuary Zone border adjacent to this site in the lower estuary.

It was not until 7 months after the zoning change that all areas had similar crab numbers again. This coincided with a major flood in each estuary suggesting that flooding accelerated spill-over of crabs from the protected areas, as they are upstream of the fished sites. This aids in replenishing stocks in the lower reaches of the estuary. Hill (1975) found dead and dying crabs

on the banks of a South African estuary during a period of low salinity whereas in Australia, crabs were found crawling out of the water and up the banks after a major flood in February 2001 in the Richmond and Macleay Rivers on the North Coast of NSW (Macbeth *et al.* 2002a, 2002b). No mortality occurred during this study despite prolonged periods of low salinity after high rainfall events. However, crabs showed the greatest movement patterns in a downstream direction during floods, possibly as a response to the changing salinity levels or to some associated factors. Mud crabs can survive in salinities from 2 - 42 ppt and show no preferences between salinities in this range (Davenport and Wong 1987). Therefore, changes in salinity concentrations from flooding should not directly affect mud crabs to a point where they are forced to find higher concentrations downstream.

Mud crabs have also been caught in low salinities (<20 ppt) after a cyclone event in the St Lucia Estuary South Africa (Forbes and Hay 1988) and sub-adult and juvenile crabs have been seen in creeks inundated with freshwater for the entire wet season in northern Australia (*pers. comm.* Tracy Hay, Department of Primary Industries and Fisheries, Northern Territory Government, 9th August 2002). The only water quality variable that might impact on mud crabs is dissolved oxygen when it reaches levels below 0.4 mg/L. At these levels, mud crabs climbed riverbanks and moved downstream (Macbeth *et al.* 2002a, 2002b). The movement downstream during flooding may also be a response to tracking whatever food source is being pushed downstream. Whatever the reasons, there is a period when crabs are being moved around in the estuary and at least one annual spill-over period occurred where crabs are displaced from the upstream Sanctuary Zones to the lower fished areas. Without flooding, there is the potential of overfishing in the fished sites with minimal spill-over at the zone border. This could potentially increase compliance problems, as fishers would be tempted to take crabs from the protected area. Secondly, if Sanctuary Zones were located in the lower sections of estuaries there would be little chance of crabs moving upstream during these events and providing this annual spill-over to fishers.

Fishing pressure and mud crab gender

Not only does fishing selectively harvest larger crabs, it alters the ratio of male and female crabs. Prior to the zoning change, an association was found between the area crabs were caught (fished/unfished) and gender. In areas where no fishing takes place, there were significantly more males than females while in fished areas similar numbers of males and females were

caught. While this suggests that males are more likely to be caught in traps and removed from the population than females (Section 3.7), it is most likely to be because the not fished areas are downstream of the fished areas. These fished areas have large numbers of female crabs moving through them during their spawning migration offshore. The recaptures of crabs by recreational anglers revealed larger numbers of females were caught in the fished area during summer each year.

Over the 13 month sampling period after the zoning change, it was surprising to find that the gender ratio had changed from almost 1:1 to 2:1 in both fished sites at Wooli and Corindi, while the newly fished sites had not been fished-down in males with the gender ratio actually increasing at Corindi from 1.5 to 3:1. In Moreton Bay, Australia, Heasman (1980) found ratios of 3:1 in commercial catches while Onyango (2002) and Cheeswasedtham (1990) found ratios were 1:1. Cheeswasedtham (1990) found ratios of 1:1 at Khlong Ngao, Thailand, during January to August but few females from September to December. In Heasmans (1980) study, only males were targeted by fishers, so a population where males and females are not exploited, like the current study, would give an even larger ratio, as males would be protected.

One hypothesis of why more male than female crabs are caught is that when large females leave the estuary to spawn, they may never return, leaving the population to consist of smaller female crabs. This may not be the case in my study as there were female crabs caught in the 165 - 195 mm carapace width range in each estuary. This suggests that a return migration is possible after spawning or that these crabs either spawned in the estuary the previous year or did not migrate or spawn at all the previous year.

Opening strategies for zoning schemes

Future opening strategies (direct, spatial, temporal) for estuaries of the Solitary Islands Marine Park were considered to minimise the mass decline of crabs once areas are reopened to fishing at future zoning changes. Strategies were assessed based on their potential effect on mud crabs and the feasibility of having alternative options that fishers could understand as 'the successful management of our recreational fisheries is largely dependent on the voluntary acceptance of fishing rules' (AFFA 2004).

Directly opening protected areas to fishing as a reopening strategy was discarded for use with mud crabs. Results of this study and others (Russell 1998) show that stocks can be depleted in a short period (months) and the benefit of originally closing this area to fishing previously is diminished. The long-term benefit of reopening the area may be essential to the long-term zone design and more important than the transient decline in stocks when the area is opened to fishing. However, it is equally important to maximise the time taken to harvest resources that have been previously protected and not see the results of the previous year's protection diminish as a consequence of not incorporating opening strategies when implementing new zoning schemes. In doing this, it may take pressure off other areas of the estuary by providing a longer period where crabs are available to fishers before stocks are fished too low.

Temporary openings are not recommended due to the small size of the area opened to fishing in each estuary. The Wooli Estuary had 1.05 km^2 and the Corindi Estuary had 0.32 km^2 of previously protected areas opened to fishing at the zoning change. Temporary and spatial zone openings would not be successful on such a small area because mud crabs inhabiting channel areas which are opened to fishing would move within and between the opened and closed areas and be susceptible to capture anyway (Chapter 5). While temporally opening areas would distribute the amount of fishing pressure on the area, it would intensify the 'pulse' pressure during open periods and lead to compliance problems. Compliance and understanding of what areas are opened to fishing would be confusing for users as a large number of fishers using these estuaries are visitors (Byrnes 1997; McDonald 1997), with 76% of people unaware of the zoning schemes in the Sandon Estuary alone (Kuster 1997). This may result in a rise in illegal activity when the area is closed as there are many access points to each estuary which are not signed with Marine Park regulations. Visitors would be unaware of when these areas are opened to fishing.

Direct opening, with gear restrictions, was also considered as less environmental damage may occur if fishing is divided by periods of stock recovery within the confines of this method (King 1995). This was seen as the most effective model to incorporate. As the NSW MPA has already implemented gear restrictions through 'no crab trapping' areas, it is recommended to use this in sections of all estuaries in the SIMP and to restrict trapping using dillies to daylight hours only in these zones. New regulations to be implemented for professional fishers in 2004 will restrict the use of netted dillies to daylight hours only throughout estuaries in NSW (*pers.*

comm. Claudia Jordan, NSW Fisheries, 1st June, 2004). The removal of netted dillies during the night will affect a small portion of recreational fishers that target crabs at night only and a few professional fishers that rarely frequent the estuary anyway. The small loss to them will be offset by the potential increase in crabs that will enter the fished areas each night and be available to a larger range of fishers during the day. As crabs are easily caught during the night and day (Robertson 1989), restricting access at night will not reduce captures to daytime fishers. Not only will this stop illegal fisher activity at night in the upper sections of the estuary, crabs will have the opportunity to move out of Sanctuary Zone and into fished areas without being influenced by traps. These crabs will be able to move further out into fished areas, as there will be no fishing pressure at the zone borders. This method would provide an increase in crab availability to all fishers and not just those that fish at the zone borders.

The use of dillies is the preferred gear type option for the zoning scheme because traps can be "ghost fished" unintentionally by fishers and intentionally by illegal fishers. Lost gear "ghost fishing" increases mortality (Dayton *et al.* 1995; Hall 1999) and by preventing the legal use of traps, it is likely that fewer traps will be lost by fishers or during floods when the traps wash away. Bullimore (2001) found that lost traps continued to catch fish months after the bait had been consumed. Fish that were initially attracted to the bait were trapped until the bait decayed. These fish then died from the lack of food and became the new bait source. This process keeps occurring until the trap material decays, allowing fish to escape. There have been periods during the study when local fishers have had their traps removed by vandals cutting the ropes of their traps at night. Removing trapping altogether in these areas at night will prevent nocturnal vandalism of fishers traps and will reduce the chance of "ghost fishing". It also stops illegal fishers using unmarked, and fishing too many, traps.

If gear restrictions are going to be effective, alteration to fisheries legislation on the number of dillies allowed per person needs urgent attention. In NSW, recreational fishers can each use five dillies (NSW Fisheries 2004). The problem with this regulation is that most families use their full entitlement. A family of 2 parents and 3 children can use 25 dillies. Estuaries of the SIMP are relatively small in area opened to fishing with Wooli being the largest at 2.31 km^2. The current regulation is increasing the fishing pressure in these small estuaries more than would otherwise be the case if Queensland regulations were used. In Queensland, any person over fifteen years of age can have four wire traps or netted dillies, or any combination adding

to four (QLD DPIF 2004). While I do not suggest a change to the number of dillies or traps used in NSW, NSW Fisheries or NSW MPA should enforce that traps or dillies are only used by those over the age of 15 or have a maximum number of dillies per boat.

The use of dillies also restricts the activity of commercial fishers in the estuaries. With new regulations being introduced by NSW Fisheries for professional fishers (*pers. comm.* Claudia Jordan, NSW Fisheries, 1st June, 2004), the fishing effort in estuaries of the SIMP could increase. Gear restrictions may displace effort throughout the estuary. Professional fishers will be allowed to use 10 fish traps and 10 crab traps under different endorsements. For those holding a fish trap endorsement, fishers can currently have 10 netted dillies. With the new regulations, mud crab endorsements will allow 10 traps or 10 netted dillies. A maximum number 10 fish traps plus 10 dillies and 10 crab traps/dillies at any one time will be used if professional fishers have both endorsements. This fishing pressure may be alleviated if fishers using netted dillies are required to use them during daylight hours only under the regulations.

While these restrictions minimise fisher activity, the effects would be highest during times of spill-over to fished areas. The benefit of this spill-over will be short-lived if high fishing effort associated with commercial trapping is combined with high effort from recreational anglers. It is recommended that estuary-specific regulations be enforced by NSW Fisheries so that traps (not netted dillies) are banned from the majority of areas in these small estuaries of the SIMP.

4.4.3 Closing areas to fishing

A tool to increase crab stocks

Using protected areas to recover overfished crab stocks is a successful tool in estuarine management. Areas that were previously fished in the Sandon Estuary showed a significant increase in abundance of all size classes of mud crabs within 2 months of the area being protected. This type of response by targeted species to fishing removal also occurred on Brambles Reef on the Great Barrier Reef where the number of legal sized coral trout (*Plectopomus leopardus*) increased by 300% during the 3.5 y closure (Russell 1998). This increase was magnified by a highly successful recruitment period immediately after the closure on Brambles Reef and the adjacent control fished reefs. However, the cohort of fish on the control fished reefs from this high recruitment period were quickly depleted once they grew to legal size (Ayling and Ayling 1997), while the same cohort on Bramble Reef remained with higher densities during the entire 3.5 year period of closure. In another study, the Japanese government closed off areas for the Zuwai (Tanner) crab (*Chionoecetes opilio*) fishery (Yamasaki and Kuwahara 1990). Scientific catches from the reserve found an increase in crab densities over time suggesting that the reserve was protecting crabs. The closure provided an increase of 10 - 42% in the number of large male crabs in the area.

As two sites in the Sandon Estuary were fished by one commercial fisher and no recreational fishers prior to the zoning change it was expected that the number of crabs at each site would be similar once the zoning change occurred. It was envisaged that the sporadic effort of one commercial fisher over the entire length of the estuary (2.48 km^2) would not have affected the catch significantly. However, there was no reduction in the number of crabs caught at the site opened to fishing while the number of crabs increased twofold at the site closed to fishing 2 months after fishing was removed. This suggests that the fishing pressure exerted by one commercial fisher over the previous 12 years was similar to that by recreational anglers once the area was opened. While the commercial fisher had exclusive access to this area, his fishing effort was having an impact on crabs, which were supposedly being protected by preventing fishing pressure under the original zoning scheme. This type of Ministerial arrangement allowing commercial fishing should not be permitted in the future as it is undermining the

objectives of the zoning scheme implemented by NSW MPA and causes conflict between commercial and recreational fishing sectors.

Commercial fishing effort and seasonal patterns contributed to variation in monthly catches. Prior to the zoning change, there was a period between January and September 2001 where March was the only month in which the two commercially fished sites had significantly more crabs than the fished site. There seems to be large variation among sites during January and February possibly due to the increased fishing pressure by the commercial fisher when some sites were fished more intensively than others. It is likely that the large variation between April and September occurred firstly because the professional fisher may have been targeting this area during this period as the majority of crab trapping was done by the professional fisher in the upper estuary (Kuster 1997) and secondly, because of seasonal variation through annual low catches during June to August.

While there was a significant increase in CPUE in the area protected from fishing, the previously fished site near the estuary mouth showed an increase in crab numbers after the zoning change, presumably because there was little fishing effort at this site once the new area had been opened upstream. This also occurred at Corindi. Fishing was still permitted here but fishers had moved effort into the previously commercially fished only 0.92 km^2 stretch of water in an attempt to catch more crabs. In the previous 2 years before the change, few crabs had been caught in the lower estuary and the ones that did were taken from December to March. These crabs were primarily large females moving offshore to spawn. The reduced fishing effort at this site now provides an opportunity for a larger number of crabs to successfully migrate without being taken by fishers.

Removing commercial fishing caused an increase in the average size of crabs at the protected site while maintaining the same average size at the recreationally fished site. Differences in catches after the zoning change occurred in the size classes above 125 mm with significant differences between 135 - 165 mm. These would have been crabs above the legal size limit of approximately 128 mm. These results confirm that protection does increase the number of larger crabs, as they are not being removed by fishers. As there was no difference in the captures below 125 mm, this suggests that undersize crabs were not being taken once fishing occurred. This was the case for Corindi and Wooli while there was little difference before and

after the zoning change in the number of crab caught in the size ranges above 175 mm at Sandon.

As was the case at Wooli and Corindi, there was an association between area and gender before the zoning change at Sandon but not after. Both commercial fished sites at Sandon had more males than females while the fished site had more females than males captured before and after the zoning change. The small number of crabs that were caught at the fished site consisted of large female and small male crabs leading to the theory that few crabs actually spill-over into this area. This is because it lacks the habitat to maintain high numbers of crabs in the lower estuary. As crabs are mostly found in mangrove habitats (Hill *et al.* 1982; Hyland *et al.* 1984), it is likely that females occur in higher numbers in this area during their spawning migration offshore. As was the case for Corindi, where the zone border was located near the estuary mouth in unsuitable mud crab habitat, there is no other reason that crabs would be found in this area other than if both sexes were displaced downstream into this area after a flood.

The current zoning scheme

The two Sanctuary zones implemented in the Sandon Estuary as part of the zoning change in 2002 may not be effective. While Toumbaal Creek was ideal for protecting crabs in terms of habitat, it was also effective for compliance as the entrance is in view of the local village in the lower section of the estuary. This provides good protection as residents and visitors can report fishers with traps entering this area. However, this area may not be suitable to provide regular spill-over of crabs into the fished area downstream because a large 300 m sandbar is located at the mouth of this Sanctuary Zone. This restricts mud crabs from moving across this bar. Few crabs moved between the northern and southern arms of the estuary and, only after floods were crabs found in different arms. If this was the only Sanctuary Zone in the estuary, problems with over-fishing may occur because of the lack of spill-over in the upper section of the estuary. The use of the second Sanctuary Zone located 4.5 km upstream from the estuary mouth provides another potential spill-over source of crabs at this junction. While no permanent sites were sampled at the junction, there was regularly a high number of traps at the zone border suggesting that spill-over of crabs is occurring as the presence of fishers at zone borders is indicative of this (Gell and Roberts 2002). The benefit of this second Sanctuary Zone is that it reduces the pressure at the Sanctuary Zone at the mouth of the estuary providing opportunity for female crabs to move offshore to spawn without the interference and attraction of traps. It is

also the ideal structure for an estuary by having multiple Sanctuary zones to provide spatial protection as well as distributing fishing pressure over the estuary and not a single point source or "gauntlet".

The future

The response to closures were increases in abundance and the average size of crabs within 2 months of closing the areas to fishing. Therefore, this could be used as a management tool to restock areas if heavy exploitation occurs in estuaries of the SIMP. Areas would not be totally closed to fishing indefinitely for the 5-year period until the next zoning review, but instead periodical closures could be used. As the number of tourists grows, a proactive approach to dealing with this potential impact must be identified. My research has identified a tool that will enable managers to use temporary closures if mud crab stocks become threatened in the future. This will provide interim protection to stocks until permanent zoning schemes can be implemented to alleviate the problem.

If closing areas to improve crab numbers is used it must be considered that, although protected areas caused increases in crab stocks this may not occur if crabs do not frequent the area for habitat reasons. For example, Rudkin *et al.* (2003) suggested that the reason why there was no difference between crab numbers between a fished and no-take reserve in the Daintree River, Queensland, was that historically that area had low catches of crabs. This is possibly related to the habitat type of the area and the low carrying capacity. Therefore, in the estuaries within the SIMP, a protected area in the lower estuary would not provide significant increases in mud crabs unless they contained the muddy substrate and mangroves needed to sustain higher abundances similar to the middle and upper regions of estuaries in this study.

4.4.4 Mud crab movement patterns

Mud crab movement

Spill-over of crabs occurred in random periods that cannot be assigned specifically to any event. However, two periods of highest recaptures by recreational fishers between January - June 1999 and March - June 2002 coincided with major floods in the estuary. During most occasions when floods arrived, there was no difference in captures among sites within estuaries suggesting that crabs move downstream from the protective areas to the fished area during flooding. Tag returns after February 2003 should have been high as this flood caused the highest salinity changes over the study period but there were few fisher tag returns. The lack of tags returned after the flood may have been a result of few crabs being caught, as there was little fishing effort in the estuary in the months after the flood in any estuary. This lack of fishing may have resulted in an underestimation of the number of crabs that are actually pushed downstream during these flooding periods. Alternatively, it may magnify the number of crabs recaptured when floods do not occur because fishing effort is high in targeting the few tagged crabs that may have moved downstream.

Prior to the zoning change in August 2002, the majority (64%) of crabs recaptured by recreational anglers in the Wooli Estuary were caught within 1 km of the Sanctuary Zone border. This suggests that there is little opportunity for crabs to move through these areas as the majority of crab traps were located in this region too (Section 4.4.5). As crabs are likely to enter traps if they come across them (Section 3.7), there would be little movement further downstream. The total number of crabs recaptured by anglers decreased with distance from the Sanctuary Zone border, suggests that while there was spill-over of crabs into the fished area, the benefits were not being received by fishers further downstream. As the Sanctuary Zone is 8 km upstream from the main boat ramp and no public access is available via land to the Sanctuary Zone border, there is little chance that fishers without boats will gain benefits from the Sanctuary Zone.

Once the zoning scheme changed, 31% of recaptures from fishers came from throughout the new area opened to fishing in the left arm of the estuary but the highest (42%) recaptures still came from the Sanctuary Zone border. Fishers would not persist at targeting these areas if they did not believe that larger catches could be taken (Gell and Roberts 2002). The traps at the

zone borders are probably acting as an attractor through their bait odour during flood tides, encouraging crabs to move out of the protected area to find the food source. This itself is a problem at zone borders because as more and more traps are fished at the zone border it results in a higher concentration of odour in the water and a greater chance that crabs will be lured towards the source. This problem was addressed at the 2002 zoning change using the 'no crab trapping' area. It was more effective in terms of providing benefit to fishers downstream as it prevented trapping with wire traps at the zone border. This spread the fishing effort out and away from the protective zone border and provided a greater opportunity for crabs to move downstream.

Factors affecting spill-over

The large variation in monthly captures suggests there are various external factors that contribute to the movement and distribution of mud crabs in each estuary. Large flushes of freshwater and a drop in salinity concentrations coincided with crab movement downstream resulting in similar captures among sites in each estuary for that month. Salinity in the central basin region (Site 1) at Wooli was not affected as much by flooding as the main channel sites in each estuary during flooding. It is likely that the basin acts as a refuge for crabs when freshwater is travelling down the main arms. This site does not have a large catchment and only drainage lines feed this area, so there is little direct movement of freshwater into this region. It is likely that some crabs move into this area and out of the main flow when freshwater flushes occur. The tag data at Wooli showed recruitment from other sites, but as tags were only collected over three days each month and sampling times did not occur during peak flood days, there was little opportunity to detect the temporal scale over which crabs moved into this area. Floods and changes in salinity seemed to be the driving force behind crab movement downstream and, most importantly, the replenishment of fished areas (see section 4.4.2). There is a high chance that flooding will occur at least annually. There has been at least one flood per year in the estuary over the past five years during the study causing increases in crab catches in the fished areas and increased catches of tagged crabs. This environmental factor will continue to aid protected areas as a management tool only if Sanctuary Zones are located in the upper sections of the estuary as crabs seem to only move downstream during the flood events. This will result in upstream areas being natural 'sources' and the downstream areas natural 'sinks' following flooding (Conover *et al.* 2000).

The migration of females to offshore regions during the study provides a potential spill-over source to fishers but creates a problem trying to design zoning schemes that will protect the mature migrating females. As no ovigerous females were caught during the study, it suggests that females do not spawn in the estuary and instead move offshore where conditions are optimal for larval survival and dispersal (Hill 1994). Only three crabs were recaptured offshore during the study after previously being caught 27 km away in the Wooli Estuary. These crabs were neither gravid nor contained spent ovaries when captured but their capture shows some crabs moved offshore. While crabs moved relatively small distances within the estuary, they have been found to move up to 65 km between estuaries (Hyland *et al.* 1984). The only other reason that these crabs would be located at sea during the current study would be a result of major flooding events flushing crabs out of the estuary. As no major flooding events occurred around December 2003 when the females were caught offshore, it is unlikely that floods would have pushed the crabs so far from the estuary mouth. Crabs have been caught offshore from the same estuary in the past with one professional fisher trapping off Wooli reporting catching approximately 40 crabs of which most were females (*pers comm.* Robert Howard, Professional fisher, Wooli, 15th October 2000).

The high number of female crabs captured during the study and by recreational anglers during the period from December to February (1999 - 2002) and March to June (2003) suggests that an offshore migration by females does occur. These catches of females were particularly evident at Sandon and Corindi where few crabs were caught at downstream fished sites but increased during this period with large female crabs, suggesting that they were probably only there because they use the area on their way offshore. In Australian waters, females migrate offshore in September and October, with high numbers of ovigerous females being caught off the northern coastline in prawn nets during October and November (Hill 1994). The movement of females during this study is later than reported in other studies, this is likely to occur because these studies were done further north than the current study sites. This is also the case for corals in the SIMP, which are late spawners (Wilson and Harrison 1995). These northern areas have higher annual water temperatures and it is not until January and February that the East Australian Current brings warm seawater to the waters of the current study (Appendix 8).

Movement of crabs offshore to spawn may vary annually as mud crabs from different regions exhibit distinct breeding cycles. For example, Robertson and Kruger (1994) found that on the east coast of South Africa, spawning occurs all year round. The movement of females has been illustrated by large schools of mud crabs being observed moving across sandbars and into the sea (Hill 1975). This phenomenon occurred locally within the SIMP with female crabs being observed moving across the sandbar bar at the mouth of the Woolgoolga ICOLL (*pers comm.* David Greenhalgh, NSW Marine Parks Authority, 3rd January 2004). These females then move offshore to areas unknown to scientists, but professional fishers have reported female crabs caught in depths between 10 - 60 m and at distances ranging from 4 - 95 km offshore from northern and eastern Australia (Hyland *et al.* 1984; Hill 1994; *pers. comm.* Robert Howard, Professional fisher, 15th October 2000).

There is a variety of reasons why mud crabs move offshore to spawn at different times. Firstly, it may improve larval dispersal and survival by using the ocean currents (Hill 1994). Because of this wide dispersal, stocks in NSW could be replenished from larvae released on the Queensland coast as these move southward in the East Australian Current (Heasman 1980; Hill 1982). Ocean currents are also used as a dispersal mechanism by other portunid crabs (Smyth 1980). Secondly, previous studies by Hill (1974) have concluded that the zoeae, which hatch from eggs, cannot tolerate temperatures above 25 °C and salinities below 17.5 parts per thousand. These limitations prevent mud crabs using flood-affected estuaries for spawning. Similarly, the shallow waters of estuaries and mangrove areas would heat above 25 °C in summer, causing large mortalities of mud crabs zoeae.

It is unknown whether females undertake a return migration to estuaries after spawning. As large female crabs were found each year in the estuary, this suggests that females do move back into the same estuaries after spawning, or that some are spawning without migrating offshore. Although no females were found with carrying eggs, it is likely that ovigerous females would be caught if they were in the estuary as these gravid females fed in experimental holding tanks during the study (Section 3.7). Heasman *et al.* (1985) found females with spent ovaries in inshore regions suggesting that females return after spawning. However, Robertson and Kruger (1994) sampled over 7000 crabs in South Africa of which none contained spent ovaries, suggesting that the population is built on recruitment of juveniles. Ovigerous females have been found offshore in the Philippines (Ariola 1940), India (Pillai and Nair 1968;

Shanmugan and Bensam 1980), Hawaii and Ponape (Brick 1974; Perrine 1978), and Australia (Hill 1994). Hill (1975) also caught ovigerous females in a lagoon cut off from the ocean. Observations in Australia are rare (Hill 1994).

This movement through the estuaries renders females vulnerable when they are leaving to spawn and when they return. With the highest fishing pressure occurring during these times, zoning schemes need to be designed so that female crabs are not overfished. This can be done by protecting all females as in Queensland or more appropriately either protecting an entire reach of estuary from mouth to tidal limits, creating a mosaic of protective areas at different intervals up the estuary, or restricting gear use to minimise the number of crabs taken by fishers. This has been factored into the proposed zoning schemes in each estuary (Chapter 7)

Problems with the tagging program

While the benefits to society of MPAs can be recognised through tagging (Stevens and Sulak 2001) and effort changes (fishing the line) (Gell and Roberts 2002), these benefits can be strengthened further if fishers participate and have "ownership" of the research program. This can be done by returning tags from recaptured individuals to help determine if crabs are moving between protected and fished areas to identify where areas of "source" and "sink" occur (Gell and Roberts 2002).

While it is reassuring to conclude from research projects that MPAs will benefit users, how do we know if these are benefiting fishers when tag returns from fishers are low? Tag returns were low from fishers in the Sandon and Corindi estuaries while large quantities of tags were retuned from Wooli. This may have resulted as the project field accommodation was situated at Wooli. However, this is unlikely as an extensive advertising program was conducted throughout the SIMP (section 3.8.2, Appendix 4). Although high tag returns from crabs caught during monthly research sampling trips in each estuary were made, insufficient returns were collected from fishers to provide any indication of movement patterns at Sandon and Corindi, while a detailed analysis of Wooli was conducted.

Why there were small tag returns at Sandon and Corindi is unknown as crabs were recaptured during monthly sampling trips in fished areas and fisher traps were regularly seen at each site during monthly sampling trips. Potentially not having tags retuned by fishers places a limiting

factor on the tagging program, as it may under-estimate movement patterns. All effort was made to include fishers in the research program by advertising in the media (television, newspaper, radio, posters, tag lotto) to inform the public about the project and what help was required. There was some support from the public but many fishers were tourists (Byrnes 1997; Kuster 1997; McDonald 1997) new to the area and they may not have come across the research information. A monetary "tag lotto" was held at the end of the sampling program to encourage people to hand tags in if they were hesitant about doing so initially. Previous research on tag returns suggested that monetary incentives has no effect on the number of tags returned by fishers. A program using Floy tags at Lake Lanier, Georgia, America offered a $0 - $20 reward on each tag. The return rates were highest from the $0 reward category, indicating reward level may not be important to fishers (Weaver and England 1986). Despite this, programs advertising rewards should be implemented at the beginning of the tagging program so that people are aware of it. In this case, it was unsuccessful at the end of the program as no further tags were handed in during the lotto competition dates and by law, a prize winner could not be drawn. It also created some conflict as fishers who regularly handed tags in during previous years were not rewarded with the chance to enter "tag lotto" other than if they had caught a crab in that period. Alternatively, fishers that did not hand in tags regularly during the study had the opportunity to hand in those they had stored at home, which increased their chances of winning the cash prize.

I was also told that people were releasing crabs because they had tags in them and they did not understand what the research was. Some people also retained tags from crabs but did not report them (*pers. comm.* Wally McDonald, recreational fisher, Wooli). Other fishers suggested that people did not report tags as they were unsure whether the study would be beneficial or detrimental to future exploitation of crabs by recreational fishers in the estuaries and they did not want to help if the research was going to lead to further fishing exclusions. Despite the wide media coverage, people may have been driven by the reasons outlined above. It must be assumed in any tag recovery study that not all fishers will participate but if large quantities of crabs with tags were caught, results can still be compared between recreational tag returns and those recaptured during monthly sampling times to determine if the same patterns are occurring.

4.4.5 Fisher pressure under different zoning structures

Recreational fishing effort (identifying hotspots)

Recreational trapping effort is high in estuaries of the SIMP with the highest effort in the Wooli Estuary before and after the zoning change. This may be due to the larger accessible area to fishing at Wooli than Sandon and Corindi. Wooli is a larger village than Sandon and Corindi and consists of many more caravan parks and holiday outlets than the other estuaries. For this reason, a greater number of people visit the estuary and fish compared to the more localised fishing effort from residents that seems to occur in the Corindi and Sandon estuaries. An estimated 472,790 people visited Wooli in 1997 of which 84% fished and 10% used boats (Byrnes 1997). At Sandon a similar percentage of people fished but there was only 51,000 visitors over the same period (Kuster 1997). This means that Sandon only has 11% of the potential fishing effort that occurs at Wooli. Future studies after the zoning change will provide evidence on whether the fishing effort will sustain regular pulse or press impacts on the area as a direct result of opening more area to fishing.

Prior to the zoning change, fishers targeted areas adjacent to the Sanctuary/Refuge Zone borders at Wooli and Corindi and areas only accessible to the professional fisher at Sandon. This is a good indication that spill-over of individuals is occurring from protected areas. Fishers will generally target borders where larger individuals are moving from the protected area (Sladek-Nowlis *et al.* 1999; Murawski *et al.* 2000; Kelly *et al.* 2002). This is known as "fishing the line" (Gell and Roberts 2002). In 1983, the closure of areas from fishing for the Zuwai (Tanner) crab (*Chionoecetes opilio*) fishery showed that the success of the closure is evident in the behavior and fishing effort of fishers (Yamasaki and Kuwahara 1990). Fishers began targeting the area directly around the reserve, "fishing the line", suggesting that the MPA is working and that larger individuals are spilling over from the protected area (Gell and Roberts 2002).

After the zoning change, fishing effort moved into the previously protected areas in each estuary. While no traps were found at the Sanctuary Zone borders at the mouth of the Sandon and Corindi estuaries, an increase in trap effort was noted at the upstream Sanctuary Zone border at Sandon and some trapping effort was maintained at the Wooli border when the zones

opened to fishing. This change in fisher effort suggests that crab catches upstream were being made throughout the areas opened to fishing and that fishers did not need to target the zone borders to catch crabs in the immediate period after the zone change. At Wooli, it was evident when crab catches upstream in the new area were declining because most of the fishing effort moved back to the Sanctuary Zone border six months after the zone change. This was where the chance of catching a crab spilling over from the Sanctuary Zone was highest.

At Corindi and Sandon, fishing effort after the zoning change was still small with substantial increases during the holiday periods between December and January. While effort remained low in these estuaries, the effort did shift upstream and there were no fishing traps below the zone border at Corindi and only a few traps at Sandon during July 2003. This change in effort suggests that fishers believe that the chance of catching a crab upstream is greater even though the Sanctuary Zone borders still occur at each of these sites near the downstream section of the estuary. The 13-month period after the zoning change may not have been long enough to detect a change in fisher effort back to the zone borders. During this period fishers continued to fish upstream, even after effort at Wooli showed movement back to the Sanctuary Zone borders after six months. It is possible that the abundance of crabs upstream was keeping fishers satisfied and that stocks had not declined sufficiently to support a move back to the Sanctuary Zone borders. Future studies will most probably reveal that, as the new area opened to fishing becomes depleted to low levels of crabs, fishers will move their effort back to the Sanctuary Zone border where their chance of catching a crab spilling over increases when low abundances occur in the fished area. This type of response before and after the change in the zoning scheme is expected at all future opening periods. Management options described in Chapter 7 have taken into account issues raised in this section.

The short-term effort survey conducted in late December 2002 and January 2003 in the Wooli estuary provided an assessment of monthly effort variation and where actual fishing effort took place at 1 km intervals from estuary mouth to the tidal limits of the estuary. Daily fishing effort was extremely variable and often increases by 100 traps within days. This variation was highest when weather conditions such as strong winds and rain or holiday breaks (e.g. Christmas Eve/Day) resulted in little fisher activity, whereas periods in the early holiday season and weekends saw large fisher effort. Catches in the fished area could be variable during the study for this reason as it was hard to know the fishing pressure in the area

immediately prior to the monthly sampling program. Secondly, in relation to fishing effort, compliance should be at its highest during weekends and days where weather conditions permit people to use the estuary in large numbers. Variation in patrols by NSW Fisheries/Marine Parks should be made, as illegal fishing is likely to occur when there are fewer users in the estuary. This would be especially the case in these estuaries as Sanctuary zones are isolated from major population areas with fewer people around; this increases the chance that illegal activity could occur. This remoteness also lead to compliance problems on the Great Barrier Reef where the lack of tools for enforcement to monitor remote areas lead to regular trawling within a no-take area at the far northern section of the Great Barrier Reef Marine Park (Gribble and Robertson 1998).

While effort was highly variable, the location targeted by fishers was not. There were few traps found above the rock bar located 11 km from the estuary mouth. This rock bar seems to act as a natural Sanctuary Zone border as it restricts fisher access upstream (Chapter 6). Fishing effort was primarily targeted at the "no crab trapping" area border and 1 km upstream at the Sanctuary Zone border during this period. At these two sites, traps and netted dillies were found across the entire estuary at distances less than 5 m from each other on days when high fishing effort occurred. These traps provided problems for boating access as the ropes and floats attached to the traps were difficult to navigate around. These traps should not be allowed to obstruct the main boating channel for safety reasons and compliance/control should be enforced under the Maritime Services Act 1935 – Section 13U (Obstruction of waters or lands by vessels or articles). This would, in turn, provide access for fishers upstream without navigating traps and provide some opportunities for downstream movement by crabs without facing traps across the entire zone border.

The number of traps found in the lower estuary was small. These fishers were probably targeting blue swimmer crabs (*Portunus pelagicus*) on the lower sand flats, which frequent these areas during the summer months, between December and March each year. These fishers are not a threat to mud crabs during the year except during summer when they may accidentally catch migrating females moving offshore. However, it is unlikely that fishers in the lower estuary would catch many female mud crabs as they mainly target blue swimmers during the day and female mud crabs are only active at night in the lower estuary when migrating.