6.0 Using natural barriers as a zoning tool in marine park management: a case study of mud crabs in the Wooli Estuary, NSW

6.1 Introduction

Estuaries of the Solitary Islands Marine Park (SIMP) face heavy fishing pressure from tourists (Byrnes 1997; Kuster 1997; McDonald 1997). To minimise this, marine park management regulates fishing activity to provide protection to potentially threatened species (MPA 2001) and controls access to naturally occurring populations for tourism or research by zoning and a permit system (Ballantine 1995) as 'fished' or 'no take' zones (MPA 2001). Managers face the problem of maintaining these 'no take' areas through compliance monitoring and education, but this alone may not protect species from illegal fisher activity. As the 'no-take' zones in the three largest estuaries of the SIMP are susceptible to high fishing pressure, especially over the four-week period during December and January public holidays, illegal activity is an added problem. This places increased pressure on the species being caught and public demand on the NSW MPA to maintain compliance and be visible throughout the SIMP (*pers. comm.* Luke Williams, NSW Fisheries/NSW Marine Parks Authority Compliance Officer, Coffs Harbour, 3rd July 2004).

The problem of poaching occurs in all marine protected areas across the world (Gell and Roberts 2002). While marine park zone borders have traditionally been located at points easily identifiable to people (MPA 2001), these locations may not be the most effective to minimise compliance issues as they provide easy access for poaching. Current zone boundaries allow illegal activity and may not protect targeted species. Using natural barriers at zone borders may alleviate some compliance problems.

Natural barriers are features, which restrict movement of species from natural habitat fragmentation (Sale *et al.* 1984; Tewfik and Bene 2003). While this study aims to maximise species movement between marine park zones of fisher-targeted species, natural barriers may restrict access to fishers themselves. Further research on naturally occurring barriers at zoning borders could help maintain population abundances and increase the size of individuals while restricting fisher access (Kramer & Chapman 1999; Tewfik and Bene 2003). Additionally, leaving areas open to fishing using natural barriers as a border might be an added tool in the

7.0 Synthesis

7.1 Application of research outcomes to estuaries of the Solitary Islands Marine Park

A problem associated with using single species indicators is that management may become focused on the indicator species in isolation rather than being representative of what is occurring across multiple species in that area (Simberloff 1998). As this study specifically set out to use a single species as a 'condition indicator' to compare between 'fished' and 'no take' zones within the SIMP, any conclusion drawn from this study is for mud crabs only. Managers may be tempted to extrapolate from this study to suggest that by protecting mud crabs, this provides protection to other species 'umbrella protection'. This assumption needs testing because if it is false, it may result in serious errors in zoning and park management, especially if the response of mud crabs to these zones is different to other species.

This study has provided managers with a detailed analysis of how mud crab populations responded to different marine park zones in the SIMP over 2 - 4.5 years. Results suggest that "no take" zones are an effective tool for estuarine management in the SIMP. These zones protect mud crabs leading to higher abundances in the Sanctuary zones than fished areas, sharp increases in abundance and mean crab size when fishing is excluded and spill-over to fishers of legal size crabs downstream.

The mud crab is potentially vulnerable to increasing fishing pressure by recreational and commercial anglers in the SIMP. Although commercial catches have been quantified, the exact fishing pressure exerted by recreational anglers in NSW is unknown. In the Northern Territory, a single survey found that recreational fishers harvested about 40 - 50 t, or about 3 - 5% of commercial catch levels (EA 2002). The commercial catch of mud crabs in the Northern Territory is approximately 1000 t annually, at a value of A$13 million (Phelan and Hay, 2002). This catch has increased dramatically in the past 15 years from 18.8 t in 1985 to 1037 t in 2000. The commercial mud crab fishery in NSW is much smaller than in the Northern Territory, with an annual average of 137 t between 1998 and 2003 worth A$1.7 million/year (Tanner and Liggins 2001). The most southerly fishery along the eastern seaboard is in the Bega River in Southern NSW (Pease and Grinberg 1995), with recreational fishing as far south

as Two Fold Bay near Eden. This fishery in NSW has the potential to increase recreationally and commercially, placing increasing pressure on estuaries within the SIMP.

While the benefits of zoning were identified, this study also revealed problems for mud crabs with the current schemes and timing of zone changes. These issues included accelerated depletion rates of crabs when opening previously protected areas, the removal of under-sized crabs from fished areas and the limited spill-over of crabs into fished areas in the absence of flooding or in periods when females do not migrate offshore to spawn. The previous zoning scheme, between 1991 and August 2002, magnified the effects of fishing pressure leading to the majority of fisher effort occurring at or within a short distance of the borders. This meant that there was little chance of crabs moving downstream and providing a fishery to the entire estuary. This scheme introduced particular problems for females that need to move through these areas when migrating offshore to spawn.

While the Sanctuary zones in each estuary have consistently more crabs, catches in the fished areas are so low that intense fishing pressure is required to catch even one crab at Wooli and it is virtually impossible to catch any crabs at the Corindi and Sandon estuaries during the colder months. In NSW, recreational fishers are permitted one trap and five netted dillies to take five crabs per person. With the catch rates in both estuaries, much time and effort is needed to catch the daily limit of crabs in these fished areas. Even then, it is unlikely that legal sized crabs will be caught more than 3 km from the zone border at Wooli or away from the zone borders at Corindi or Sandon. However, at no time during the study did fishers complain about not being able to catch a crab in the fished area suggesting that even the fishers are satisfied with how many crabs they are catching and the layout of the zoning. At times, a few anglers who regularly fish the estuary for crabs in the Wooli Estuary have been caught by NSW Fisheries for having too may traps, or fishing the protected zones, in an attempt to catch their bag limit. Regular or intensive illegal fishing may remove any benefit produced from the Sanctuary Zone (Jennings and Polunin 1996; Russ and Alcala 1996; Ward *et al.* 2000)

Zoning schemes need to build around the species being protected (which is currently not the case in the SIMP), by taking into account that crabs are more likely to be found in the upper estuary. Placing protective zones closer to the estuary mouth may provide a buffer zone and protection to the few crabs that live there but provides little spill-over of crabs. While crabs at

Corindi before the change in 2002 were being protected because the zone border was near the estuary mouth, there was little benefit to fishers as few crabs moved into the fished area. Likewise, at Sandon there was little fisher benefit as a result of the commercial activity upstream. When crabs moved into the fished area, they usually consisted of gravid females migrating offshore to spawn.

The telemetry and natural barrier studies helped identify gaps in the current zoning schemes for mud crabs. The telemetry study showed that mud crabs are more likely to move further in channel areas, providing a greater opportunity for crabs to spill-over into fished areas and less chance of crab stocks being overfished because of their capacity for fast replenishment if an area is depleted by fishers. The natural barrier study showed how habitat features might be used when locating zone boundaries. Naturally-occurring obstacles such as rock bars, sandbars or fallen trees provide a physical barrier to fishers, providing protection to crabs and allowing spill-over to fished areas without actually closing the area to fishing. This has social gains as closing too many areas to fishing is not publicly acceptable in the region, which was demonstrated when public lobbying opened an area that was to be closed to trapping in the Wooli Estuary.

Mud crab populations have survived in the highly exploited waters of the SIMP through their high fecundity, protracted spawning, rapid growth and early sexual maturation. However, if habitats are destroyed and fishing pressure increases, these attributes may not be sufficient to maintain viable populations (Heasman 1980). The migration of females to offshore regions during spawning leaves them vulnerable to fishing activity, while the destruction of mangrove habitats will affect juvenile development. These threats occur in the Sandon, Wooli and Corindi estuaries, and management to address these is essential.

The following section outlines future research and makes some recommendations based on results from this study. Although the five-year zoning plan allows for changes in public requirements, updated information on the species being targeted is also necessary to help justify future zoning scheme designs.

7.2 Future research

In 1998, this project was the only research on estuaries of the Solitary Islands Marine Park to compare differences between fished and unfished zones. Since then, even with a zoning review being completed in 2002, there are still only two other studies designed to look at estuarine zoning schemes. The first is a university study using multi-mesh panels to sample fish and mud crabs in areas open and closed to fishing in the Wooli and Corindi Estuaries. The second study is a pilot study developed by myself and the SIMP Scientific Officer Hamish Malcolm to provide a preliminary overview of mud crab stocks in four Intermittently Closed and Open, Lakes and Lagoons (ICOLLs) of the SIMP (Butcher and Malcolm 2003, 2004). Preliminary results suggest that closing some areas off to fishing in isolated areas is detrimental to mud crabs because catches declined in these areas after they were closed to fishing. It is likely that having protective status on these ICOLLs is drawing attention to them, leading to illegal fishing. These types of studies should continue in all estuaries of the SIMP to generate long-term data sets to show the spatial and temporal variation in these populations as fishing pressures change.

Collaboration between NSW Fisheries with other states on mud crab research is another necessity, identified at the National Mud Crab Workshop in 1993 (Bartleet *et al.* 1993). At this workshop, it was proposed to assess the stocks of mud crab throughout Australia and to consider prohibiting the use of dillies (witch's hats) in the recreational fishery. Since then, several studies by Keenan *et al.* (1998) and Gopurenko *et al.* (2002) were conducted. Gopurenko *et al.* (2002) described the regional genetic structure among mud crab populations from western, northern and eastern Australia (Gopurenko *et al.* 2002). However, the samples collected from the eastern States were only taken halfway down the eastern seaboard at Moreton Bay in southern Queensland, and should have also involved crabs from NSW populations. It is now timely to compare populations along the entire east coast of Australia to assess any genetic linkage. These studies will determine if crab larvae spawned in Queensland are recruiting to NSW estuaries, removing the need for an extensive network of "no-take" zones for mud crabs. On the other hand, If NSW mud crab populations are genetically distinct; "no-take" zones may be critical to ensure that these stocks are protected from overfishing or any impact.

A future gear study on recreational gear types is recommended possibly through the NSW Fisheries Recreational Fishing Trust. Netted dillies and traps pose different problems to the mud crab fishery. Potential problems include limb loss through entanglement and damage to under-sized crabs when fishers are removing them from the net for release. This limb loss and stress may cause mortality like that seen in catch-and-release studies for some fish species after release by recreational anglers (Broadhurst 2004). Traps also pose a threat through their ability to "ghost fish" if they are lost. Determining the optimum mesh sizes for traps to allow juvenile crabs to escape is also essential.

The NSW Marine Park Authority and NSW Fisheries have approved the current study to continue as a monitoring program until after the third review phase in 2007. The importance of continuing this current research was recognised to provide a long-term database. Sampling will only take place during December and April each year as these periods were identified as providing a good indication of mud crab abundances in fished and no-take zones. These sampling periods will indicate abundances, size, gender and movement in fished and no-take zones before and after major fishing which occurs as part of the school/public holidays in December and January each year. In conjunction with this study, it is recommended that the same sites be investigated using other recreational and commercially targeted species to determine whether the response to zoning schemes occurs across multiple species. This would help with the management process and improve justification for future zoning schemes.

7.3 Conclusion and recommendations "adaptive management"

As management plans for the Solitary Islands Marine Park are in their early stages of development and zoning schemes are now reviewed every five years, information from this research can be used to help ensure a future mud crab fishery. Substantial changes to the initial zoning scheme used between 1991 and 2002 were made during the 2002 review process. During this review phase, a detailed submission was made to the NSW Marine Parks Authority on the requirement to successfully complete this study and how the zoning scheme could be altered based on results to date. Unfortunately, the NSW Marine Parks Authority caused considerable problems when they changed the zoning scheme, as a site at Wooli was split in half, compromising my study design for BACI analysis. If long-term monitoring programs are going to be successful then reference sites need to be maintained for the duration of the study to ensure the stability of the design. The change in zoning was brought on by public pressure rather than sound science. While the study continued and adapted sites to the change, the results would have been more robust if the same sites could have been used before and after the zoning change as initially planned.

Due to the significant changes at the 2002 review period, I suggest only minor adjustments to the current zoning scheme by the NSW Marine Parks Authority (Table 7.1; Figure 7.1-7.3). This would most appropriately be done after the 2007 review period, depending on data from annual surveys over the next three years. At this point, management needs to include a variety of options for zoning schemes, which include selective fishing practices (Rowley 1992). As marine park zoning schemes need to be developed so that they are easy for the public to understand, many recommendations were discarded as they were deemed too complicated for the user and impossible to police. The recommendations made below have been developed to incorporate the user, management and the target species by proposing 'no crab trapping' areas which incorporate gear and time-use limitations in each estuary. These zones are not complicated yet they address issues with the current zoning scheme. In the context of zoning schemes in the SIMP, this means that measures should be taken to care for resources outside the protected Sanctuary zones without having a definitive border between either fished or not fished areas. The use of 'no crab trapping' areas creates a buffer between these two definitive zoning types and is the right direction for the development of *in situ* management without depending solely on no-take areas to provide protection. Gribble and Robertson (1998) also

suggested that 'buffer areas' should be used where high infringement is expected. In their case, the 'buffer' aimed to reduce the number of trawlers fishing while they pass through protected areas in the Great barrier Reef Marine Park, while the current study aims to reduce the number of traps in different areas and the occurrence of illegal trapping.

Table 7.1. Size of the area affected (km^2) by my proposed zoning scheme changes in the Sandon, Wooli and Corindi estuaries.

Estuary	**Zoning scheme (since Aug 02)**			**Proposed changes**		
	Not Fished	Fished		Not Fished	Fished	
		1- Dillies	**2-Traps/Dillies**		**1- Dillies**	**2-Traps/Dillies**
Sandon	0.94 (38%)		1.54 (62%)	0.94 (38%)	0.92 (37%)	0.62 (25%)
Wooli	0.92 (29%)	0.62 (19%)	1.69 (52%)	0.92 (29%)	0.74 (23%)	1.57 (48%)
Corindi	0.51 (40%)		0.75 (60%)	0.61 (48%)	0.44 (35%)	0.21 (17%)
Total	**2.37 (34%)**	**0.62 (9%)**	**3.98 (57%)**	**2.47 (35.5%)**	**2.1 (30%)**	**2.4 (34.5%)**

7.3.1 Sandon

The current Sanctuary and Habitat Protection zoning schemes will remain unaltered with gear restrictions (type and time) implemented in an attempt to redistribute fisher effort and to minimise illegal fishing. As this estuary is isolated and over 2 hours away from the head office at Coffs Harbour, the chance of illegal fishing in this estuary is greatest of all the estuaries within the SIMP. In an attempt to minimise this, a 'no crab trapping' area, with time restrictions on gear use, should be introduced similar to that used in the Wooli Estuary since the last zoning change. This zone will be best located from the junction of Toumbaal Creek upstream including all the tidal waters of Candole Creek (Figure 7.1b). Firstly, this zone will prevent any fishers from taking traps further upstream than this junction near the entrance to the village. The probability of catching a fisher attempting to go upstream of this point with traps is higher than if the zone started further upstream. Secondly, the 'no crab trapping' area allows netted dillies, which can be used between sunrise and sunset only, similar to the restrictions for professional fishers after 2004. This type of trap needs to be attached to a float and checked regularly as crabs can escape the netted mesh. Traps on the other hand, can be sunk without floats making it easy to use many traps (illegally) at the same time. Traps can also be set for 24 h without attention while dilly fishers will generally work them for a period of 2 h and check them regularly over the day. This reduced pressure each night also allows crabs to move out of the Sanctuary Zone and further into the fished area rather than being taken at the zone border by traps.

Public acceptance of this new zoning scheme should be high as there is no difference in the available fishing area and few recreational fishers target crabs at night with dillies. The only difference is a restriction on the type of gear and the time it can be used in certain areas. This gear restriction will ultimately benefit the wider fishing community as the chance of catching a mud crab improves while at the same time crab stocks are being protected from overfishing.

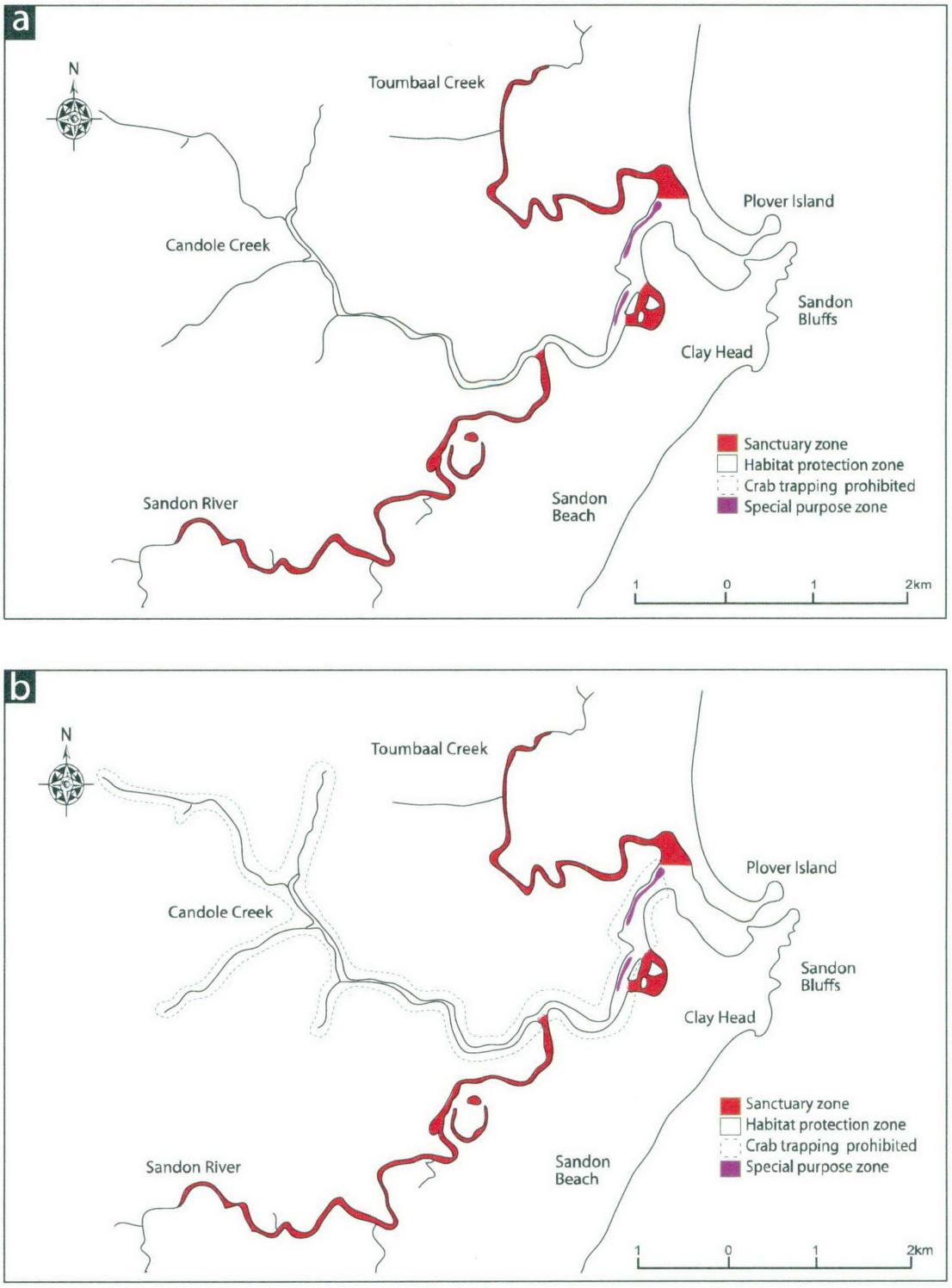

Figure 7.1. Comparisons of (a) current and (b) recommended zoning schemes for the Sandon Estuary based on conclusions from this study.

7.3.2 Wooli

The current zoning scheme at Wooli will largely remain the same. My data collected since the 2002 zoning change indicate that this scheme currently protects crabs while providing a steady supply to fishers. The estuary also has a major rock bar situated up the left arm (Barcoongere River) of the estuary. This rock bar is acting as a natural Sanctuary Zone boundary (Chapter 6) as it prevents fishers going upstream which in turn protects crab stocks while providing a spill-over of crabs to fishers.

The use of the 'no crab trapping' area worked effectively when introduced in 2002 as the number of traps being found at the Sanctuary Zone border decreased significantly. Before the zoning change, it was common to see up to 10 traps permanently positioned along the Sanctuary Zone border. Now, this area is worked using dillies during the day, enabling crabs to move further out into the fished zone.

The only change to the zoning will be enlarging the 'no crab trapping' area a further 1 km downstream and restricting dillies to use between sunrise and sunset as described for Sandon (Figure 7.2b). There are two main reasons for increasing the size of this zone. Firstly, the current zone border is situated where a large sandbar has built up forming two channel areas. Mud crabs use these channels to move downstream and from recreational anglers' reports, these channels concentrate catches, minimising the effectiveness of the zone border. Moving the border downstream to a wider section of estuary with a deep channel will provide a greater chance of spill-over than the present scheme as the high perimeter to area ratio may improve spill-over across the zone border (Buechner 1987). Secondly, this move downstream will help minimise illegal activity by fishers using traps. The proposed border is near the local caravan park, allowing local residents to observe and report illegal activity. Local fishers value the estuary and commonly report any illegal activity.

Wooli has the highest fishing pressure encountered in estuaries of the SIMP. Zoning schemes need to be designed to meet the needs of these fishers while ensuing that the resource they are targeting is protected from overfishing. The refined zoning scheme should alleviate increasing fishing pressure by using gear restrictions and repositioning zone borders.

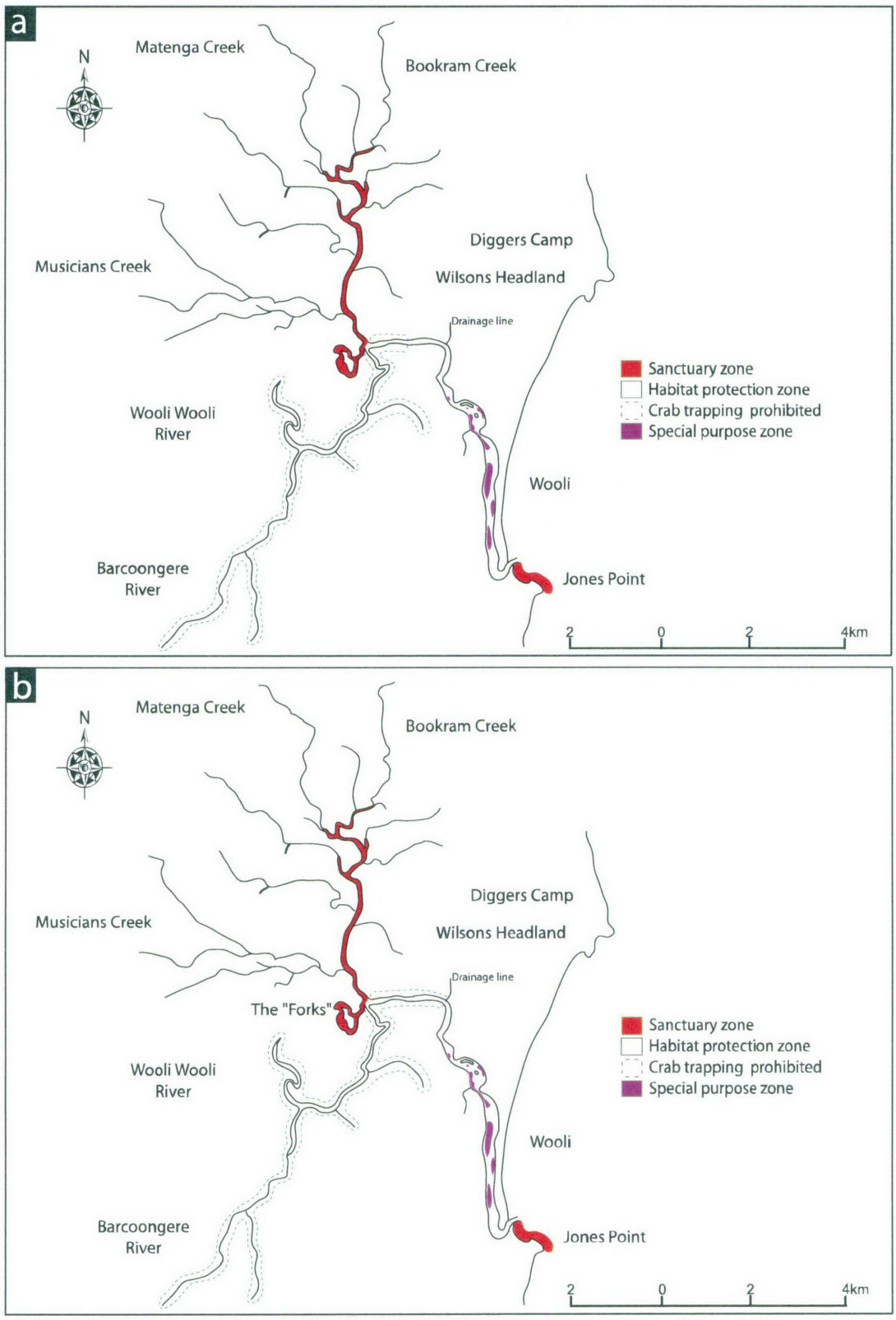

Figure 7.2. Comparisons of (a) current and (b) recommended zoning scheme for the Wooli Estuary based on conclusions from this study.

7.3.3 Corindi

The most significant change in zoning will occur in the Corindi Estuary. The estuary will benefit from implementation of a 'no crab trapping' area with time restrictions as described for Wooli and Sandon. This new zone will include the southern arm known as Corindi/Redbank River (Figure 7.3b). The major alteration will be the continuation of the Sanctuary Zone from Saltwater Creek through to the current downstream Sanctuary Zone at the mouth of the estuary. While this will be a contentious issue with the public and perhaps managers, I see it as imperative for several reasons. Currently, no estuaries within the SIMP are protected from estuary mouth to the upper tidal limits leaving species that move up and down the estuary and migrating species such as mud crabs vulnerable to capture all year round. The estuarine characteristics at Corindi provide an opportunity to provide total protection to species without removing large fishing areas. The two natural arms of the estuary allow one arm to be fished while the bottom end of the estuary is divided by two channel areas consisting of large sand flats with small islands. While it would be ideal to close the southern arm (Corindi/Redbank River) of the estuary to enhance spill-over, this is not possible as it would remove options for line-fishing anglers because the northern arm is so shallow. Therefore, zoning plans were developed to ensure that some deep habitat was included in a Sanctuary Zone.

Ideally, zoning schemes should be designed so fishers do not need to pass through Sanctuary zones to reach fishing areas. This approach should be taken to minimise the temptation of fishing in these regions. The proposed design at Corindi requires fishers to pass through a 1 km stretch of Sanctuary Zone before they reach the second of two fishing areas in the Corindi River Arm. I think this is an acceptable scheme at Corindi where only a small transit distance is required. The chance of illegal fishing in this zone would be small due to the location of the zone near the town of Red Rock but effort should be put into education and self-compliance.

This new design at Corindi resembles the current scheme but the implementation of further features through the 'no crab trapping' area (gear and time) and the extension of the Sanctuary Zone will provide additional protection to mud crabs and benefits to fishers through spill-over. The new Sanctuary Zone will provide a continuous link along the entire estuary. As Corindi will be the only estuary within the marine park where it is logistically possible to create such a scheme, this will provide a model to demonstrate the importance of protecting the migration

pathway for mud crabs down the estuary. Results could guide zoning schemes in the future, and will be assessed with the intended bi-annual sampling scheme described earlier.

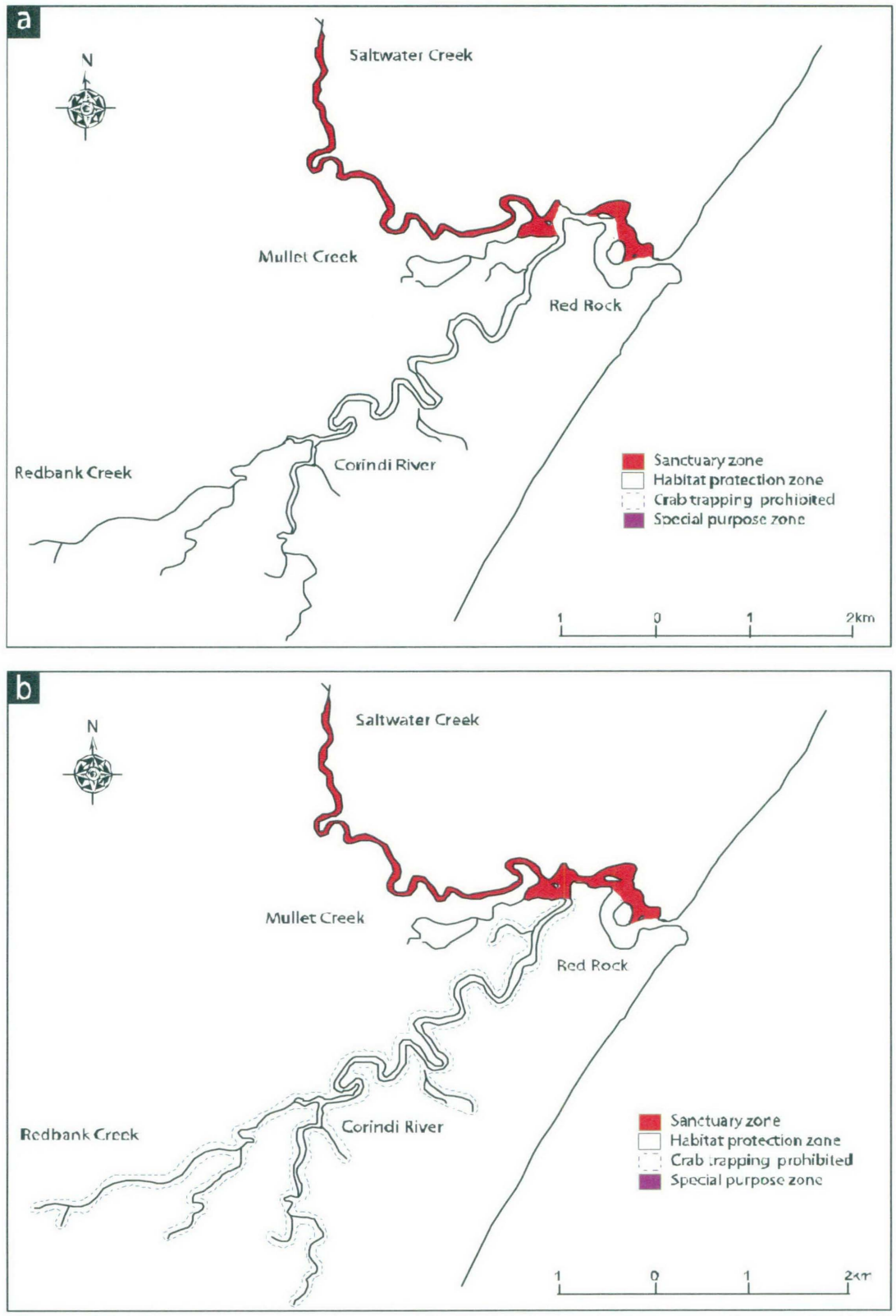

Figure 7.3. Comparisons of (a) current and (b) recommended zoning schemes for the Corindi Estuary based on conclusions from this study.

zoning process. Maintaining the current zoning scheme, where small spill-over or recruitment occurs from the Sanctuary Zone, may lead to little fisher benefit and reduced societal acceptance of the zoning scheme (Kramer & Chapman 1999) as not all marine reserves lead to spill-over. Davidson (2001) found that spill-over did not occur for the Blue Cod (*Parapercis colias)* even though abundances had grown 300% within the marine protected area. Davidson (2001) suggested that densities had not built high enough within the reserve to permit spill-over to the adjacent fished area.

Some areas in estuaries may be more accessible and heavily fished than others so direct access to these areas may have consequences for the species being targeted (Broad *et al.* 2002). In terrestrial park management, ease of access is related to the number, distribution and condition of roads and trails (Hammitt and Cole 1987). These roads can be closed off to prevent access and impact from users. More importantly, if areas which have been closed to fishing allow direct access from fishers by land, the chance of illegal fishing increases as there are more access and escape points for offenders.

Before natural barriers are used as a zoning border, the life cycle of each species being protected needs to be fully understood (Kramer & Chapman 1999). We need to know whether species abundance and size will change and if spill-over will occur from increased numbers in the protected area. Tewfik and Bene (2003) working with a slow moving gastropod (*Strombus gigas*), found that natural barriers at marine park boundaries were effective for increasing abundance within the 'no take' zone but ineffective for individual recruitment (spill-over) from the 'no take' zone. In this case, the boundary was a shallow sandbar, which lacked food for the species. This habitat was not normally frequented by the gastropod, and therefore, the population was overfished in the fished zone as no recruitment was occurring across the sandbar.

The benefits of no take zones are already known (Section 1.2; Chapter 4) and these benefits can be amplified by refining the selection process of where zones are allocated. The main objective of the project is to provide a scientific basis for fisheries/marine park management in exploited estuaries. Firstly, it needs to be determined whether natural barriers can be used as natural Sanctuary Zone borders or buffer zones in marine parks using mud crabs as indicators. This will be achieved by comparing the demographic structure of mud crab populations

upstream and downstream of a rock bar before and after fishing was reintroduced. I also aimed to assess the usage by and accessibility to fishers above and below the natural barrier.

I predicted that once fishing has been reintroduced to the area, a 'press disturbance' may occur (Section 1.1.3). There will be a greater abundance and larger size class of crabs upstream of the naturally occurring barriers once fishing starts. This will occur as a 'press response' from crabs caused by the concentrated number of fishers in the area downstream of the natural barriers. The natural sanctuary (upstream) will act as a source of recruitment downstream. If regular recruitment occurs during flooding, the downstream area may have a 'pulse' response where crabs will be depleted but will recover from time to time, otherwise the area may become depleted steadily as a press response.

6.2 Study site

The Wooli Estuary is a popular tourist destination, with particular emphasis on fishing (Kuster 1997). The location of the zoning borders is ideal to explore whether natural barriers may aid in the protection of fisheries resources. The right and left arms of the Wooli Estuary upstream at the point known as 'the Forks', are classified as a Sanctuary Zone and may easily become depleted if reopened to fishing (Figure 6.1). In August 2002, the left arm was reopened to fishing while the right arm remained closed (Section 4.2.3 - 4). The left arm contains several rock bar barriers which are unnavigable by boat on most tides. Results from pilot studies (Appendix 5) suggested that the area above and below the rock bar is similar in abundance with large captures of crabs. The area below may become overfished (nearly to depletion) once the area is re-opened to fishing in August 2002 as fishers only target up to the rock bar barrier.

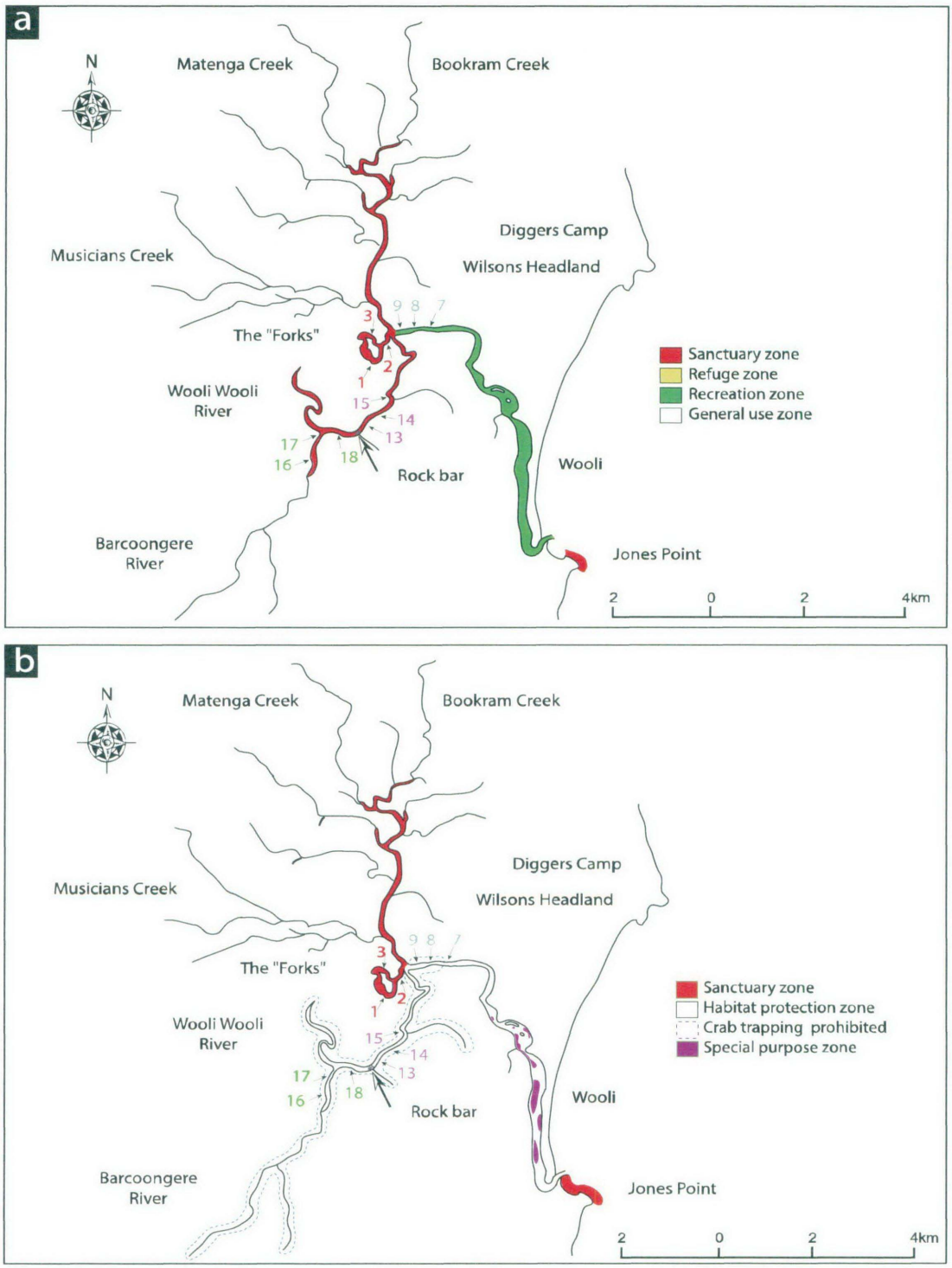

Figure 6.1. Diagram of Wooli Estuary with reference to natural barriers (rock bar) before (a) and after (b) changes in zoning in August 2002. Trapping sites upstream (16 - 18) and downstream (13 - 15) of rock bar with not fished (1 - 3) and fished (7 - 9) control sites.

6.3 Methods

6.3.1 Survey design

The intention was to investigate one estuary and then test this across a larger collection within the Solitary Islands Marine Park. As there was a limitation on the number of naturally occurring barriers that would be suitable for this project, time limitations and financial restrictions, only one estuary was used. Therefore, caution is needed in extrapolating these results to other estuaries. The Wooli Estuary was seen as an ideal example as it had several rock bars in the upper reaches, was about to be reopened to fishing after 12 years of protection, and mud crabs were abundant in the area, which is heavily fished by recreational and commercial anglers.

The methods for the project were standard techniques for trapping mud crabs (Section 3.6). Four treatments were chosen to show different change before and after the 2002 marine park zoning change. A treatment was selected upstream (Treatment 1) and downstream (Treatment 2) of the rock bar. These treatments were unfished prior to the August 2002 zoning change and fished thereafter (Table 6.1, Figure 6.1). Treatment 3 (control fished) and Treatment 4 (control unfished) were selected at other locations in the estuary for comparison (Table 6.1, Figure 6.1). Trapping occurred over three consecutive nights, every three months from January 2002 to April 2003. This provided samples before and after the change in the zoning scheme in August 2002. Temperature and salinity were measured each day of trapping (Section 3.5).

Table 6.1. Changes in fishing pressure in each treatment at the August 2002 zoning change and the corresponding site no. for Figure 6.1

Treatment	Pre August	Post August	Change	Site no.
1 (upstream)	Unfished	Fished	U – F	16 - 18
2 (downstream)	Unfished	Fished	U – F	13 - 15
3 (Control fished)	Fished	Fished	F – F	7 - 9
4 (Control not fished)	Unfished	Unfished	U - U	1 - 3

6.3.2 Zoning

Prior to the marine park zoning change in August 2002, 43% of the Wooli Estuary was Sanctuary Zone (no take), while after the zoning change; this was reduced to 29% Sanctuary

Zone (Table 6.2). The loss in Sanctuary Zone occurred in the left arm of the estuary, which was reopened to fishing. Whether the loss in Sanctuary Zone is significant may be offset by the large rock bar 3 km (16 ha of water) upstream from where the zone was opened (Figure 6.1). If the rock bar is restricting access to fishers and working as a natural sanctuary, the 33 ha above the rock bar may be an additional Sanctuary Zone, because 16 ha may have been lost to fishing.

Table 6.2. Change in zone sizes at the August 2002 zoning change

	Zoning type	Location	Water area (ha)
Pre Figure 6.1a	Sanctuary	Above 8 km border	140
	Recreational	Below 8 km border	182
			Total 322
Post Figure 6.1b	Sanctuary	Above 8 km border- Right Arm	57
	Sanctuary	Above 8 km border- Central basin	35
	Habitat Protection	Above rock bar – left arm	32
	Habitat Protection	Below rock bar to Forks – left arm	16
	Habitat Protection	From "Forks" to mouth	182
			Total 322

6.3.3 Fishing pressure

To assess fishing pressure, the estuary was divided into 1 km sections from the estuary mouth and the number of traps, boats and people counted in each section (Section 3.10). This will determine any change in fisher effort before and after the zone change and specifically identify if the natural barrier restricts fishing effort from moving upstream of the rock bar.

6.3.4 Statistical analysis

Univariate analysis was used to test the null hypotheses of no differences in catches (Catch per unit effort) between various treatments. Data were ln(x+1) transformed to model treatment effects as approximately multiplicative (Zar 1999) and tested for heteroscedasticity using Cochran's test. The abundance data were analysed by 4-factor (Treatment (fixed), Site (random), Zoning period (fixed), Month (random)) orthogonal analyses of variance (ANOVA). Where appropriate, to increase the power of the F-test for the term of interest, the MS denominator was pooled with the residual if it was non-significant at $P>0.25$ (Winer 1971). All significant main effects were tested using a *post hoc* Tukey's (HSD) comparison of means test.

A Kolmogorov–Smirnov test was used to test the hypotheses of no differences in size class distributions among treatments. Due to small catches each month, treatments were pooled to provide before and after totals (i.e. January, April, July 2002 = before). Each pooled treatment was tested against the same treatment before and after the zoning change and among treatments for the corresponding zoning period.

Even if there are no differences in size class distributions between populations using the Kolmogorov–Smirnov test, differences may lie in the number of crabs caught within size classes before and after the zoning change. A two-sample t-test (months pooled) was used to test the hypothesis of no difference in the total number of crabs within a size class before and after the zoning change. This may give an indication of the selective harvesting of individual size classes once fishing commenced.

To test the null hypotheses that there is no association between area and gender among sites before and after the zoning change a χ^2 square analysis was conducted. This test was carried out on the total number of males and females caught in each "treatment". We wanted to know if there was a difference in the number of male or female crabs caught among treatments before and after the zoning change and if it changed at treatments which were opened to fishing.

6.4 Results

6.4.1 Abundance

The unfished control (Treatment 4) contained the highest catch per unit effort (CPUE) in most months (Figure 6.2). This was followed by Treatment 1, Treatment 2 and Treatment 3 (control - fished), which had the lowest CPUE in all months. There was a significant month effect ($F_{4,215}$ = 24.45, P = 0.0001) and treatment x month interaction ($F_{12,215}$ = 4.08, P = 0.0001) suggesting that crab catches were different between treatments each month (Figure 6.2; Table 6.3, 6.4(a), 6.4(b))

Pre zone change

Highest mean abundances before zoning changed occurred in January 2002 (Treatment 1) and April 2002 (Treatment 2, 3 and 4) while all treatments were lowest in July 2002 (Figure 6.2; Table 6.4a). Prior to the zoning change the unfished Sanctuary Zone sites (Treatment 1,2 and 4) had significantly larger catches of crabs than Treatment 3 (fished - control) in January and April 2002, while crab numbers at all sites were not significantly different in July 2002. (Table 6.4a).

Post zone change

Highest abundances occurred in January 2003 (Treatment 1 and 4) and April 2003 (Treatments 2 and 3) while the lowest catches occurred in April 2003 (Treatment 1 and 4) and January 2003 (Treatments 2 and 3) (Figure 6.2; Table 6.4a). Crab numbers in Treatment 1 (above rock bar-fished) and 4 (control - no fished) were significantly larger than in Treatment 2 (below rock bar - fished) and Treatment 3 (control - fished) in October 2002 and January 2003. All sites were not significantly different in April 2003 (Table 6.4a).

Temporal Changes within Treatments

Crab captures between months was highest at Treatment 2 below the bar. *Post hoc* Tukey's tests found that captures were significantly lower once fishing commenced, except during April 2003 which coincided with a flood and larger captures of crabs. At treatment 1 (above rock bar) and the control (not fished) Treatment 4 captures were only significantly different during July 2002 while there was no significant difference each month at the control fished site (Table 6.4b).

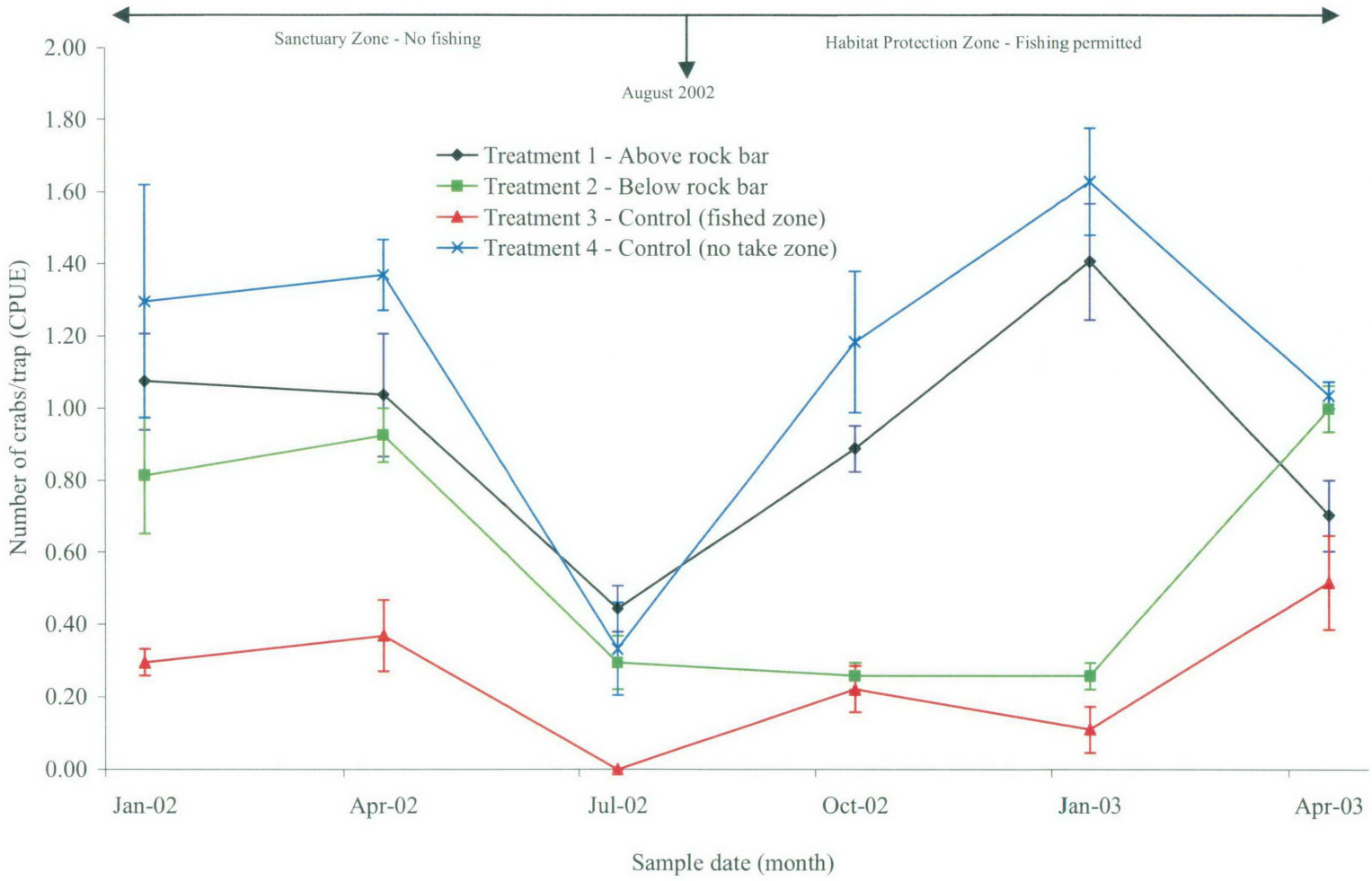

Figure 6.2. Temporal and spatial variation in mean (±SE) abundances (CPUE) of mud crabs caught in wire traps among treatments.

Table 6.3. Summary of results of four-factor ANOVA comparing the catches from four treatments (Above Rock bar, Below Rock bar, Fished control and Unfished control) sampled over 6 months before and after changes in zoning scheme.
The F-ratio for the interaction term (site x month) was non-significant at p = 0.25, and the sums of squares and DF were pooled with the residual. (ic) = incalculable F-ratio.

Source of variation	**DF**	**MS**	**F-ratio**	**P**
Treatment	3	9.0952	(ic)	-
Site	8	0.1397	0.9875	ns
Zoning	1	0.4534	(ic)	-
Treatment x Zoning	3	0.6561	(ic)	-
Site x Zoning	8	0.1974	1.3953	ns
Month	4	3.4583	24.45	0.0001
Treatment x month	12	0.5772	4.0807	0.0001
Site x month	(pld)	(pld)		
Residual	176	0.1414		
Total	215			

Table 6.4. Results of Tukey's comparison of means test for (a) monthly among treatment differences and (b) within treatment among months differences as a result of significant treatment x month interaction (Table 6.3). Different letters show means that are different from each other.

(a)

Month	**Treatment 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**
January 2002	A →	A →	B →	A
April 2002	A	A	B	A
July 2002	A	A	A	A
October 2002	A	B	B	A
January 2003	A	B	B	A
April 2003	A	A	A	A

(b)

Month	**Treatment 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**
January 2002	A ↓	A	A	A
April 2002	A	A	A	A
July 2002	B	B	A	B
October 2002	A	B	A	A
January 2003	A	B	A	A
April 2003	A	A	A	A

6.4.2 Gender

A total of 305 males and 167 females were collected over the study period. The pattern of male and female crabs caught overall varied within and among treatments (Figure 6.3). All "fished" treatments had more males than females while "unfished" treatments had similar numbers of males and females except Treatment 1 (above rock bar) after the zoning change which maintained a high proportion of male crabs. This treatment was theoretically a fished area but was thought to act like an unfished area as no traps or boats were seen during the trial. χ^2 square analysis suggested that there is an association between treatment (capture site) and gender (χ^2 7.99, df 3, P = 0.0462) with the largest variation between the observed and expected values occurring at the fished control Treatment 3. At Treatment 3, the number of males to females was (0.63) while on average more males were caught than females at the protected above rock (1.55), below rock bar (2.66) and control-unfished (2.37) treatment. After the zoning change there was no association between treatment and gender (χ^2 3.52, df 3, P = 0.3187). Trends suggested that it was more likely that male crabs were removed from below the rock bar after the zone change as the gender ratio halved (1.27), while the ratio doubled at the fished control site, lthough there were only small numbers of crabs caught here (Figure 6.3).

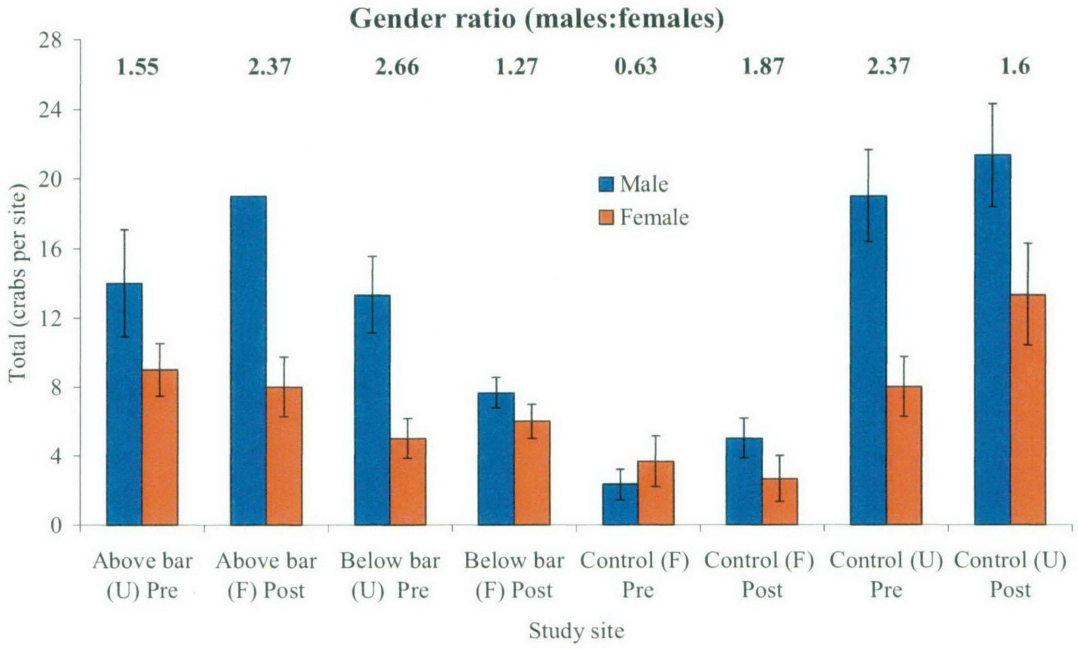

Figure 6.3. A comparison of the mean number (± SE) of male and female crabs caught at each site pre and post zoning change. (F) = fished site, (U) = unfished site.

6.4.3 Size class

Monthly size class distributions

Captures at fished and unfished treatments were expected (Figure 6.4). All treatments had consistently low numbers of crabs in July 2002, which coincided with winter when low water temperatures restrict crab activity. The major trends identified were the two control treatments that behaved as expected with high quantities of large crabs in the unfished control and low numbers of all size classes of crabs in the fished control. Treatment 1 and 2 were expected to behave similarly prior to the zoning change, as they were adjacent to each other in an unfished environment. Post zoning once fishing commenced, Treatment 1 above the rock bar maintained large sizes of mud crab numbers similar to pre CPUE while Treatment 2 below the bar experienced a decline in mud crabs above 130 mm for the first two months. All fished treatments had increases in legal size mud crabs above the 120 mm size class category when salinity concentrations declined during flooding in April 2003 (Figure 6.4).

Treatment 1: unfished (pre) / fished (post)

This treatment maintained similar size class structures pre and post zoning change in August 2002. This site still had large numbers of crabs above the legal size limit once fishing commenced (Figure 6.4).

Treatment 2: unfished (pre) / fished (post)

This treatment had diminished numbers of crabs post zoning change except April 2003 where large numbers of legal sized crabs returned. This coincided with a flood and low salinity concentrations. While the percentage of legal sized crabs did not vary pre and post zoning, it was the actual numbers of crabs that reduced once fishing commenced in this site (Figure 6.4).

Treatment 3: control - fished

Small numbers of crabs and particularly legal sized crabs occurred in most months except April 2002 and April 2003. This coincided with minor (April 2002) and major (April 2003) floods in the estuary. The percentage of legal sized crabs was large in the site but the actual number of crabs was extremely low (Figure 6.4).

Treatment 4: (control - unfished)

Large numbers of crabs were caught in all months while the percentage of large legal size crabs was similar in each month (Figure 6.4).

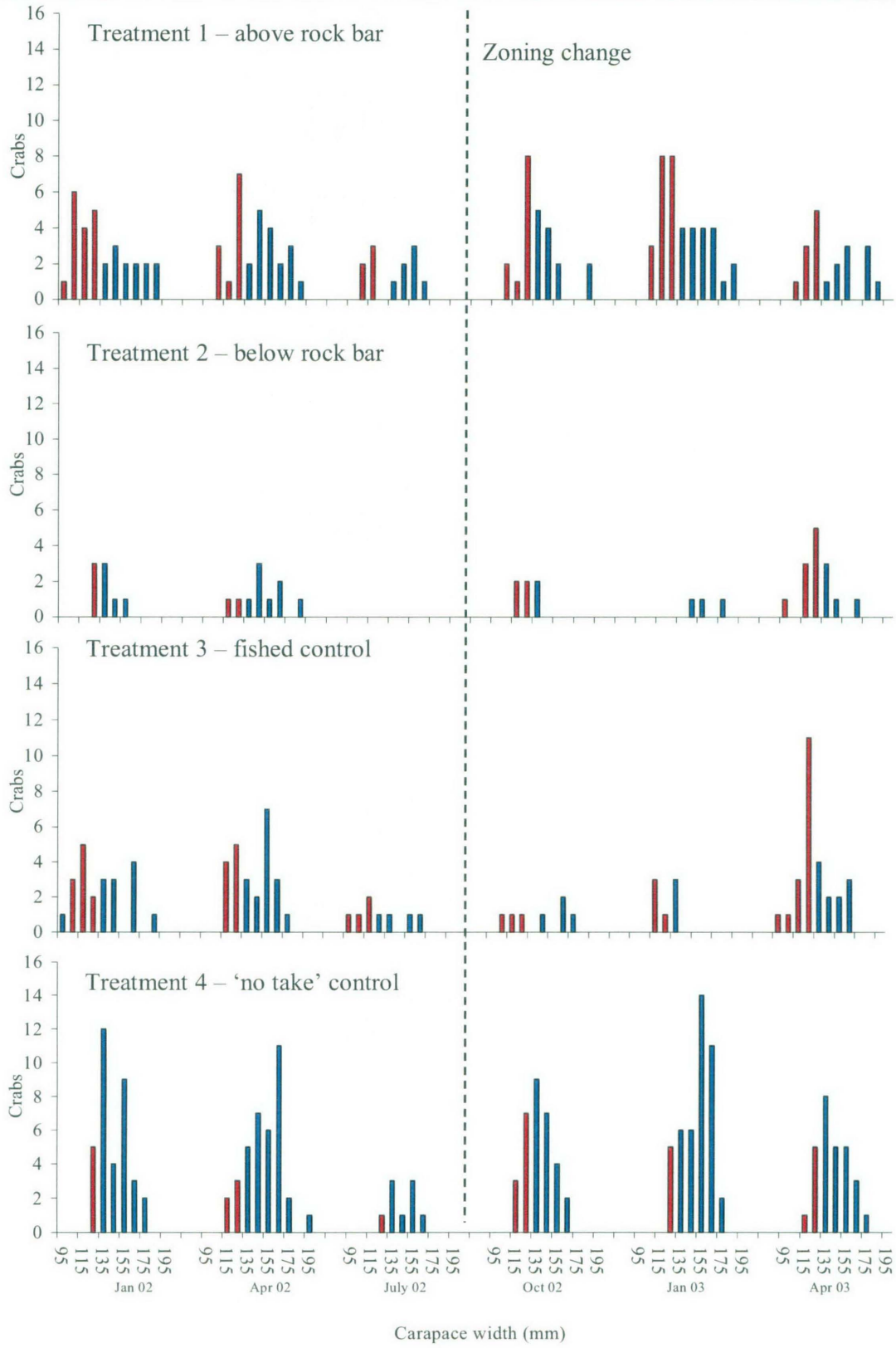

Figure 6.4. Variation in monthly size class distribution for each Treatment. Orange bars (undersize) and blue bars (legal size) indicate the number of crabs caught each month.

Proportion of abundance

Overall, the size-class distribution of mud crabs was similar within each treatment before and after the change in zoning scheme (Table 6.5). However, there were some notable differences in distributions between treatments. Prior to the zoning change, Treatment 4 (unfished) had significantly larger crabs than Treatment 1 (unfished) (Kolmolgorov-Smirnov KS = 0.33, P = 0.0007) and Treatment 2 (unfished) (Kolmolgorov-Smirnov KS = 0.32, P = 0.0026) (Table 6.5). Post zoning change, Treatment 4 (unfished) still had significantly larger crabs than Treatment 1 (fished) (Kolmolgorov-Smirnov KS = 0.28, P = 0.0016), Treatment 2 (fished) (Kolmolgorov-Smirnov KS = 0.36, P = 0.0010) and Treatment 3 (fished) (Kolmolgorov-Smirnov KS = 0.36, P = 0.0139).

Even though there was no significant change in distributions within treatments pre and post zoning change using the Kolmolgorov-Smirnov test, there were visible differences in trends, which are worth noting (Figure 6.5). Treatment 1 (above rock bar) and Treatment 4 (unfished–control) maintained similar size class structures pre and post zoning change while 150 mm crabs were removed from Treatment 2 (fished) post zoning change once crabs were subject to fishing pressure. Treatment 3 (fished – control) had a larger percentage of crabs prior to the zoning change in the size classes 140 -160 mm. Due to small samples sizes this was only a couple of crabs (Figure 6.5).

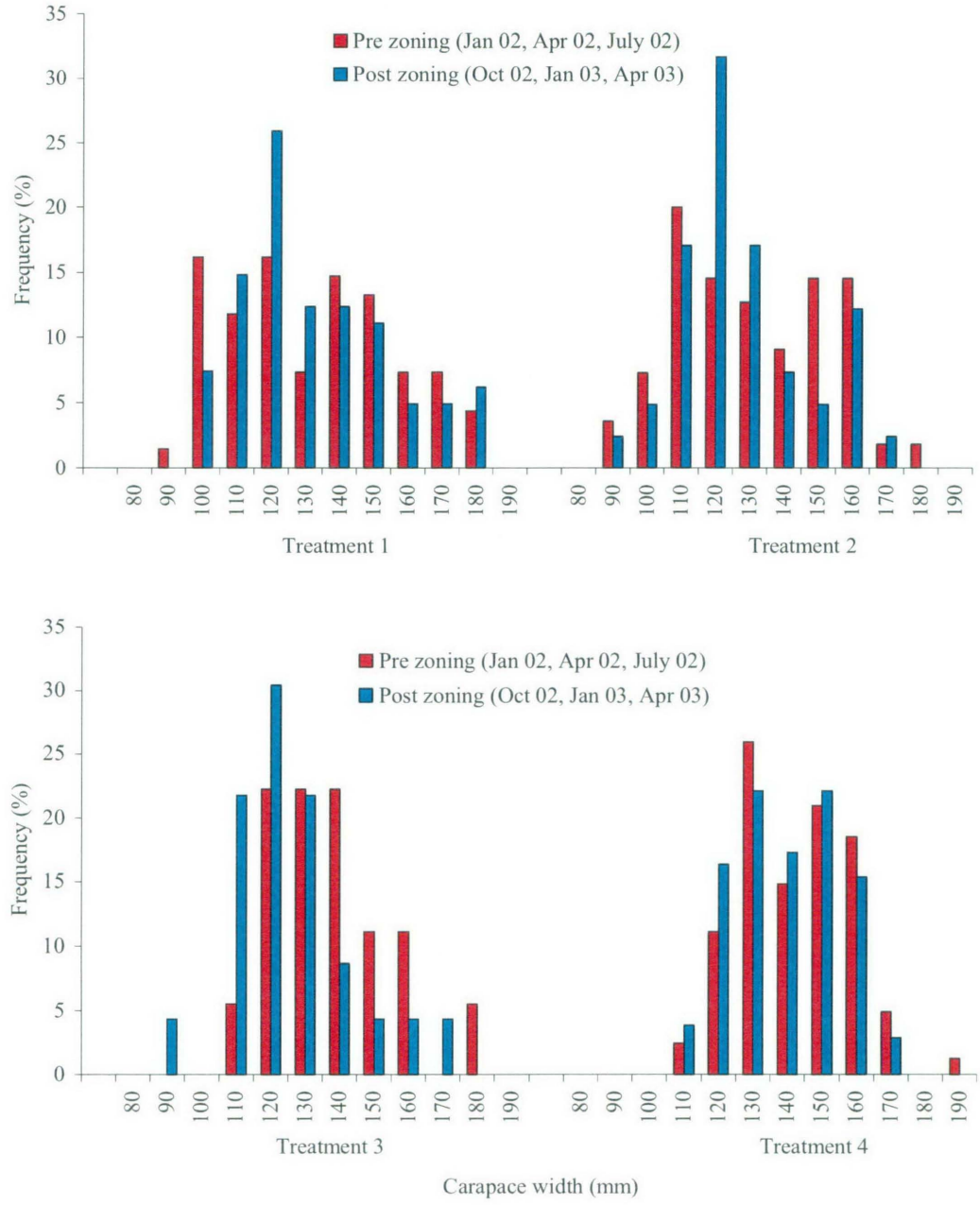

Figure 6.5. Proportion distribution of size classes for mud crabs tagged at Treatment 1 (n =69 (unfished) and 81(fished)); Treatment 2 (n = 55 (unfished) and 41(fished)); Treatment 3 (fished) (n =18 and 23) or Treatment 4 (unfished) (n = 81 and 104), pre and post marine park zoning changes in August 2002.

Table 6.5. Probability values using the Kolmorgorov-Smirnov goodness of fit test comparing width cohorts for mud crabs within and among treatments, before and after the change in zoning. Bracketed numbers are the number of crabs used in the analysis for each treatment.

Treatment	Pre			Post			
Treatment	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**
T1-pre (above bar) (69)	1.000	0.417	0.000	0.952			
T2-pre (below bar) (55)		0.349	0.003		0.696		
T3-pre (fished control) (18)			0.680			0.377	
T4-pre (unfished control) (81)							1.000
T1-post (above bar) (81)					0.834	0.645	0.002
T2-post (below bar) (41)						1.000	0.001
T3-post (fished control) (23)							0.014
T4-post (unfished control) (104)							

Actual abundance

Individual size classes were tested within treatments to determine any difference between totals before and after zones were changed. This may give an indication of selective fishing of larger crabs once zones were reopened to fishing. Due to the large variation and small sample sizes between sites within treatments, the only size class to show a significant change before and after the zoning change was the 120 mm size class in Treatment 1. There were significantly more 120 mm crabs in Treatment 1 after the zoning change ($t = 3.37$, $df = 4$, $p = 0.028$).

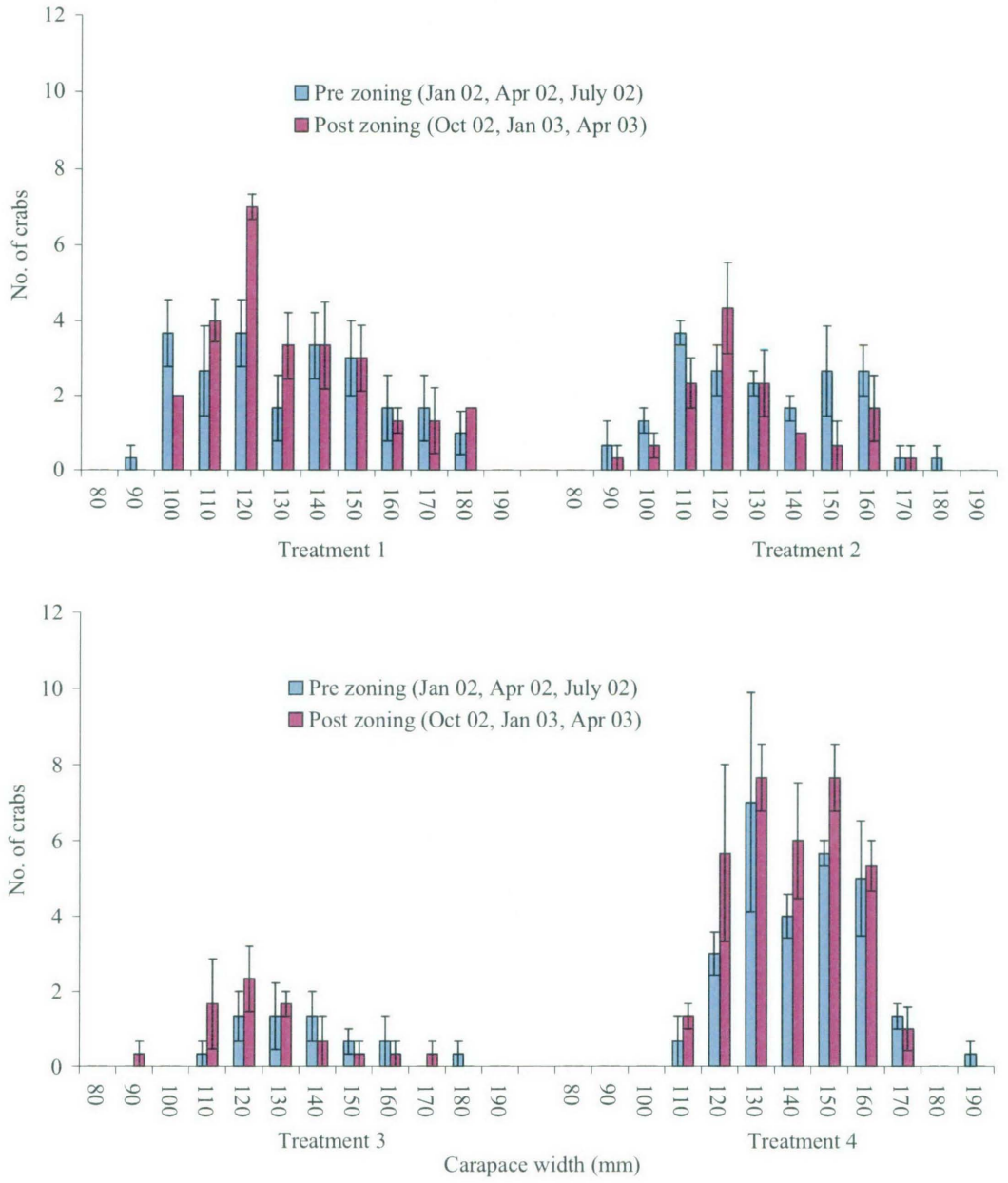

Figure 6.6. Abundance (±SE) by size class for mud crabs tagged at Treatment 1 above bar (n =69 and 81); Treatment 2 below bar (n = 55 and 41); Treatment 3 control fished (n =18 and 23) or Treatment 4 control unfished (n= 81 and 104), pre and post marine park zoning change in August 2002.

6.4.4 Movement

The highest number of recaptures occurred at Treatment 4 (unfished control) each month except April 2003 (Figure 6.7). Treatment 2 – below bar had higher numbers of recaptured crabs during April 2002 and April 2003. This coincided with flooding and low salinity concentrations. Treatment 1 (above rock bar) maintained low recaptures while Treatment 3 (control fished) had only two recaptures during April 2003.

Crabs moved between Treatments 1 and 2 and between 3 and 4 but no movements were made between other treatment combinations (Figure 6.8). Of the 43 crabs recaptured at Treatment 4, 34 had been tagged at that location in previous months, 2 crabs had moved from Treatment 3 – control fished and the remainder were recaptures from other sites tagged during the monthly sampling regime (Chapter 4). Treatment 2 (below rockbar) had the highest number of crabs moving from other treatments. During April 2002 and April 2003, 3 of 6 and 12 of 13 recaptured crabs had originally been tagged in Treatment 1 (above rockbar) and had moved downstream over the rock bar to be caught. All crabs caught in Treatment 1 had been previously trapped at Treatment 1. Treatment 3 (control fished) had 2 recaptures during the 6 months of trapping which had moved from Treatment 4.

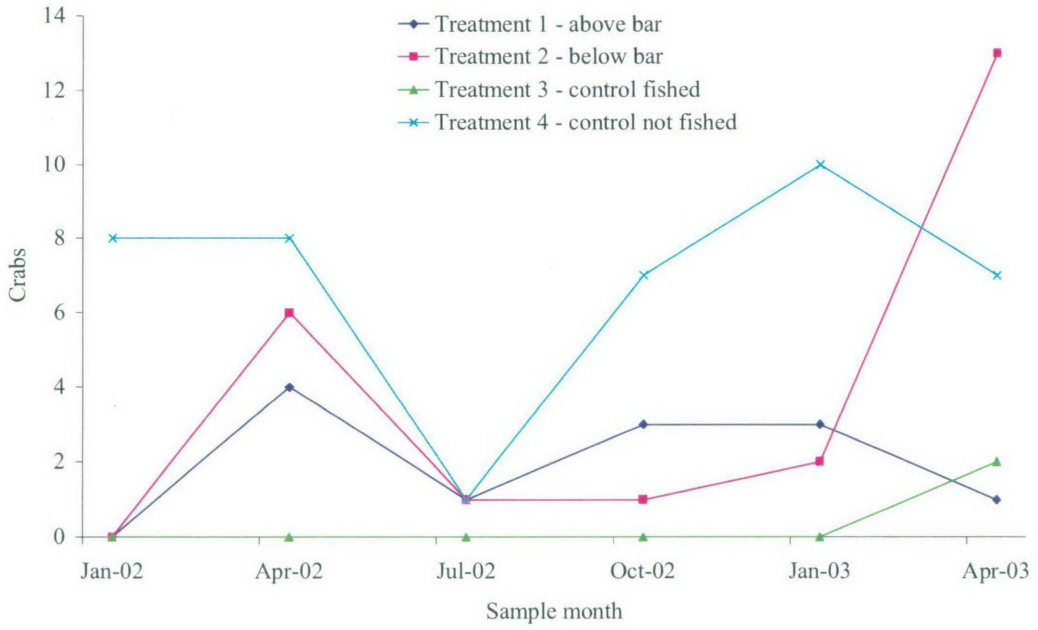

Figure 6.7. The total number of crabs recaptured monthly at each treatment irrespective of whether they were caught there initially.

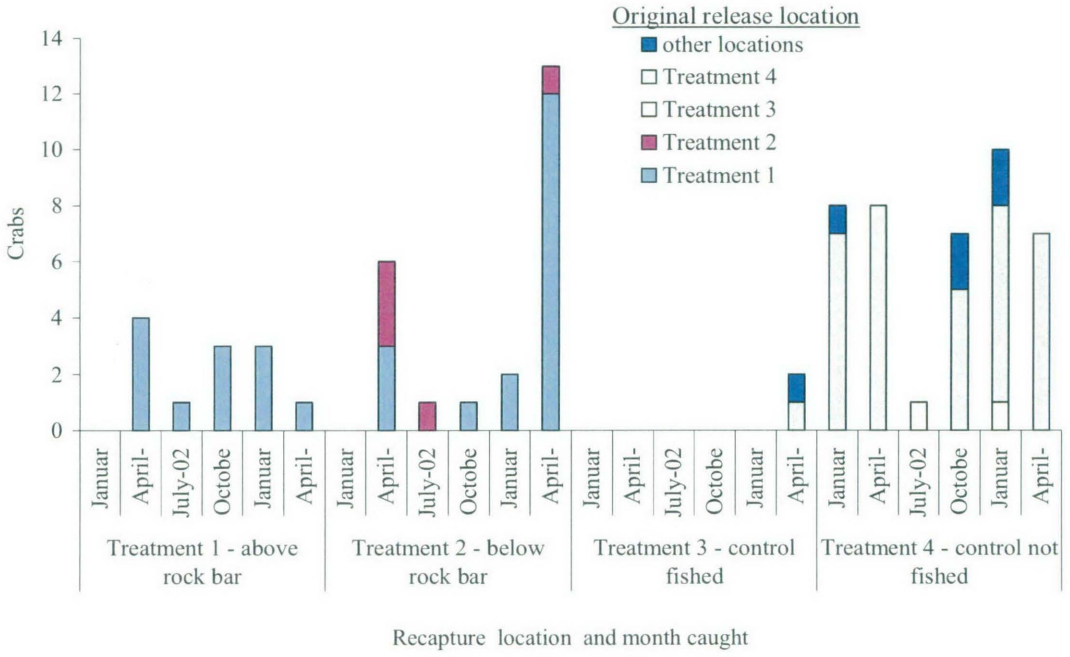

Figure 6.8. The total number of monthly recaptures at each treatment and the treatment where each recapture was originally released.

6.4.5 Recreational fishing effort

The number of traps, boats and people in each boat were counted at 1km intervals from the river mouth each month. No traps or boats were located in any month above the 12 km site in the left arm (rock bar) or at any location in the right arm of the estuary including the central basin (Treatment 4 – control sanctuary).

Individual months

Varied trapping effort was seen in each month from the 1 - 8 km sections of the estuary (Figure 6.9). In January, April and July 2002, trap effort was highest at the Sanctuary Zone border (7 - 8 km section). In October 2002, January and April 2003, trapping effort moved upstream into the newly gazetted fished zone above section 7 - 8 (Figure 6.9). Large numbers of boats and people occurred in Sections 3 - 4 and 6 - 7 in January 2003 while the greatest numbers of boats in the new fished zone occurred in October 2002 in Sections 8 - 11 with the greatest in the 10 - 11 km at the base of the rock bar (Plate 6.1; Figure 6.10: Figure 6.11).

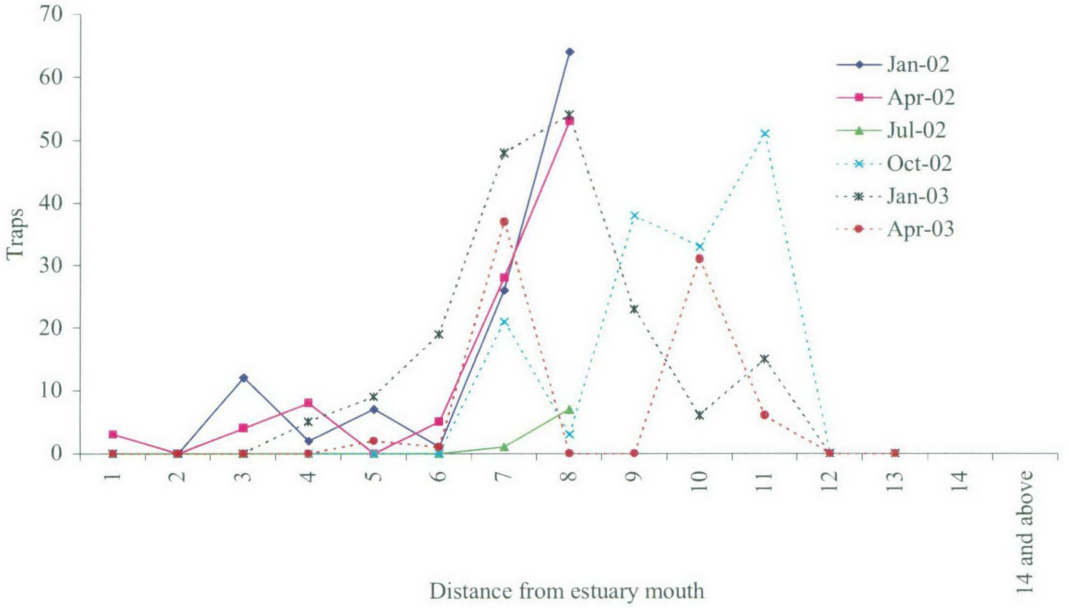

Figure 6.9. The total number of traps each month at 1 km intervals from the river mouth to 14 km upstream before and after the August 2002 zoning change.

Plate 6.1. Trapping pressure below the rock bar in August 2002 after the zone was reopened to fishing. Numbers indicate where traps are located.

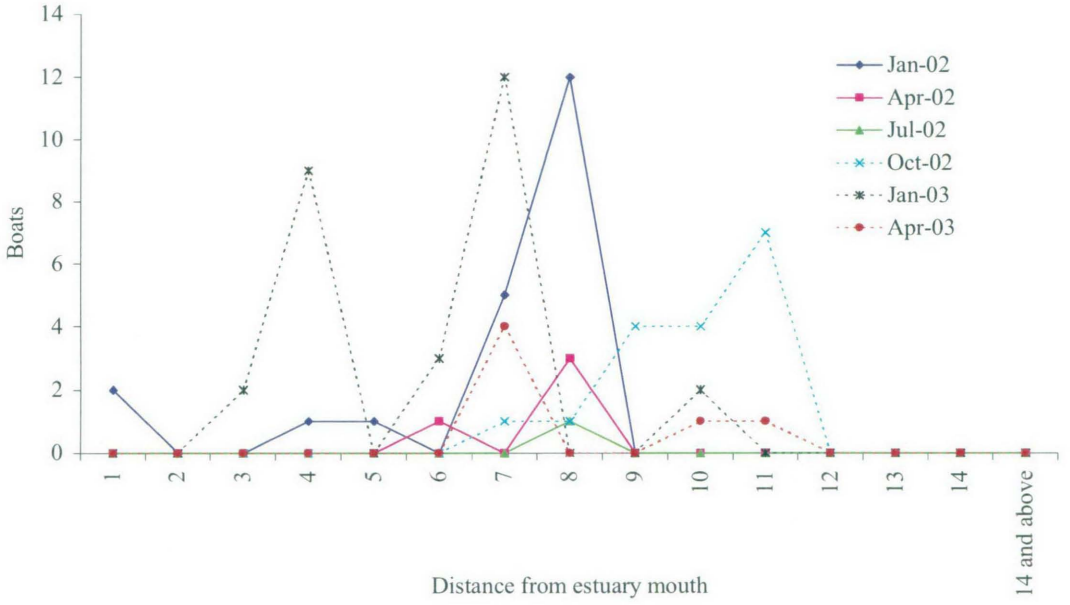

Figure 6.10. The total number of boats each month at 1 km intervals from the river mouth to 14 km upstream before and after the August 2002 zoning change.

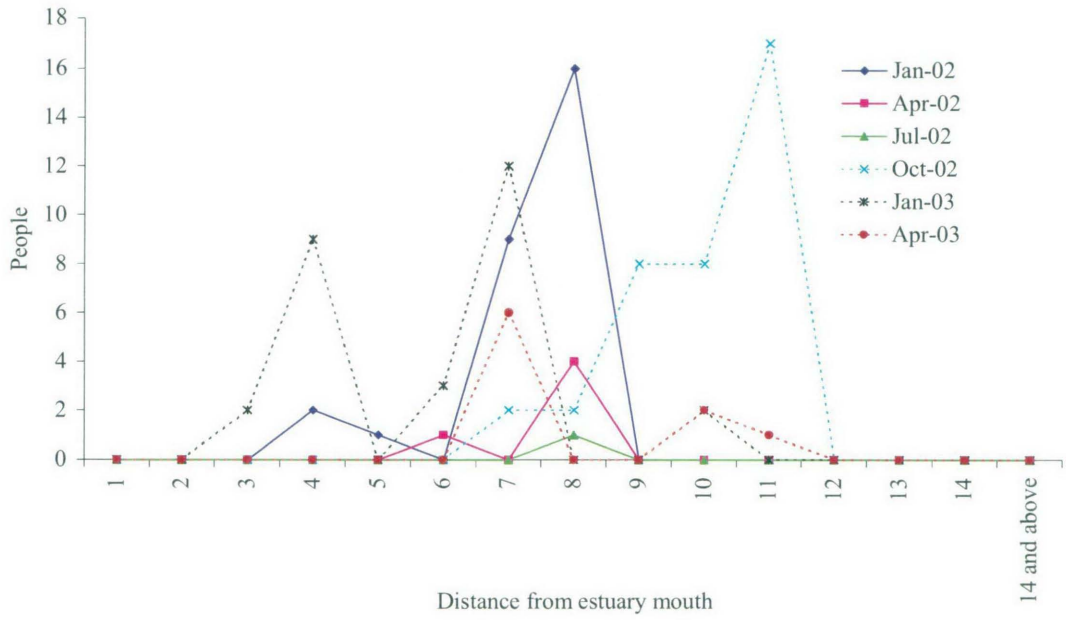

Figure 6.11. The total number of people on the estuary undertaking any activity each month at 1 km intervals from the river mouth to 14 km upstream before and after the August 2002 zoning change.

Months pooled – Pre-zoning change

Months (January, April, July 2002) and (October 2002, January, April 2003) were pooled to give pre and post zoning levels of effort. The total number of traps was highest at the 7 - 8 km section where the Sanctuary Zone border occurs. These traps were usually located just inside the Sanctuary Zone border and several traps were often found connected to the bank with no buoy. (Plate 6.2; Figure 6.12). The high number of traps coincided with the highest number of boats and people at this site (Figure 6.13, Figure 6.14). Damage to the sandbar from boats attempting to cross into the Sanctuary Zone was found at the 7 - 8 km section (Plate 6.3). The total number of traps had two peaks. The highest peak occurred at the Sanctuary Zone border 8 km from the mouth of the estuary while a smaller peak occurred 3 km from the mouth. This smaller peak was closest to the many boat ramps in the lower estuary and may have been fishers targeting blue swimmer crabs with traps during January and April school holidays. No boats or people were noted above the 7 - 8 km section on any occasion.

Plate 6.2. Site 8 in the Wooli Estuary at the junction of the fished and unfished zones before the August 2002 zoning change. Traps 1 - 4 are inside the Sanctuary Zone and therefore illegal along with the traps in the front of the boat which were illegally tied to the bank where the boat is sitting. Numbers 1 - 9 indicates where traps are located. (.....) indicates the border between the Sanctuary and fished zone.

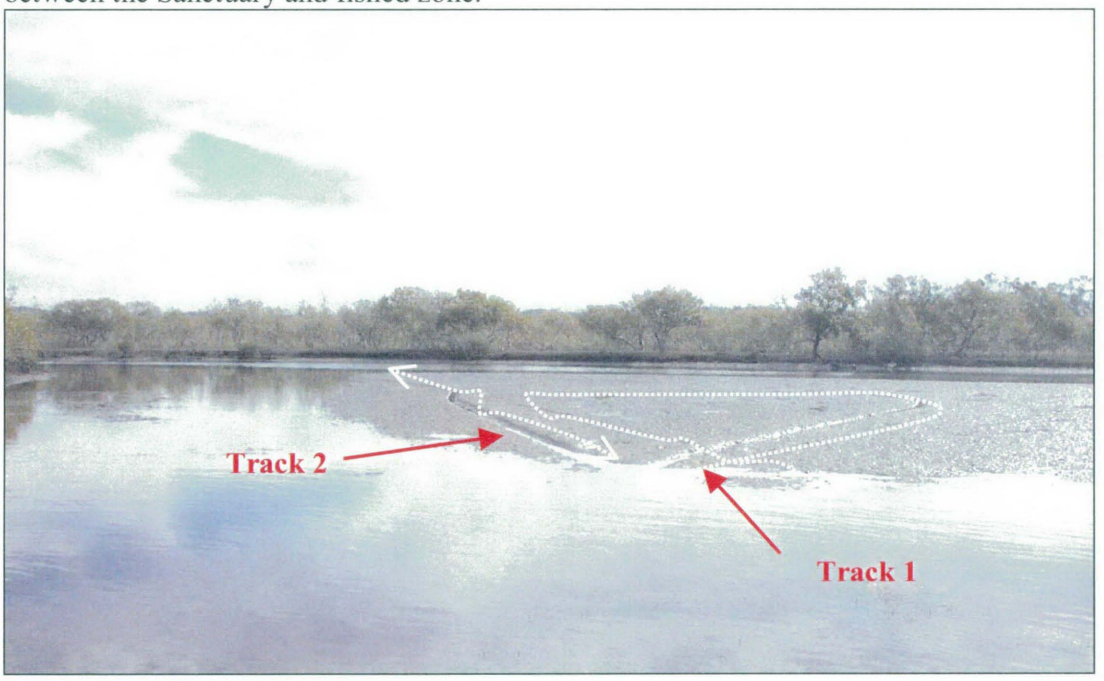

Plate 6.3. A sandbar located at the junction of the Sanctuary and fished zone at Site 8 during January 2003. Note the outboard motor tracks (.....) that lead into the bar and turn around half way (track 1), while track 2 ploughed its way through the sand and into the Sanctuary Zone.

Months pooled – Post-zoning change

The number of traps at the 7 - 8 km section decreased by 46% while traps at the 6 - 7 km section increased 52% once the zone changed in August 2002 (Figure 6.12). This increase occurred at the border of the new "no crab-trapping" area (Figure 6.1), which prohibited the use of wire crab traps above this point but still allowed netted dillies. Above this point large numbers of netted dillies were found in equal numbers upstream for 3 km in the previously no fished zone. No traps were found above the 11 km section. At this site, a large rock bar occurred which was only navigable at very high tides. While the number of boats and people was highest in section 6 - 7 km, an increase in boats and people was observed in section 3 - 4 km (Figure 6.13, Figure 6.14), yet there was no increase in trap numbers during this time. Once the new zoning change was introduced the number of boats and people increased above section 7 - 8 km up to section 11 - 12 km where a rock bar occurred. Above this, no boats or people were found.

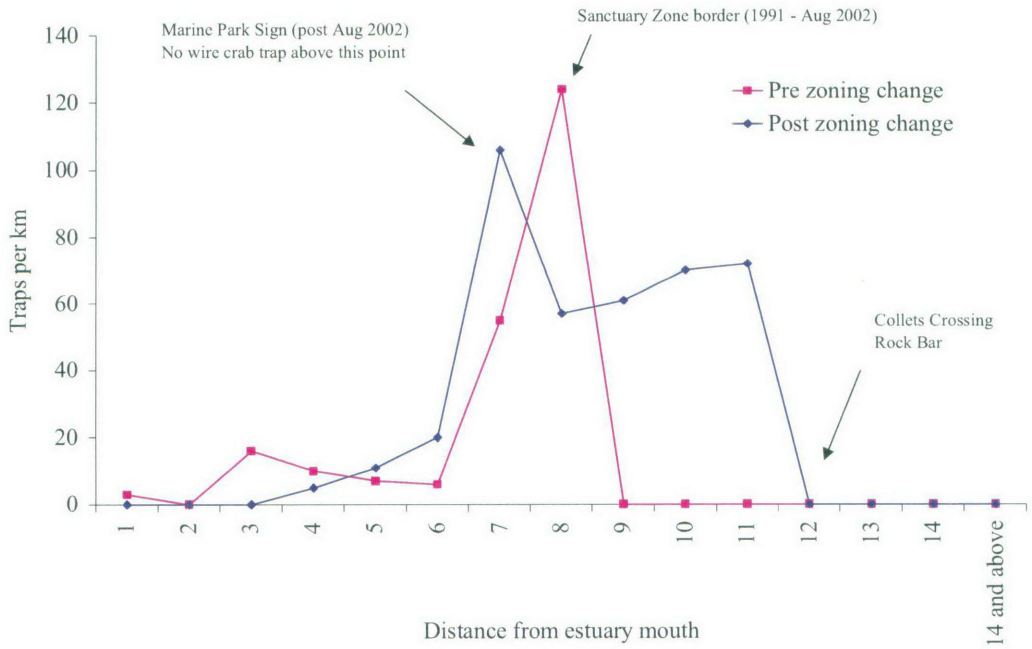

Figure 6.12. The total number of traps at 1 km intervals from the river mouth to 14 km upstream before and after the August 2002 zoning change. Months are pooled pre and post zoning.

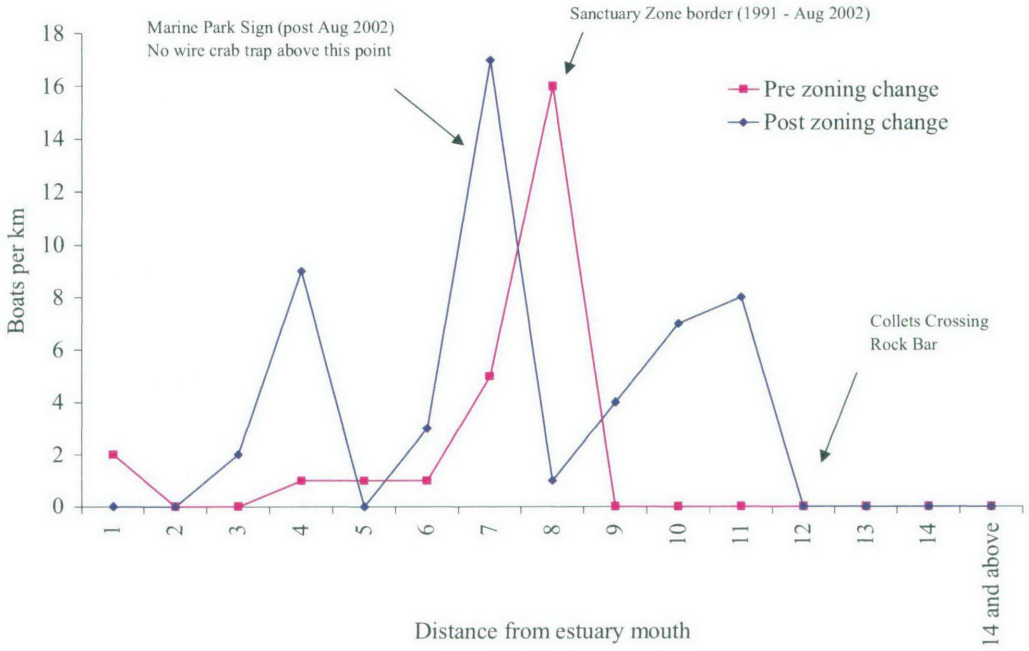

Figure 6.13. The total number of boats at 1 km intervals from the river mouth to 14 km upstream before and after the August 2002 zoning change. Months are pooled pre and post zoning.

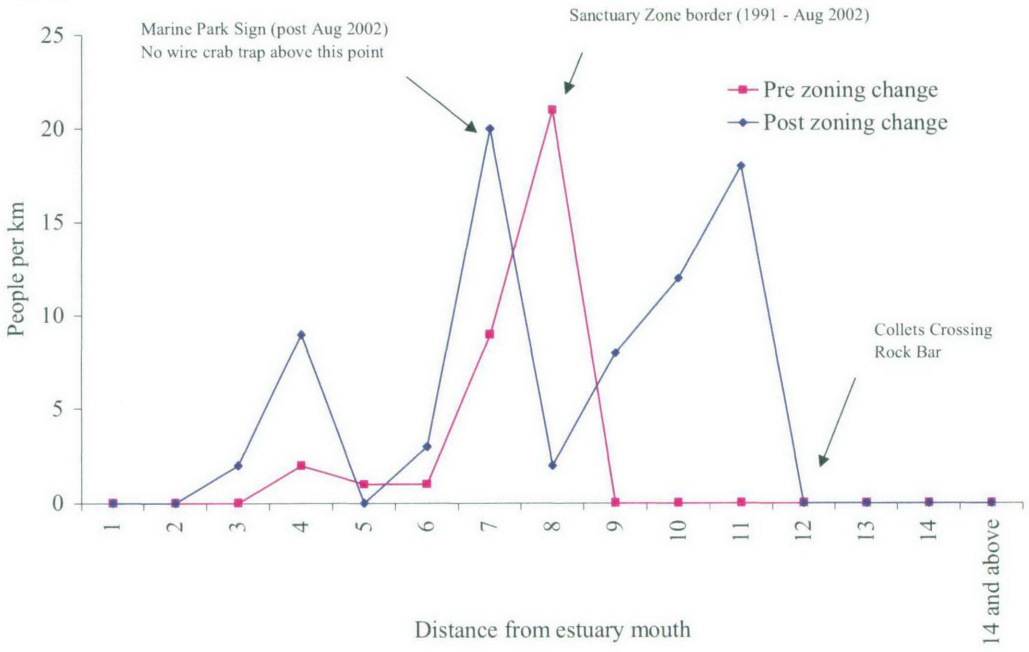

Figure 6.14. The total number of people on the estuary at 1 km intervals from the river mouth to 14 km upstream before and after the August 2002 zoning change. The total number of people for each month before and after the zoning change was pooled

6.4.6 Water quality

There was a significant difference between monthly water temperatures at each treatment ($F_{15,71}$ = 16.94, P < 0.0001) (Figure 6.15A). *Post hoc* Tukey's tests showed that temperature was higher in all months at the control not fished Treatment 4. Temperatures followed a seasonal cycle with the highest temperatures during January (30 °C) and lowest in July (12 °C). There was a significant difference between salinity concentrations each month ($F_{15,71}$ = 2.99, P < 0.002) (Figure 6.15B). Flooding caused salinity levels to decrease with increasing distance from the estuary mouth. The highest salinity concentrations occurred in most months except April 2002 and 2003 when high rainfall events caused flooding in the estuary and the water was visibly turbid (Figure A5 – Appendix 8).

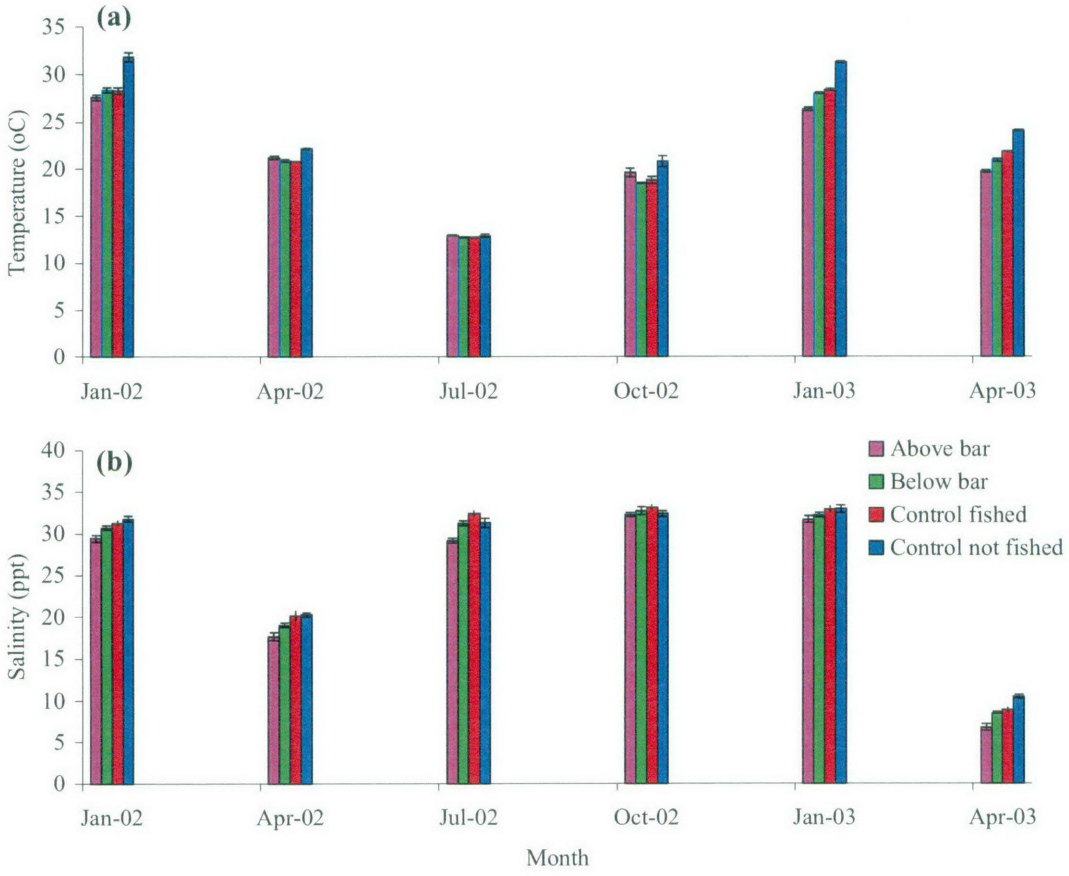

Figure 6.15. Monthly treatment means (±SE) (a) temperature and (b) salinity during the study period.

6.5 Discussion

6.5.1 "Natural barriers" as "Natural sanctuaries"

Natural barriers have shown that they maintain high numbers of fisher targeted mud crabs upstream of the rock bar and displace fishing pressure from Sanctuary Zone borders while preventing fishing upstream of the barrier due to their inaccessibility. Broad *et al.* (2002), found that longfin eel (*Anguilla dieffenbachia*) populations at locations that were not accessible to fishers in a New Zealand tributary were more abundant and larger suggesting that fisher access is a major factor to consider in zoning protected areas.

To apply this in other estuaries, the NSW MPA needs to undertake mapping surveys to detect structures (rock bars, sandbars) in all estuaries of the marine park. Captures of crabs at these barriers could determine if populations respond the same as mud crabs at Wooli. This would allow larger areas to remain as fished zones while providing protection to fisher targeted species. This may be politically and environmentally effective as resources are being protected without closing areas to 'no take'.

Natural barriers have the potential to help restrict access in fished systems without completely closing off to 'no take' Sanctuary zones, which may not be accepted by society (Kramer and Chapman 1999). Rather than the animosity of legislated barriers, such as signs and compliance officers, associated with Sanctuary zones, natural barriers allow recreational fishers to fish freely without impacting on the sustainability of mud cab populations in the estuary. This system provides equity between management and society as it allows access for fishers, while from a management perspective, mud crab population protection is achieved above the barrier as it prevents people entering this area.

6.5.2 Stock depletion and selective harvesting

Once fishing commenced at the Wooli rock bar, the area below the rock bar became depleted of crabs within months to levels associated with the control fished site downstream. These crabs were mostly male legal sized crabs. This outcome was similar to other sites which were opened to fishing at Wooli and Corindi (Chapter 4), and a study conducted on coral trout (*Plectropomus leopardus*) at Bramble Reef on the Great Barrier Reef, Australia (Russell 1998). Russell (1998) suggested that areas which are to be reopened to fishing should be done so by

staged temporal or spatial openings. This could minimise the effect of fisher concentrated effort when the area is opened to fishing. The site upstream of the rock bar resembled the unfished control site suggesting that crabs were not being taken by fishers and the rock bar was providing a refuge barrier for crabs. The crabs that were taken downstream of the rock bar by fishers were dominantly legal sized (>85 mm) male crabs suggesting that they are subject to capture first. Male mud crabs are likely to enter traps before females (Section 3.7). This study may not have sampled long enough after the zoning change to detect a temporal change in female abundance, as the males were being depleted first. In addition, the occurrence of females below the rock bar may have been female crabs moving downstream on their spawning migration to sea (Hill 1994).

6.5.3 Mud crab spill-over – fisher benefit

There was no difference in total catch before or after the change in zoning scheme for any treatment. This result most probably occurred due to the flood in April 2002 and 2003, which caused large increases in CPUE in the downstream Treatment 2 and 3. This masked any fish down (depletion) caused in previous months after fishing had been reintroduced. The major periods of recruitment at these treatments occurred during April 2002 and April 2003, which coincided with floods and low salinity concentrations in the estuary. During this period, a high percentage of the recaptured crabs below the rock bar had previously been caught upstream, suggesting that floods aid in replenishing stocks downstream. These crabs may become depleted by fishers again to pre-flood levels in the months following the flood. Without these floods, there was little recruitment downstream and abundances remained low. As this study concluded due to logistic reasons (time/money) after the flood occurred it is not known whether those crabs moving down over the rock bar from Treatment 1 were removed by fishers once the flooding stopped. No tags were reported from fishers to indicate this. Ruello (1973) found that the estuarine school prawn (*Metapenaeus macleayi*) moved downstream during marked increases in freshwater in the Hunter River, NSW, Australia. He suggested that the disturbance in the river sediments caused by the high water flow from the flood caused problems with normal burrowing and respiratory activity so the prawns moved downstream to more optimal conditions. This may also be the case with mud crabs as they bury in the estuarine sediments and flooding disturbance may cause them to move downstream. This was evident each time a flood occurred (Section 4.3.4). Not having regular flooding events each

year may lead to stocks becoming very low within a short period of time, placing increasing pressure on crab numbers and increasing the chance of illegal activity from fishers. These fishers may move into the Sanctuary Zone or use more traps than the legal allowance. The NSW MPA then faces extra work to reduce poaching of protected species inside the Sanctuary Zone. Effective zoning schemes should be designed at maximising spill-over to minimise this effect of poaching or using too many traps. This could be achieved by eliminating the total use of wire traps in the estuary and only allowing netted dillies, which are not usually left out overnight because crabs can destroy the trap. Secondly, the area needs further enforcement through regular patrols. This would be effective through a permanent compliance officer in the northern section of the SIMP as currently officers travel two hours if called out to enforcement problems in the northern section of the park. By the time officers arrive offenders have usually moved on.

6.5.4 Fishing effort

Fisher effort was primarily targeted at the zone borders before and after the zoning change. This is called 'fishing the line' where fishers deliberately fish at zone borders to maximise their catch from spill-over of species in the protected zone (Gell and Roberts 2002). In Japan, a 13.7 km^2 area was closed to fishing to protect the Zuwai crab (*Chionoecetes opilio*) (Yamasaki and Kuwahara 1990). The commercial boats concentrated their effort at the zone borders which resulted in increased catches due to spill-over from crabs inside the protected area. This has also occurred in other fisheries across the world (Bohnsack 2000; Murawski *et al.* 2000). Opening the left arm of the Wooli Estuary and the introduction of a 'no crab trapping' area displaced effort across the estuary. Wire trap effort was pushed further downstream from the Sanctuary Zone border and other trap effort moved upstream to the natural barrier after the zoning change. While the displacement of effort provided a relief at the Sanctuary Zone border, fishing effort may increase the impact on other unprotected areas within the estuary (Parrish 1999). This new design gives crabs further opportunity to move out into the fished areas, as there are fewer netted traps concentrated at the border. Therefore, the chance of being caught is reduced while spill-over of crabs from the Sanctuary Zone may increase into the fished zone. Although, the benefit of spill-over might be reduced where intensive fishing-the-line takes place as much of the spill-over may be caught locally within a small distance of the Sanctuary Zone. Fishers downstream may be disadvantaged if they do not have boats to travel upstream to the zone borders (Gell and Roberts 2002).

No traps or boats were located above the rock bar suggesting it is successfully restricting fisher movements. Discussions with local residents and tourists have suggested that it not worth damaging their boats to go over the rock bar at high tide. This provides further evidence of the success of this barrier in restricting fisher access and protecting crabs within this area.

What this study did not detect, is if the area downstream becomes overfished and regular floods do not push crabs downstream to replenish stocks, effort may move upstream. Fishers may begin to move across the rock bar in search of crabs. Although fishers do not want to 'damage their boats' now, this might be their current attitude because crab resources are plentiful below the rock bar. If numbers become low below the bar, fishers may become more inclined to risk taking their boats over the rock bar in search of crabs. This area upstream may then become depleted. Fortunately, for the Wooli system, several more rock bars and large trees occur across the estuary upstream of the rock bar. Although we managed to cross around these barriers, it took some time and effort to do so. Tourists may not be so eager to get through and may turn around. Overtime, these trees will decay, fall into the creek and provide access but trees may continue to fall over the creek due to natural processes. This occurrence may provide an annual blockage across the creek, leading to further crab protection and restriction to fisher access.

6.5.5 Future direction

This study strongly recommends incorporating the use of naturally occurring barriers (e.g. rock bars) as a zoning tool (border marker) in fished areas of marine parks. Shipp (2002) suggests that a fisheries management tool is one that sustains and increases the yield of a species through time. Identifying and using natural barriers as a management tool will help in the selection process of zoning estuaries. Theoretically, if several areas are in need of protection and only a small proportion can be taken by sanctuary due to environmental, political or social grounds, the results from this study will show several points. The area containing the natural barriers can be left open to fishing as it will also serve as a natural sanctuary while the adjacent area, having no natural barriers is more susceptible to over fishing and should be closed as a Sanctuary Zone. Barriers such as rock bars can be used as natural Sanctuary Zone borders, as they restrict access to fishers, thus lowering fishing pressure and providing protection to crabs upstream. This also aids in reducing illegal activity as the size and number of areas that must

be patrolled by compliance officers is reduced. Natural barriers reduces rapid stock decline once fishing occurs. The protected crabs upstream of the bar are a natural recruitment source of legal sized crabs to the fished area downstream of the rock bar. Natural barriers could be used in tandem with Sanctuary Zones as added protection in areas left open to fishing.