1.0 General introduction

1.1 Fisheries and their impacts

1.1.1 Types of impacts

Fishing activities from commercial and recreational sectors have an impact on the marine environment (Dayton *et al.* 1995; Kennelly 1995; Wahle 1997; Hall 1999). Impacts have occurred through the removal of target species, alteration of trophic relationships, changes in natural rates of predation (overfishing), removal of non-target species and the destruction of the physical environment (e.g. by trawling) (Robinson and Frid 2003).

In order to detect these changes you need to have a measure of natural variation in the population, such as seasonal change or water quality. Failure to separate this variation between natural and anthropogenic impact can lead to mitigation solutions being incorrect and the potential for the problem to be exacerbated.

The number of fishing boats worldwide has doubled since 1970 and marine fishing provides 90% of the world's fish catches (Moore 1999). This growing dependence on marine fish and the increasing number of fishers has the potential to magnify impacts. What a few people do on a sustainable basis over the years may become unsustainable when done by thousands of people (Agardy 1997). When a fishery becomes depleted, fishers may move effort to different areas (Prince and Diver 2001), a different fishery (Laurenson *et al.* 1993) or alternatively increase effort (Beddington and Rettig 1984) in an attempt to sustain catch rates. For example, boats in the Orange Roughy (*Hoplostethus atlanticus*) fishery in the South Tasman Sea resorted to either market fishing, changing fishing grounds or stopping fishing completely when catches remained low at the South Tasman Rise in 2001 (Prince and Diver 2001).

1.1.2 Impacts on the marine environment

There has been a decline in fisheries in Australia (Zann 2001). Of the 100 described fisheries in Australia, nine are overfished, 23 are heavily or fully fished, nine are under-fished and 59 are of unknown status (Zann 2001). Each fishery has direct and indirect impacts on the marine environment leading to changes in ecosystem processes (Zann 2001; Robinson and Frid 2003). These impacts have caused changes in a number of important processes. The removal of target species has caused changes in predator–prey interactions (Anderson and Ursin 1977; Carpenter *et al* 1985; Hall 1999) leading to complications for top-end predators such as marine mammals (Hall 1999; Kaiser and de Groot 2000). Fishing has also increased mortality of undersized fish (Frid *et al.* 1999; Hall 1999), destruction of benthic assemblages (Rainer and Munro 1982; Rainer 1984; Sainsbury 1991; Jones 1992) and affected other fisheries by habitat destruction (Sainsbury 1987, 1988, 1991). For example, intensive commercial mesh netting resulted in the decline of immature female catfish (*Cnidoglanis macrocephalus*) in a West Australian estuary (Laurneson *et al.* 1993). It was not until the biology of the catfish and the mesh selectivity of the gear being used was known that legal limits were raised. This increased the likelihood of females reproducing before being kept by fishers (Blaber *et al.* 2000).

1.1.3 Assessment of impacts

Whether these impacts continue to affect individual fisheries depends on how quickly the impacts are identified and proactive management strategies are produced to deal with the problems. This can occur through environmental impact assessment (EIA). Wahle (1997) suggested a three-step process for determining the impacts of fisheries activities. This is to: i) identify the effect or problem; ii) determine whether it is natural or fishing-related; and iii) if fishing-related, then implement management strategies to deal with the problem. To achieve this, information must be collected across all fisheries so that impacts or changes can be identified in the early stages of their development. Management strategies for individual fisheries can be formulated after preparation of an Environmental Impact Statement (EIS). An EIS provides a framework for assessing the impact of a fishery under management guidelines (Planning NSW 2003). In general, an EIS considers the impacts of fisher effort, the impacts on retained by-catch and bait species, impact on the wider aquatic environment, the economic issues and cost effectiveness of management, protection of key habitats and protected/threatened species, habitats or communities, influences of other activities on the fishery, and social issues associated with the fishery.

Impacts are usually caused by different rates of 'pulse' and 'press' disturbances that have 'pulse' and 'press' responses from the environment (Bender *et al.* 1984). A pulse disturbance occurs over a short period of time (Figure 1.1a) while press disturbances occur over a longer period (Figure 1.1b) (Underwood 1991). The response of populations to these disturbances can be long (press) or short (pulse) (Figure 1.1a, 1.1b). If a pulse disturbance is severe, the population may not recover for an extended period resulting in a press impact. Short term impacts may not require management intervention because the system may recover from the disturbance, but short-term impacts may alter other components of the ecosystem and need managing before they affect the ecosystem as a whole (Otway and Macbeth 1999). Press disturbances are harder to detect and are usually not done so until they have become large in magnitude while the impact of these disturbances on the environment are often hard to rehabilitate (Underwood 1991).

Below is an example of how 'Pulse' and 'Press' disturbances theoretically occur in a fishery for 'species A'.

'Pulse' disturbance

Recreational fishing effort increases during school or public holidays (pulse disturbance). During this time, effort is increased as more people are undertaking fishing which eventuates in more individuals of *species A* being taken than normal (Figure 1.1a). Frequent 'Pulse' disturbances without recruitment would result in a 'Press' response (i.e. a decline in Catch per unit effort (CPUE) until all legal sized individuals *of species A* are removed). A 'Pulse' response would occur when *species A* numbers return to normal after public holidays once the increased fishing effort has declined or a recruitment event occurs (i.e. flooding).

'Press' disturbance

Closing areas to fishing concentrates effort in other parts of an estuary causing a 'Press' disturbance (Figure 1.1b). The response of *species A* to closure may be a 'Press' response. Thus, abundance in the protected site increases as there is no fishing pressure and obviously declines in the fished area as effort has been concentrated on the remaining, available area.

As fishing can have 'Pulse' and 'Press' disturbances on populations, changes in targeted species could be detected as: (1) a reduction in CPUE and the average size in fished areas compared to unfished areas; (2) a decline in CPUE and average size after fishing has recommenced in areas previously protected from fishing activity (depletion experiment); and (3) an increase in CPUE and size after fishing is removed from an area (replenishment).

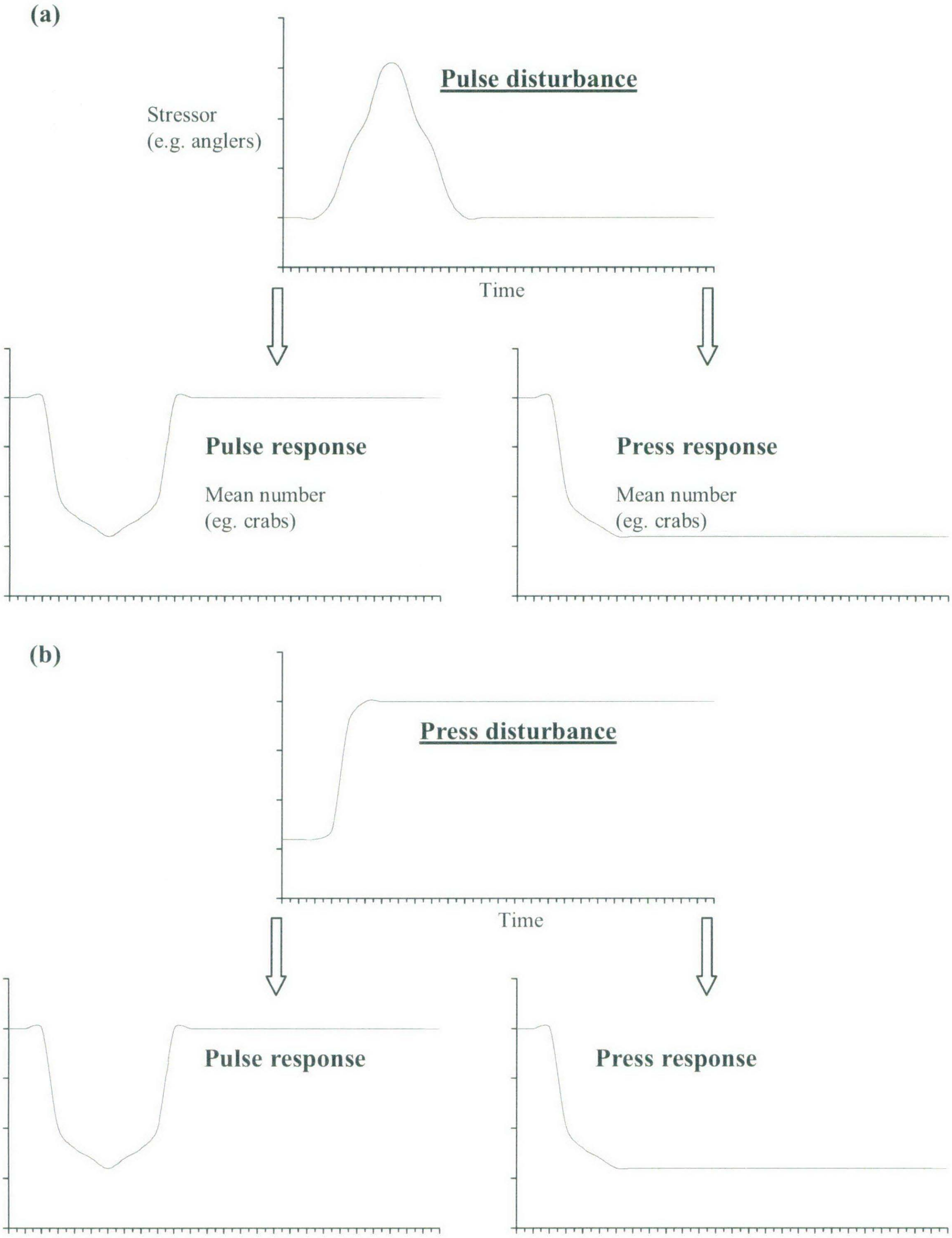

Figure 1.1. Responses of variables to (a) 'pulse' and (b) 'press' disturbances. These responses can be either long-term or short-term responses. (derived from Bender *et al.* 1984).

1.2 Managing the marine environment

1.2.1 Protection of the marine environment

Marine ecosystems in Australia have had few protection or management regimes designed to provide for their ecologically sustainable use. The first Marine Protected Area (MPA) in Australia was declared at Green Island off the Victorian coastline in 1938, followed by the Great Barrier Reef Marine Park in 1975 (Davey 2003). The implementation of the first MPA showed that the social, economic, political and environmental importance of the marine environment was being recognised. Since then, numerous MPAs have been established to provide protection to a large range of ecological values. MPAs are any area of intertidal or subtidal terrain and includes all the overlying water and associated flora, fauna, historical and cultural features which have been declared by law to protect part or all of the enclosed environment (Kelleher and Kenchington 1992). The objective of MPAs are (Agardy 1997: 88):

"*to protect critical ecological processes that maintain the ecosystem and allow for the production of goods and services beneficial to human kind, while allowing for the utilisation of ocean space and resources that is sustainable in an ecological sense*".

The value of MPAs are that they provide protection to populations of marine life causing increases in fish growth, average size, abundance, recruitment, spill-over and ecosystem benefits through reduced disturbance while providing an opportunity for research, education, use and enjoyment (Cole *et al.* 1990; Roberts and Polunin 1991; Roberts 1994; Bohnsack 1996, 1998; Ballantine 1997; Childress 1997; Wahl 1997; Guenette *et al.* 1998; Murray *et al.* 1999; Crowder *et al.* 2000; Jennings 2000; Ward *et al.* 2001; Halpern and Warner 2002, Russ 2002). For example, the abundance and average size of spiny lobsters in the Florida Keys National Marine Sanctuary is larger in the no-take reserve than surrounding fished areas (Causey 2003) while male mud crabs (*Scylla serrata*) have been found to be more abundant and larger in a no-take reserve in the Moresby River in North Queensland (Rudkin *et al.* 2003).

Special features can be protected and allowed to recover if disturbed, providing ecosystem maintenance, production and long-term sustainability (Agardy 1997). MPAs also provide employment through fisheries, recreation and tourism and contribute to community awareness and understanding of the marine environment. For example, the Great Barrier Reef Marine Park, Australia, produces about $1 billion annually through tourism and $150 - $200 million, through commercial fishing. It also provides education through centres such as Reef HQ, which was opened in 1987 as an educational centre to promote the reef and management of this area (GBRMPA 1999).

1.2.1.1 Types of Marine Protected Areas

Declaration of aquatic reserves, closed areas, harvest refugia, and multi-use marine protected areas (Marine Parks) are approaches being used to protect the marine environment (Agardy 1997). Aquatic reserves, closed areas or harvest refugia are used to conserve stocks and habitats threatened by over-exploitation and destructive fishing, whereas marine parks aid in resolving user conflicts by protecting critical areas while allowing the long-term sustainable use of marine resources. Aquatic reserves, closed areas or harvest refugia regulate only fishers while marine parks regulate a broad range of activities covering fishers, tourism, shipping, defence and mining (Fisher *et al.* 2003). Marine parks have been introduced as an effective means of managing coastline and for protecting species vulnerable to over-exploitation or disturbance (Roberts 1994). Marine parks incorporate zoning plans to provide strategic frameworks for managing activities as they specify the purposes of each zone by regulation and enforcement. These vary from highly protected areas that enable species protection or habitat restoration to areas that allow multiple users from different groups. Within marine parks in NSW, Australia, four zoning types are used. These range from no-take sanctuary zones to general use zones that have minimal restrictions (MPA 2002).

These management tools have been developed in response to the increase in our understanding of the environment through population dynamics, ecological forces and the identification of critical areas. Critical areas are of the highest value as they protect the breeding, feeding and habitat areas essential to the survival of organisms in the marine environment (Kenchington 1990; Agardy 1997). Recently, Grey Nurse Shark

(*Carcharias taurus*) aggregation sites along the NSW coastline, Australia, were identified as critical habitats under a discussion paper on Grey Nurse Sharks. Protecting these critical areas are essential to recovering shark numbers which had declined due to hook and line fishing and spear fishing (NSW Fisheries 2003).

1.2.1.2 How do Marine Protected Areas work?

MPAs provide insurance against declining fisheries in surrounding fishing grounds (Lauck *et al.* 1998). Theoretically, these areas aim to increase abundance and the average size of individuals leading to spill-over into surrounding areas. This insurance may only be successful if enforcement is effective (Gel and Roberts 2002). Paddack and Estes (2000) found densities of fish were 12 - 35% higher at some Californian marine reserves, which had a history of serious compliance problems, leading to smaller benefit or change to species in the MPA than what might have occurred under total protection and enforcement.

Gell and Roberts (2002) suggested that scallops (Murawski *et al.* 2000), abalone (Wallace 1999), and some fish (Russ and Alcala 1998, Murawski *et al.* 2000, Roberts *et al.* 2001) were more likely to respond to MPAs than other marine organisms. These species are all relatively sedentary which restricts their home ranges and minimizes the areas that need to be protected. Less sedentary species may also increase in abundance in MPAs. For example, lobsters migrate large distances during their life but have been shown to increase in MPAs in several studies (Edgar and Barrett 1999; Kelly *et al.* 2000; Goñi *et al.* 2001; Rowe 2000). These mobile species can be protected at spawning aggregation sites or juvenile habitats within the MPA where they are highly vulnerable in large numbers (Apostolaki *et al.* 2002).

The time taken for a MPA to be effective may vary between species that live within the MPA. Halpern and Warner (2002) studied the effects of MPAs on 80 species and found that density, biomass, organism body size, and species diversity increased within 1 - 3 years in these areas and that abundance could double or triple within 3 - 5 years.

1.2.1.3 Size of Marine Protected Areas

The size of a MPA and management zones within the MPA depends on the species or habitat being protected. For lobster populations, the benefit of protected area depends on the size of the region, the range of habitats for use by each life-stage and the relative movement of different life-stages (Agardy 1997). This is an important factor to consider when creating zoning schemes within marine parks, as protective areas which are too small have little effect on species conservation, whereas too large an area can result in social complications with users (Agardy 1997). Marine reserves protect juveniles until maturation, leading to increased densities of mature animals (Childress 1997). This is true for populations that spend their life-cycle within the limits of the reserve, but consideration must be given for species whose life-cycle stages expand across different areas. For example, in NSW, the most common and valuable commercial species in estuaries are migrants, few are residents and virtually none are transients (Roy *et al.* 2001), so MPAs need to be designed to protect the different stages of their lifecycle. Activities such as fishing that occur outside or adjacent to MPAs can have direct impact on these species (MPA 2001).

1.2.2 Marine Parks in NSW

1.2.2.1 NSW Marine Parks Authority

Multi-use marine parks are one way of managing a broad range of activities. The Marine Park Authority (MPA) in NSW was formed in 1997 under the *Marine Parks Act 1997*. It consists of representatives from the Premier's Department, NSW Fisheries, and the NSW National Parks and Wildlife Service (MPA 2001). The role of the NSW Marine Parks Authority (NSW MPA) is to (1) investigate, assess and consider proposals for marine parks or variations of the areas of marine parks, (2) to make recommendations as to the appropriate classification of areas within marine parks, (3) to prepare an operational plan in respect of each marine park, (4) to manage and control activities that may affect marine biological diversity, marine habitats and marine ecological processes in marine parks, (5) to provide for and regulate the ecologically sustainable use (including commercial and recreational fishing) of marine parks, (6) to disseminate information about marine parks to encourage public appreciation, understanding and enjoyment of marine parks; and (7) to encourage and permit, when appropriate, scientific research into the ecology of marine systems (MPA 2004).

To successfully fulfil these roles, the NSW MPA sets goals to manage parks as a whole and includes strategic objectives within each park to meet different needs. These goals aid in achieving a comprehensive, adequate and representative system of marine protected areas that include a full range of marine biodiversity at ecosystem, habitat and species levels (MPA 2004).

A variety of management tools aid in managing activities (MPA 2001). These include (1) zoning plans which provide different levels of protection throughout the marine park, (2) operational plans that set management objectives for the marine park, (3) permits that manage current or proposed activities, (4) management plans that handle specific activities such as aquaculture and commercial fishing, (5) "Codes of conduct" developed by specific groups and industries that manage certain activities and (6) "Closure controls" that allow the NSW MPA to modify current zoning for nominated areas.

The development of Marine Parks in NSW has been to establish a marine park in each of the bioregions as part of the 65 identified around the Australian coastline (Creese and Breen 2003). In NSW, six bioregions were identified which included Lord Howe Island. These bioregions and individual marine parks provide a comprehensive and adequate representation of all marine areas in NSW (MPA 2001).

1.2.2.3 Solitary Islands Marine Park

The oldest marine park in NSW is the Solitary Islands Marine Park. The Solitary Islands Marine Park (SIMP) was established in January 1998 under the *Marine Parks Act 1997*. Prior to this, the area had been managed as a marine reserve since May 1991 under the *Fisheries and Oyster Farms Act 1945*. The SIMP covers an area of 71 000 ha along the mid north coast of NSW. It spans from the Sandon Estuary in the north (lat. 29°40.4S) to Muttonbird Island at Coffs Harbour in the south (lat. 30°18.4S) (MPA 2001, Zann 2001) (Figure 2.1). The region contains a range of habitats including estuaries, sandy beaches, rocky headlands, subtidal reefs, island fringing reefs, open ocean and soft substrate.

These habitats support a mix of tropical, sub-tropical and temperate marine communities (Zann 2001). As the area also includes many endemic species, it is an important region to conserve (MPA 2001).

The SIMP is bordered by urban development and the Yuraygir National Park. The National Park gives further land-based protection to the area. Some of the barrier lagoons and intermittently closed and open lakes and lagoons (ICOLLs) are in almost pristine condition because of their bordering to the National Park (MPA 2001, Zann 2001). Areas within the SIMP are also sacred to Aborigines with many cultural and spiritual sites being found throughout the marine park (MPA 2001, Zann 2001).

As part of the conservation process, zoning and operational plans were developed to manage the SIMP (Table 1.1). The operational plans outline how the NSW MPA will manage permits, closures and activities within the SIMP. This is an important area as there are many users within the SIMP covering all aspects of commercial and recreational fishing, tourism, and scientific research. The zoning scheme provides for the protection of the environment while allowing reasonable access for commercial and recreational activities. The zoning scheme aims to maintain or improve the present state of the environment by reducing the effects of these activities.

Table 1.1. The different zones used to manage activities in the Solitary Islands Marine Park before and after the 2002 zoning change (MPA 2001).

Zone	Objective
- Recreation (pre August 2002) **- General Use** (post August 2002)	To allow for ecologically sustainable commercial and recreational use while protecting marine life, habitats, ecological process and natural and cultural features.
- Refuge (pre August 2002) **- Habitat Protection** (post August 2002)	For the protection of marine life, habitats, ecological processes and natural and cultural features by allowing ecologically sustainable commercial and recreational use which does not have a significant impact on marine life or habitats.
- Sanctuary	Allows for scientific research, recreation and education which do not harm or affect the environment while providing the maximum protection for marine life, habitats, ecological processes and natural and cultural features
- Special Purpose (post August 2002)	Provides for both conservation and sustainable use of species, habitat and cultural features, dependant on the location and special management requirements of the zone. Special purpose zones also cater for specific activities, which are not covered in other zones such as aquaculture leases, research and Aboriginal sites. Special features such as slipways and shipwrecks are included.

1.2.2.4 Management and Importance of Estuaries in the Solitary Islands Marine Park

The Solitary Islands Marine Park has many types of habitat, which contain communities of distinctly different combinations of marine species (MPA 2001, Zann 2001). Of particular relevance to this thesis are estuarine habitats. An estuary is a:

'*semi-enclosed coastal body of water, which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage'* (McLusky 1981).

There are 14 main estuaries within the marine park consisting of two types (MPA 2001, Zann 2001). Estuaries such as Sandon, Wooli, and Corindi, are barrier lagoons while coastal lagoons of Station Creek, Arrawarra Creek and Hearns Lake are classified as Intermittently Closed and Open Lakes and Lagoons (ICOLLs) (Figure 2.1) (MPA 2001).

The estuaries of the SIMP are crucial links to marine and coastal environments. SIMP estuaries export nutrients to inshore environments and are key habitats for up to 49 species of juvenile and adult marine fish (MPA 2001). This species richness results from the abundant invertebrate life, which increases fish productivity and provides a food source for juvenile commercial and recreational fish species.

Estuaries have many different habitats but the most important of these within the SIMP are mangroves and seagrass (Section 2.2). These areas provide feeding, spawning and nursery grounds for fish and invertebrates (Saenger 1995). Mangroves in estuaries provide feeding and roosting areas for birds, insects, mammals, reptiles, and act as nursery areas for fish, crustaceans and molluscs (Hutchings and Recher 1982). Mangroves are found in all estuaries except Station Creek. Six mangrove species are found in the Sandon Estuary (the northern most estuary) and two in Coffs Creek (the southern most estuary) (MPA 2001). Three of the mangrove species are at their most southern range and are more susceptible to human impact and natural events (MPA 2001). Two types of seagrass occur in the SIMP *(Zostera capricorni* and *Halophila ovalis)* (Section 2.2). These plants grow in clear, shallow waters and help to clear and increase water quality by stabilising sediments and preventing erosion by trapping organic matter and sediments. Seagrass provides a habitat for a wide range of flora and fauna (Bell and Pollard 1989, Hannan and Williams 1998).

1.2.2.5 Fishing Pressure in Estuaries of the Solitary Islands Marine Park

Commercial and recreational fishing occurs in estuaries of the SIMP (MPA 2001). Fishing is the most important activity of visitors in the SIMP with Wooli being the most popular estuarine location (Table 1.2) (Zann 2001). The most popular types of fishing are beach and shore fishing, bottom angling, trolling and crab trapping. Individual males or groups of males principally undertook these activities with 60% being male during a 1996 survey (Meanwell 1996). Visitors mainly used boats to access the estuaries while the number of people that used boats to access the estuaries had easy access to sanctuary protected areas.

Table 1.2. Estimated tourism statistics for selected estuaries of the SIMP (Zann 2001)

	Visitor nights	Visitors fishing (%)	Boats (%)	*Reference*
Sandon	51,000	82	45	Kuster (1997)
Wooli	472,790	84	10	Byrnes (1997)
Corindi	-	90	18	McDonald (1997)

Most protective zones occur in the upper reaches of SIMP estuaries, which are only accessible by boat and four wheel drive (4wd). As there are only two Marine Park/Fisheries Officers that patrol the SIMP and the head office is a 1 - 2 h trip away from the northern estuaries at Coffs Harbour (Figure 2.1), this potentially provides compliance problems in each estuary. Illegal fishers may realise that the chance of being caught is small, due to the isolation of protective zones.

Commercial fishing pressure primarily targets mud crabs in estuaries of the SIMP (*pers. comm.* Mike Tobin, District Manager, NSW Fisheries, Coffs Harbour). The only other activity is mesh netting which occurred annually between March and September in the Sandon Estuary under the *Fisheries Management Act 1994* prior to the zoning change in 2002 (SIMP 2001). From 1991 there were four commercial fishers catching crabs in 14 estuaries of the SIMP. However, only two commercial fishers reported trapped mud crabs in the Solitary Islands Marine Park in 1999/2001 (SIMP 2002). The last reported commercial catches of mud crabs in the three largest estuaries occurred in the Wooli Estuary in October 1998, Sandon Estuary in July 2002 and Corindi Estuary in October 1991 (*pers. comm.* David Makin, NSW Fisheries (Acting Manager) Commercial Catch Records, 3rd September 2003). There are currently three active commercial fishers after the NSW Fisheries buy-out of licenses to restrict commercial fishing within the park (*pers. comm.* Mike Tobin, District Manager, NSW Fisheries' Coffs Harbour).

Despite the protective zoning in estuaries, commercial activities continued within prohibited protected zones within the SIMP. Prior to August 2002, in the Sandon Estuary, one commercial fisher had a monopoly on the estuary as he was allowed to trap in the Refuge Zone under a State government ministerial arrangement. It is unknown why this was the case as this zone prohibited crab trapping by all other commercial and recreational anglers. This fisher was reported to take up to 1 t of mud crabs, 6 t of mullet and 2 t of blackfish per annum (Zann 2001).

1.3 Using focal species to identify change

In general, management of marine systems is reactive rather than proactive as we currently aid species that are already in trouble rather than trying to identify species or systems that may be impacted in the future (Simberloff 1998). To be proactive, representatives of ecosystems such as focal species ('indicator species', 'keystone species', 'umbrella species' or 'flagship species') have been used to evaluate management strategies (Dudley *et al.* 1999; Hockings and Phillips 1999; Zacharias and Roff 2001). Focal species are defined as any species that increases our knowledge, understanding, management and conservation of our complex environment (Zacharias and Roff 2001). A Change in abundance or presence of these species detects the composition, state or change of a larger complex environment. Menge *et al.* (1994), Navarrette and Menge (1996), Power *et al.* (1996) and Simberloff (1998) all supported the use of using focal species for conservation and management as they are used to measure the success of management objectives (Hockings *et al.* 2000).

The focal species concept is difficult because it is not fully understood which species is most appropriate even when we know the effect that needs to be measured (Simberloff 1998). Secondly, we assume that patterns of distribution and habits of focal species parallel those of other species and the system from which the focal species was taken (Zacharias and Roff 2001). This can lead to conflicting management objectives as the state of the focal species seldom mirror that of the species around it.

1.3.1 Selecting a focal species

Depending on the question being asked, focal species are defined using a number of characteristics (Table 1.3).

Table 1.3. Information provided by different focal groups in marine conservation (derived from Zacharias and Roff 2001)

	Focal Species				
Identify	**Umbrella**	**Flagship**	**Keystone**	**Composition indicator**	**Condition indicator**
1*	No	No	No	Yes	No
2*	No	No	No	Yes	No
3*	Yes	Yes	No	Yes	No
4*	No	Unknown	Yes	Unknown	**Yes**
5*	Possibly	Possibly	No	No	**Yes**

1. Identify representative community and habitat types?
2. Identify distinct community and habitat types?
3. Identify geographical extent of community and habitat types?
4. Identify condition or state as a result of ecological factors?
5. Identify condition or state as a result of anthropogenic factors?

Umbrella species provide protection when the ecosystem around the species being protected is conserved as well (Launer *et al.* 1994; Simberloff 1998; Zacharias and Roff 2001). For example, the protection of the Bay Checkerspot Butterfly (*Euphydryas editha bayensis*) in central California would ensure that 98% of native spring flowering plants would receive protection from urban development (Launer *et al.* 1994). Without the protection of the butterfly, urban development would continue into the native plant habitat.

Flagship species are large enough that they can be conserved through a conservation campaign because of public interest. These campaigns are often expensive (Simberloff 1998) and management regimes of two flagships can often conflict (Polhemus 1993; CSIESA 1995; Simberloff 1998; Graham 1999; Zacharias and Roff 2001). For example, in the Everglades of Florida, United States of America, the Everglades Snail Kite (*Rostrhamus sociabilis plumbeus*) and the Wood Stork (*Mycteria Americana*) are both federally listed protected birds. While these birds are both flagships, protecting them in the same area conflicts as the kite relies on high water levels to feed on its primary food source of snails while the stork requires lower water to concentrate food sources. Conflict between these flagships occurred when the US Fish and Wildlife Service (USFWS) stopped a proposal to modify water flow in the Everglades National Park. The USFWS stated that to improve stork habitat would be detrimental to the kite (Simberloff 1998). The argument here is that both species are equally threatened but when management objectives overlap which species should come first?

Keystone species may change the entire structure of a community if removed. The species may not be important to society in terms of providing a resource, but it could promote understanding of the environment it lives in (Simberloff 1998; Zacharias and Roff 2001). Power *et al.* (1996) displays an extensive list of marine keystone species. For example, the effect of keystone species on target organisms by the consumption of limpets by oyster catchers (Hockey *et al.* 1984), or water quality on oysters (Ray 1996).

Indicator species are used for two reasons (Simberloff 1998; Zacharias and Roff 2001). Their presence or abundance is believed to reflect those of other species in the surrounding area and they reflect chemical or physical changes in the environment. Indicator species have been divided into two categories that describe different circumstances. Composition and condition indicator species are of greatest use (Zacharias and Roff 2001). Zacharias and Roff (2001) suggested that composition indicators describe particular variables such as a habitat or ecosystem (i.e. species that may live in a particular habitat). For example, the presence of the giant kelp (*Macrocystis spp.*) indicates potential sea otter habitat (Zacharias and Roff 2001) while condition indicators are most often used in monitoring programs as they describe anthropogenic and environmental change (Meffe *et al.* 1997).

Condition indicators may be the most effective and useful method for marine park management as they can identify condition or state of anthropogenic factors such as fishing pressure (Zacharias and Roff 2001). For example, the coral trout (*Plectropomus leopardus*) was used to determine the management implications of closing and reopening a reef on the Great Barrier Reef, Australia. Abundance and size of trout increased once the reef was closed to fishing and became depleted within months once fishing commenced (Russell 1998).

The approach taken to identify conservation strategies relies on society identifying which species is at the centre of the conservation effort. It can then be used to design a conservation strategy. Condition indicators specify if an anthropogenic process has had any effect on a species. To be effective as a condition indicator, the indicator needs to determine whether the presence or absence of the species selected indicates the ecological state with and without an anthropogenic impact. This may aid mitigation, restoration and monitoring strategies once reserves have been established (Zacharias and Roff 2001). Finally, by using a condition indicator it allows management to demonstrate results that infer ecological integrity (Zacharias and Roff (2001).

1.3.2 Mud crabs as a focal species

The NSW MPA has identified monitoring, evaluating and modifying marine park boundaries and zoning arrangements as a major priority area (MPA 2003). As part of the State of the Environment of the Solitary Islands Marine Park report, Zann (2001) recommended that:

"a strategic, long-term program of research and monitoring be undertaken to monitor key indictors and uses of the SIMP, particularly commercial and recreational fisheries".

This would provide specific evidence on the effectiveness of marine park zones in the SIMP. In 1998, 7 years after the formation of the zoning schemes there had been no monitoring programs established to look at the impact of zoning schemes in estuaries of the SIMP. Thus, little was known about whether the zones were affecting species or habitat condition. The first research to address this lack of information was developed in 1998 during my honours theses on the demographic structure of mud crab populations in different marine park zones in the Wooli Estuary (Butcher 1999). Since then only one current University Masters study on fish and a mud crab ICOLL pilot study (Butcher and Malcolm 2003, 2004) has looked at zoning schemes in estuaries of the SIMP.

The commercial and recreationally targeted mud crab (*Scylla serrata*) was identified as potentially the best 'condition indicator' species for evaluating the effects of estuarine zoning schemes in the SIMP (section 1.3). The mud crab is an important recreational and commercially targeted species in this area and is under pressure from overfishing. It is an ideal indicator species as it is large, abundant, relatively sedentary, actively captured using similar methods by both commercial and recreational fishers, and can be sampled and released unharmed using the same trapping methods. They also have a relatively short life cycle (3 to 4 years), which means their abundance may show a quick response to the effects of protected areas over short evaluation periods (e.g. the 5 year evaluation proposed for SIMP).

In estuaries, the use of an indicator such as mud crabs would be based on the assumption that fishing is placing extreme pressure on its population and fished and unfished zones can be sampled to determine any difference in anthropogenic and natural control sites.

As Wooli, Sandon and Corindi are the largest estuaries, the most popular tourist destinations within the SIMP (Table 1.2) and places where mud crabs are easily caught, management plans based on this thesis may aid in sustaining this resource for future use and help protect other species. This type of study has the potential to be used in other estuaries within the SIMP and to optimise the continued, effective management of this fishery and the use of multi-use zoning schemes in estuarine marine park management in NSW.

1.4 Aims and predictions of the project

The ***main objectives*** of the project were to monitor and compare mud crab catches as catch per unit effort (CPUE) in zones 'open' and 'closed' to fishing, before and after zoning changes in 2002, and to assess the influence of 'no take' sanctuary zones and 'fished' zones in the three largest barrier estuaries in the SIMP (Chapter 4 and 6). Abundance differences were supported by comparing the size (length, width), sex ratio and movement of mud crabs within and between different zones (Chapters 4 - 6) and tracking changes in fisher/trap effort across estuaries before and after zoning changes (Chapter 4 and 6)

To meet the main objectives of this research the following aims and predictions were developed:

1. To determine the effectiveness of different gears used in studies for mud crabs by determining the efficiency of using "anchor T-tags" for long term tagging studies on mud crabs. It was predicted that tags may be lost or cause problems during moulting. Video monitoring helped determine the efficiency of traps used to sample mud crab populations. It was predicted that the aggressive behaviour of crabs may restrict access to crabs while no crabs would be lost from traps after entering (Chapter 3).

2. To describe the relative abundance of mud crabs in the Wooli, Sandon and Corindi Estuaries by comparing differences between the 'fished' and 'unfished' SIMP zones. It was envisaged that there would be higher abundances of mud crabs in the unfished zone due to its protective nature (Chapter 4 and 6).

3. To describe depletion (Wooli, Corindi) or replenishment (Sandon) and changes in demographic structure of mud crab populations when zones are changed. This was achieved by re-zoning sites to have reciprocal zoning objectives (fished to unfished and unfished to fished). It was expected that previously unfished sites would be rapidly depleted within months of opening because of concentrated

fishing effort and that previously fished areas would replenish fast due to the removal of fishing pressure (Chapter 4 and 6).

4. To describe the movements of mud crabs within the Wooli, Sandon and Corindi Estuaries between Marine Park zones by tagging studies (Chapter 4 and 6) and telemetry (Chapter 5). It was predicted that there will be recruitment from the unfished zone to the fished zone because fished zones are downstream and crabs would move downstream during flooding events and when females move offshore to spawn.

5. To establish the gender ratio of mud crabs in the Wooli, Sandon and Corindi Estuaries (Chapter 4 and 6). I aim to determine when females migrate offshore to spawn from the occurrence of females in monthly captures and recaptures from fishers. During this time, females move out of the protective zones and through downstream fished areas before they can move offshore for spawning. Knowing when these females leave to spawn will help protect them as they move. Male crabs would dominate catches in protected zones while there would be no difference between male and female catches in fished areas because male crabs are being removed by fishers.

6. To describe the size class of mud crabs in different marine park zones in the Wooli, Sandon and Corindi Estuaries (Chapter 4 and 6). Size class distributions should be skewed to smaller sized crabs in the fished zones from selective harvesting from fishers. The average size of crabs will decrease once fishing recommences in sites previously protected while the average size will increase in sites when fishing is removed.

7. To determine fishing effort in estuaries of the SIMP in terms of fishers and the number of traps used in different sections of the estuary and effort change when zoning schemes are altered. It was predicted that fishers would concentrate their effort at zone borders "fishing the line" and move into new areas once they were opened to fishing (Chapter 4 and 6).

8. To describe the environmental factors associated with variation in mud crab catches (Chapter 4 and 6). Salinity and temperature are used to determine monthly variations. Temperature and salinity will have a marked effect. Lower temperature levels restrict the activity of mud crabs leading to reduced feeding and captures while low salinity concentrations associated with flooding would result in crabs moving downstream. Salinity could play a major role in zoning design and recruitment of mud crabs to fished areas.

9. Provide a scientific basis for zoning site selection within marine parks using naturally occurring landscape features. This was achieved by determining the response of mud crabs and fishing pressure upstream and downstream of a naturally occurring rock bar barrier before and after fishing is reintroduced in the Wooli Estuary (Chapter 6). It was predicted that there will be a higher CPUE upstream of the barrier once fishing is introduced because the barrier restricts access to fishers upstream while still providing a spill-over source to the area below the rock bar.

2.0 Study area

The Sandon, Wooli and Corindi estuaries are located on the North Coast of NSW, Australia (Table 2.1; Figure 2.1). The estuaries lie within the northern and middle regions of the Solitary Islands Marine Park. This park covers an area of 71 000 ha and is important for the management of marine resources in the region (MPA 2001). There are 14 estuaries within the SIMP, of which Wooli, Sandon and Corindi are the largest (Zann 2001).

The characteristics of each catchment are similar. Timbered belts dominate the upper catchment, grading to swamps, wetlands, tidal marshes and dune areas where the estuaries meet the sea (Stone 1999). There is approximately 2 km^2 of wetland adjoining the Corindi Estuary which has been identified as a key habitat for seabirds (MPA 2002). Catchment land use includes Crown land (grazing), National Park (Yuraygir) and State Forest resulting in few water quality problems. The Sandon catchment is 40% National Park, 45% State Forest and the remainder cattle grazing. Wooli is dominated by National Park and some State Forests and a small component for cattle grazing while 75% of Corindi is State Forest or National Park and 25% has been cleared for grazing. Zann (2001) identified sugar cane (Sandon) and banana farming, cattle grazing, sand mining (Wooli and Corindi) to be past pressures on the area with forestry and acid sulphate soils (Sandon), forestry and urban development (Wooli and Corindi) to be potential pressures in the future.

The headwaters of each estuary lie approximately 190 m above sea level. Each estuary is classified as 2D estuary type rating (barrier lagoon that is highly infilled) (West 1985). All estuaries are permanently open, which allows freshwater to escape during flooding and maintains tidal influences. The Sandon Estuary is naturally trained by two rocky headlands, the Wooli Estuary by twin training breakwaters and the Corindi Estuary by a headland (on the southern side) and a sandy beach on the northern side. The substrate throughout the estuaries is sandy in the lower reaches and mud/silt in the upper reaches. The water is tannin-stained at most times in the upper reaches and throughout the estuary during flooding. The shore varies with tidal flats in the lower and mid estuary and steep slopes in the upper regions.

Table 2.1. A comparison of catchment characteristics for the Sandon, Wooli and Corindi Estuaries (West *et al.* 1985). note – 'estuarine area' was calculated by SIMP staff, Coffs Harbour, 2004.

	Location (lat-long)	Catchment area (km^2)	Estuary length (km)	Estuarine area (km^2)
Sandon	29°40'S 153°18'E	109	15	2.48
Wooli	29°52'S 153°16'E	190	20	3.23
Corindi	29°58'S 153°13'E	148	25	1.26

2.1 Human activity

The Sandon, Wooli and Corindi areas are coastal tourists villages. The region is a popular and growing destination for tourism of which recreational fishing is a major component. Recreational species such as Bream (*Acanthopagrus australi*), Whiting (*Sillago ciliata*) and Mud Crabs (*Scylla serrata*) are pursued by these anglers (Byrnes 1997; Kuster 1997; McDonald 1997).

Wooli has the largest commercial fishing fleet of the three towns, capturing finfish and crustaceans. Each estuary is commercially fished with Sandon being targeted for crabs, fish and oysters and Wooli is harvested for oysters and periodically trapped for mud crabs. Before the Solitary Islands Marine Park was declared, the Wooli Estuary was harvested by commercial fishers for mud crabs, but the decline in mud crabs led to a reduced commercial effort. This occurred, as the fishery became uneconomic, because of the decline in mud crabs and the restriction in available fishing area (Bruce Leyshon, ex professional fisher, 4th January 1999).

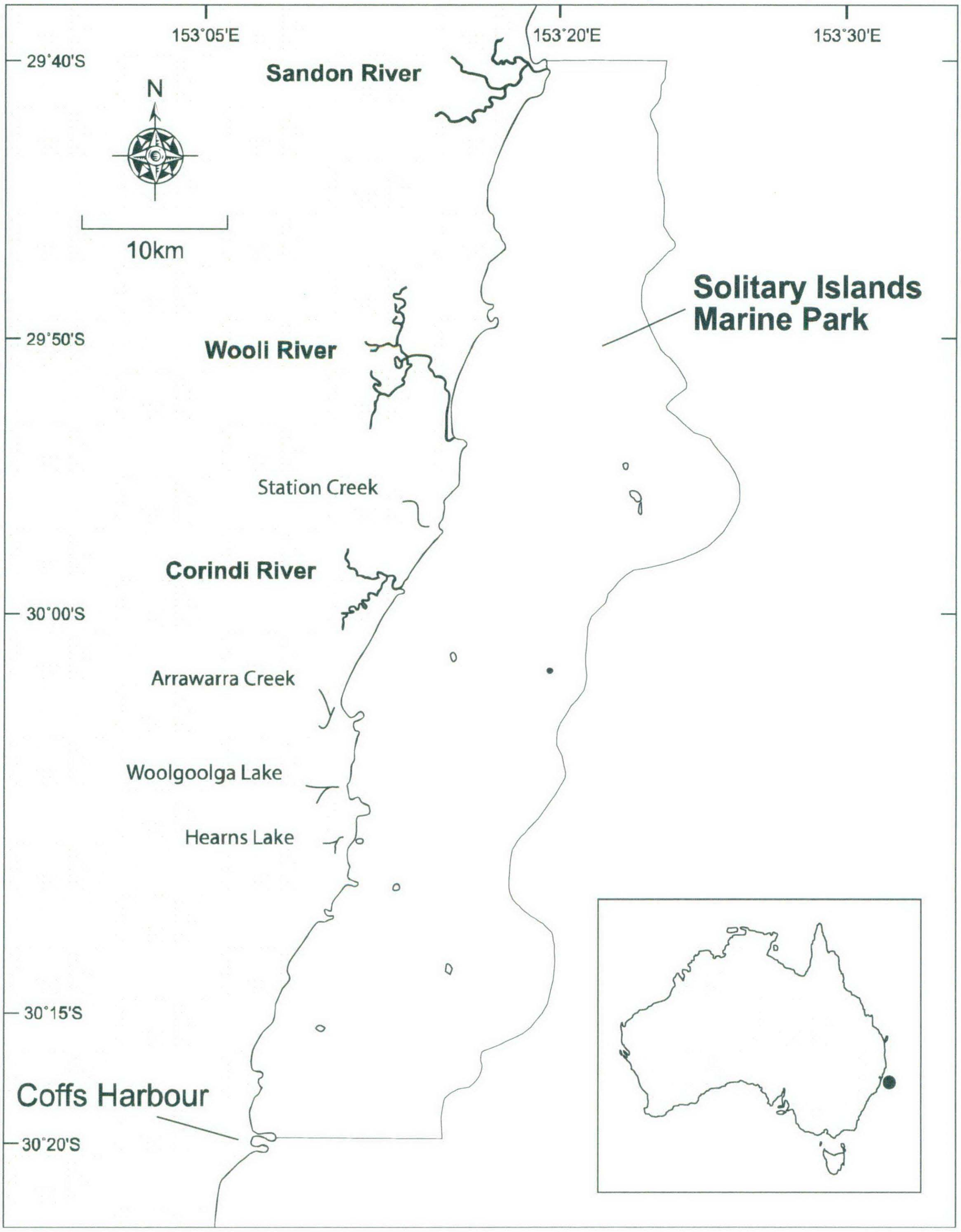

Figure 2.1. Location of Sandon, Wooli and Corindi estuaries within the Solitary Islands Marine Park.

2.2 Estuarine vegetation

The presence, absence, and areas of mangrove, seagrass and saltmarsh may vary between published reports due to the dynamic systems these estuaries are within the SIMP. Published reports from West *et al.* (1985) and Zann (2001) provide different values for the size of each of these areas and the species present. As most of these reports are based on aerial photography, a certain error will occur unless groundwork is conducted in each estuary. For this study, the highest area of each variable reported from the literature and the total number of species that were found in either study are shown in Table 2.2.

Mangroves are present along the entire estuarine system. The percentage cover of mangroves increases from the mouth to the upper reaches, with extensive intertidal mangrove areas prominent at several areas throughout each estuary. Mangrove areas are denser in the Sandon and Wooli Estuaries and more species-rich in the Sandon than the other estuaries (Table 2.2) The Grey mangrove (*Avicennia marina),* River mangrove (*Aegiceras corniculatum),* Red mangrove *(Rhizophora stylosa)* (Sandon, Wooli and Corindi), Large-leaved mangrove *(Bruguiera gymnorrhiza),* Milky or Blind-your-eye mangrove (*Exoecaria agallocha)* (Sandon/Wooli) and *Hibiscus tilliaceus* (Sandon) are found in each estuary.

The area of seagrass is similar in Wooli and Corindi (Table 2.2). Seagrass dominates in the lower and mid reaches of each estuary. Two species are found within the SIMP (Eelgrass (*Zostera capricorni)* and Paddleweed (*Halophila ovalis)* with *Zostera* being dominant in the estuaries. The Sandon estuary has the greatest area of seagrass while Wooli has fringing beds up the estuary and Corindi extensive seagrass beds at the entrance to Saltwater Creek. The Sandon and Corindi estuaries have the largest area of saltmarsh with extensive regions in the middle reaches of the estuary (Table 2.2).

Table 2.2. The estuarine vegetation for Sandon, Wooli and Corindi

	Mangrove		Seagrass		Saltmarsh
	Area (km^2)	**Species**	**Area (km^2)**	**Species**	**Area (km^2)**
Sandon	1.1	Av, Ae, Rh, Br, Ex, Hi,	0.1	*Zostera*	0.258
Wooli	0.744	Av, Ae, Rh, Br, Ex,	0.028	*Zostera*	0.028
Corindi	0.189	Av, Ae, Rh	0.033	*Zostera*	0.293

(source - West *et al.* (1985) and Zann (2001)

Key -

Av = *Avicennia marina*, Ae = *Aegicera corniculatum*, Br = *Bruguiera gymnorrhiza*,
Ex = *Exoecaria agallocha* , Hi = *Hibiscus tilliaceus*, Rh = *Rhizophora stylosa*

2.3 Tidal cycle

A semidiurnal tidal pattern occurs in estuaries along the NSW north coast with two high and low tides occurring approximately every 24 hours. Tidal range varies from 0.0 - 2.1 m with an average vertical range of 1.48 m (OzEstuaries 2004). Tidal flow influences estuarine activities and particularly immigration of crab larvae. The four tides occurring exhibit different characteristics that change based on the season and lunar phase.

The amplitude (difference between low and following high tide) changes biweekly with the largest amplitude nocturnal tide occurring either side of the spring tide, which may precede or follow the full or new moon. Lower amplitude nocturnal flood tides occur near the first and last quarter moons. The tidal influence extends approximately 15 km upstream in all three estuaries with a maximum drop of approximately 2 m between high and low tide.

2.4 Climate

The climate of the region is coastal sub-tropical. Air temperatures are regulated by the easterly trade winds which provide warm humid conditions with a range from 15 °C to 24 °C. Due to the geographical location of the SIMP, both warm and cooler water currents affect it. Ocean temperature ranges from 17 °C to 27 °C. There are currently no data available for the estuaries. The East Australian Current provides warm (27 °C) water from Australia's tropical regions during February to March (Zann 2000) while (17 °C) water currents are pushed northwards during cooler months and southerly winds (MPA 2001).

The township of Wooli has an official Bureau of Meteorology weather station, the central coastal weather station to all estuaries. Rainfall records have been kept at Wooli since 1964 with an average annual rainfall of 1444 mm. This predominantly falls from January to May (range = 147 - 174 mm) and the lowest from July to October (range = 50 - 77 mm). During this study higher and lower than normal rainfall occurred (Figure 2.2).

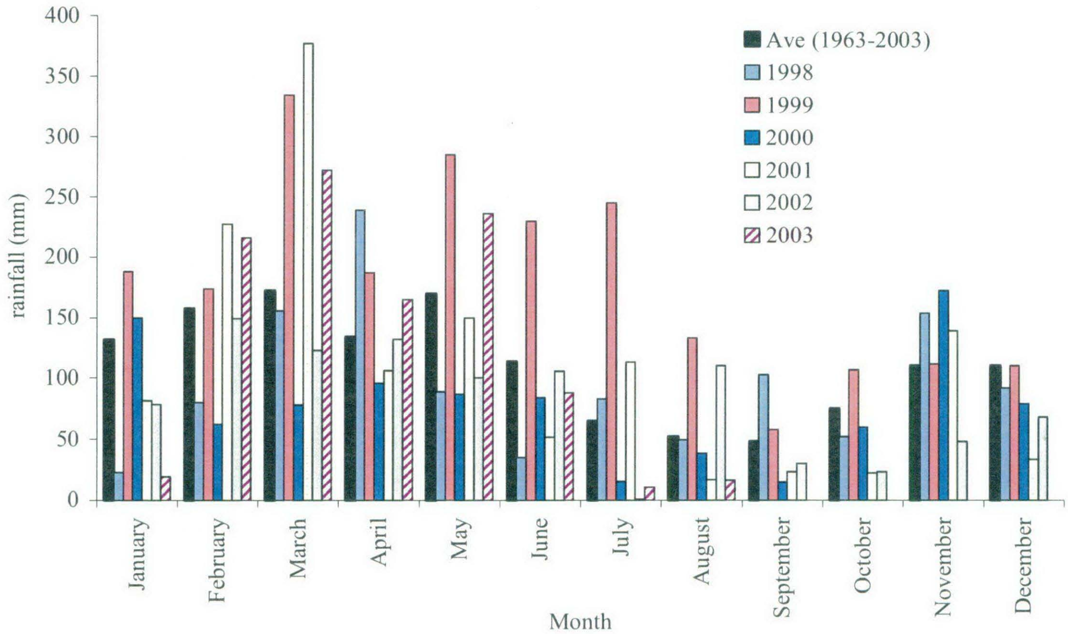

Figure 2.2. A comparison of the average monthly rainfall recorded at Wooli over the period of the study from 1998 – August 2003. (source -Bureau of Meteorology, Sydney).

2.5 Protective zoning

In 1991 the Solitary Islands Marine Reserve was established which later became a Marine Park in 1998. Prior to 1991, each estuary was not subject to any zoning. By 1998, zoning schemes were placed in each estuary to provide different levels of usage and conservation. The zones were updated in August 2002 to meet the changing environmental, social, political and economic needs of individual areas. The restructure of zoning schemes in each estuary before and after the zoning change is described in Section 4.2.3 – 4.

.

The Sanctuary Zone

Provides the highest level of protection to representative areas of different habitat types, high biological diversity, threatened or significant species and unique cultural and naturally occurring features. The only activities permissible are research and recreational activities such as whale watching and diving.

The Refuge zone *renamed* the Habitat Protection Zone in August 2002

Provides additional protection to representative areas. This buffers areas of significant habitat types, high biological diversity, threatened or significant species and unique cultural and naturally occurring features. This zone has limited commercial activity and small restrictions on recreational activity. This aims to prevent significant impact on fish populations and negligible impacts on plants, animals and habitat. Under Refuge Zone protection before August 2002, no crab trapping was permitted except for a commercial license in the Sandon Estuary. After August 2002, crab trapping recommenced in all estuaries under the Habitat Protection Zone restrictions.

The Recreation zone

Provides the least restrictions and allows a wide range of activities including recreational and commercial fishing. Crab trapping was permitted at all times in this zone.

The No Crab Trapping Area

This area prohibits the use of crab 'traps' in sections of the Wooli Estuary. It does allow the use of netted dillies (witches hats) and lift nets.

2.6 Study site selection

Within each estuary, study sites were chosen based on habitat type and marine park zoning. Three sites in each of the Wooli, Sandon, and Corindi estuaries were chosen in the different marine park zones (Figure 4.1 - 4.3). Sites were selected randomly to detect spatial variation within zones, differences in populations based on fishing pressure and recruitment across the zone border. The distance from the mouth of the estuary for each study site in the Sandon and Corindi estuaries were similar while the Wooli sites were further upstream from the mouth (Figure 4.1) because the junction of the marine park zones at Wooli is further upstream.

The previous chapters have aimed at providing a broad description of the theses and the background between how marine park management and mud crabs are related. The following chapters aim at showing how it was achieved and the results and management outcomes that were developed as a result of this.