

# **Dugong behaviour and responses to human influences**

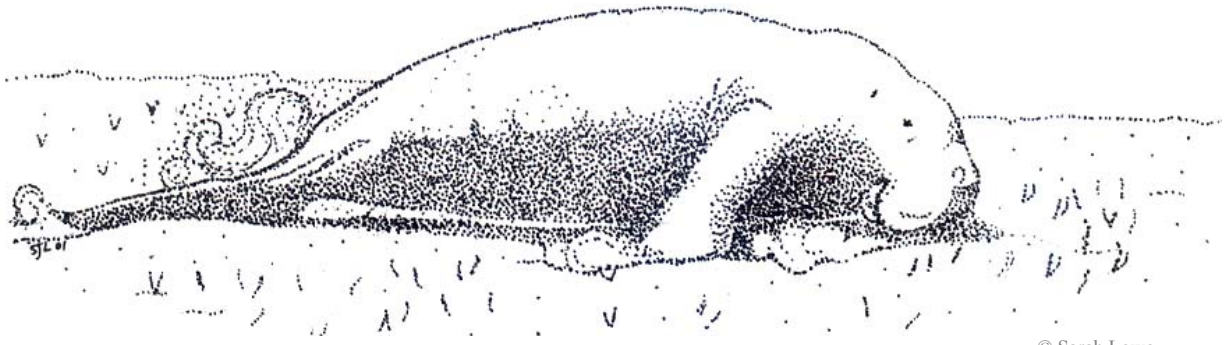
Thesis submitted by

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## STATEMENT ON THE CONTRIBUTION OF OTHERS

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## **Abstract**

Knowledge of the behavioural ecology of a species is important for the development of conservation initiatives. With an understanding of how behaviour has evolved under given environmental and phylogenetic constraints, it is possible to predict the response of a population to novel circumstances such as anthropogenic disturbance. Little is known about many aspects of the behaviour of dugongs (*Dugong dugon*). This species is difficult to observe as dugongs are benthic feeders, usually occurring in turbid waters. They tend to be wary of boats or divers and individuals cannot easily be distinguished. As dugongs occur in shallow, coastal waters, they are particularly vulnerable to human impacts; however, these impacts have not previously been quantified through direct observations of dugong behaviour.

To overcome the difficulties in observing dugongs, I developed a blimp-cam, which allowed me to video dugongs from a blimp tethered to my research vessel. The use of the blimp-cam was facilitated by selecting Moreton Bay, Queensland, as my study site, where dugongs are readily located in clear, shallow waters. I used this technology to obtain baseline information about dugong behaviour, and investigated the function of the large herds persistently formed by dugongs in Moreton Bay. I then observed the response of dugongs to boats and pingers (acoustic alarms used on fishing nets to reduce marine mammal bycatch) to determine the risk of boat strikes and effects of disturbance from these two sound sources.

At a height of 50m the blimp-cam provided an overhead view of dugongs at water depths of up to 4m, and distances of up to 200 m via a monitor on board the research vessel. Using a remote control, I could scan large herds of dugongs or continually observe individuals. Through focal follows of individual dugongs I developed an ethogram and a daily time budget for dugongs in Moreton Bay.

Dugongs spent most of their time feeding (41%), travelling (32%), and surfacing (ascending to, and descending from, surface, 18%), and relatively little time resting (7%), socialising (6%) or rolling (1%). Environmental variables accounted for little of the variability in the proportion of time dugongs spent in each behavioural category. Time budgets did not differ significantly between single individuals and mothers with

calves. However, mothers spent significantly more time feeding and surfacing, and less time travelling than their calves. Calves were observed suckling for mean bout lengths of 87 s. The mean submergence time for all individuals was 75 s, but was significantly shorter for calves (72 s) in comparison to their mothers (82 s). Submergence times were not affected by depth ( $<$  or  $\geq$  1.5 m), but were affected by behaviour.

Dugongs spent 3.5% of the day resting at the surface of the water, during which time they are particularly vulnerable to boat strike. Mother-calf pairs appear most vulnerable to boat strike because they spend more time near the surface than single individuals. Calves are especially vulnerable as they rise or submerge by crossing onto their mother's back during a quarter of their dives, and spent 13% of their time travelling and resting over their mothers' back.

I found that individual dugongs spent significantly more time feeding while in large, dense herds than when in smaller groups or scattered, suggesting that these herds are formed primarily to facilitate feeding. Dugongs did not seek large herds for resting, and calves were less likely to be surrounded by dugongs other than their mothers, than single individuals. These observations suggest that dugongs do not shelter in herds when most vulnerable to shark attack, and that herds are unlikely to have a predatory defence function. Herd structure was fluid, with individuals changing nearest neighbours after an average of 1 min, and showing no obvious preference for nearest neighbour type (single individual or mother-calf pair). Thus there was no evidence of a social function for these herds. My results support the theory that seagrass distribution and seasonality, sediment type, a lack of other disturbance of seagrass beds, and a year-round presence of dugongs on the Moreton Banks facilitate cultivation grazing.

Observations of the response of dugongs to boats passing opportunistically provided information on the risk of boat strikes. Unlike controlled passes which were restricted to the below-planing speed limit of the study area, independent boats were often travelling above this limit. Only boats travelling above planing speed were observed passing directly over the top of dugongs. I hypothesise that the distance of the flight threshold for dugongs remains constant regardless of boat speed. Thus the speed of an approaching boat determines the time dugongs have to evade the boat, and speed is the main factor affecting the risk of boat strikes.

Controlled experiments were conducted to determine the effects of boats on dugong behaviour. The behaviour of focal dugongs during a 4.5 min time sample was not significantly affected by whether there was a boat passing, the number of consecutive passes made (1 to 5 passes), or whether the pass was continuous or included a stop and restart during the pass. During the subsurface interval of the focal dugong that corresponded with the control boat's closest approach time, the travel distance, travel direction and subsurface time were not correlated with the boat's approach distance. However, during this subsurface interval dugongs were less likely to remain feeding if the boat passed within 50 m than if it passed at a greater distance. Mass movements of dugong feeding herds in response to boats were obvious but only lasted an average of 122 sec. These movements occurred in response to boats passing at all speeds, and at distances of less than 50 m to over 500 m. Relatively low levels of boat traffic in Moreton Bay in winter mean that a maximum 0.8 – 6% of feeding time may be interrupted by boats. However, if the number of boats registered in Queensland continues to increase at the current rate, the rate of disturbance is likely to increase.

The response of dugongs to pingers was tested to determine whether these alarms may prevent dugongs from using important habitat areas. An array of two 10kHz 'BASA' pingers did not cause an observable response by dugongs. There was no significant difference in the rate of dugong movement away from the focal arena surrounding the pingers, orientation of the dugongs, or the presence or absence of feeding plumes, while the pingers were active compared to when inactive.

The observed responses suggest that boat strikes are currently a bigger threat to dugongs than disturbance from boats or pingers, and support speed restrictions for boats in areas commonly used by dugongs. My results also reflect the need for detailed risk assessments to be conducted in areas where dugong habitat overlaps with areas of high boat traffic, and prior to future developments that will increase boat traffic. Further studies that build on the fundamental knowledge of dugong behaviour gained through this research will provide an understanding of human impacts in a wide range of habitats and aid in developing appropriate anthropogenic mortality targets for dugongs.



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# **Chapter 1**

## **The importance of behavioural studies in conservation biology: predicting the impacts of human activities on dugongs**

**In this chapter I outline the importance and conservation status of my study species, the dugong. I then describe why behavioural studies are a necessary tool for conservation, as they provide the background information needed to predict human impacts on animal populations. I justify the use of direct behavioural observations to determine the effects of boats and pingers on dugongs, and define the objectives of my thesis.**



# **Chapter 1. The importance of behavioural studies in conservation biology: predicting the impacts of human activities on dugongs**

## **1.1 General introduction**

To develop effective initiatives to conserve an animal species, it is essential to know how that species responds to changing environmental conditions, including human influences. It seems intuitively obvious that conservation efforts should rely heavily on the knowledge of how environmental conditions shape the behavioural strategies employed by individual animals. After all, it is these behavioural strategies that contribute to the survival and reproductive mechanisms used by individual populations and species. Yet conservation efforts rarely involve dedicated behavioural studies of a threatened species (Sutherland & Gosling, 2000; Knight, 2001). Additionally, many behaviouralists fail to make the link between the behavioural ecology and conservation of a species (Arcese *et al.*, 1997; Clemmons & Buchholz, 1997; Sutherland, 1998). Behavioural studies of obligate marine mammals are particularly limited as these animals are difficult to observe. To date, efforts towards conserving most animal species, including marine mammals, have relied mainly on knowledge of their population ecology (Pettifor *et al.*, 2000; Whitehead *et al.*, 2000; Norris, 2004). However, an understanding of the behavioural ecology of a species to accompany knowledge of population ecology, provides the opportunity to predict responses to changed conditions with greater confidence than population-based methods alone (Pettifor *et al.*, 2000; Sutherland & Gosling, 2000; Norris, 2004).

Predicting the ability of animals to adapt behaviourally to changed conditions is becoming more important as human populations continue to expand and cause modifications to natural environments. Coastal marine mammals are particularly vulnerable to these changes in the environment because of the increasing trend for people to live in coastal areas (Marsh *et al.*, 2003a). Marine mammal populations have been affected by hunting, interactions with fisheries, boat strikes, and habitat modification which includes physical habitat destruction, acoustic and chemical

pollution, and marine debris (Marsh *et al.*, 2003a; Hooker & Gerber, 2004). Monitoring has shown declines in the abundance of populations and species and has triggered conservation actions. However our lack of understanding about the behaviour of most marine mammal species limits our ability to predict their responses to both the environmental changes caused by human impacts, as well as our efforts to reduce these impacts. For most species of marine mammals there are no baseline data on their unaffected behaviour to compare with their behaviour in the presence of anthropogenic influences (Bejder & Samuels, 2003).

The limited behavioural research on many species of marine mammals results partly from the difficulties in observing them. However the few long term behavioural studies that have been conducted on cetaceans have provided important insights into their feeding strategies, social structures and mating systems (Mann, 1999; Mann, 2000 etc.). Inevitably, marine mammals have developed unique behavioural strategies that differ from those of terrestrial animals as a result of the extremely different environments in which the two groups have evolved. The fluid environment of the ocean, where resources are often patchy both in space and time, provides few refuges that can be used for protection which makes defending territories difficult (Tyack *et al.*, 2000). In comparison with terrestrial animals, marine mammals have different energetic demands such as thermoregulation and the cost of locomotion in a gravity free, but continuously moving environment (Conner, 2000). The sensory and communication systems of terrestrial and marine mammals differ according to the propagation speeds of light and sound in the two environments. Marine mammals rely mostly on sound (Richardson *et al.*, 1995); terrestrial mammals rely mostly on vision. An extension of research on marine mammal behaviour will allow comparisons between, and increase our understanding of how, both marine and terrestrial animal behavioural strategies have evolved (Tyack *et al.*, 2000). This in turn will increase our understanding of how human influences will impact on all animal populations.

This study aimed to determine how one coastal marine mammal species, the dugong (*Dugong dugon*), is affected by two sources of human impacts: boat traffic and pingers (acoustic alarms designed to reduce incidental mortalities of cetaceans in fishing nets). In recognition of the integral part that behavioural strategies play in shaping the response of animal populations to human impacts, I began this study by investigating

the normal behaviour of dugongs, about which surprisingly little is known. Previous studies on dugongs have been limited by the difficulties in observing these bottom feeding animals, which are often found in turbid water and lack unique characteristics with which individuals can be identified. Given these limitations which have plagued previous studies, I constructed the blimp-cam, an observational tool that allowed me to view dugongs throughout a shallow water column and to conduct continuous observations on individual dugongs with minimal disturbance. This development has vastly improved our capacity to study dugong behaviour. As a result of its clear water, I conducted my research in eastern Moreton Bay, Queensland, where dugongs persistently form large herds (Preen, 1992; Lanyon, 2003). Thus I also investigated the function of this herding behaviour.

Through the remainder of this introductory chapter I provide background on the importance of conserving dugong populations in Australia and the factors affecting the conservation status of this species, including habitat requirements and movement patterns. I then discuss the need for detailed behavioural observations of dugongs, as an addition to the current emphasis on population ecology, in order to assess and predict human impacts. I also outline how direct observations of behavioural responses to human activities, along with baseline information on the behaviour of dugongs, can be used to predict the impacts of human activities on dugong populations. Finally, I present the objectives of this research and explain the structure of this thesis.

## **1.2 Conservation of dugongs**

### **1.2.1 International obligations**

Dugongs are not endemic to Australian waters, but have an Indo-Pacific distribution, generally being confined to tropical and warm temperate waters (Nishiwaki *et al.*, 1981; Marsh *et al.*, 2002). It is likely, however, that Australia will provide the last stronghold for dugongs as it is the only developed country within the range of this species, and has the most extensive coastline at low risk from coastal development (Marsh *et al.*, 1999a; Marsh *et al.*, 2002). The future protection of high quality habitat for dugongs is doubtful

in most other countries within their range, as a result of high population growth and associated infrastructure and development (Marsh *et al.*, 2002).

This perspective reflects the importance of Australia fulfilling its obligations to the many international conventions that aim to protect this species. These include the *Convention on the Conservation of Migratory Species of Wild Animals* (the Bonn Convention), the *Convention on International Trade of Endangered Species of Wild Animals* (CITES), the *Convention on Biological Diversity*, and the *World Heritage Convention* (WHC). Australia's obligations under the WHC are of particular importance as dugongs occur within the Great Barrier Reef World Heritage Area (GBRWHA). Australia must protect the values for which the Great Barrier Reef was nominated as a World Heritage Area, one of which is the significant populations of dugongs which occur there (Anon, 1981).

### 1.2.2 Conservation status

The *IUCN Red List of Threatened Species* classifies dugongs as “vulnerable to extinction” based on an inferred significant population reduction (IUCN, 2003). Numbers have declined in most countries and territories where dugongs occur such that only relict populations remain, which are separated by large distances (Marsh *et al.*, 2002).

Under Australia's *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*, dugongs are a listed marine species. According to the Act *it is an offence to kill, injure, take, trade, keep, or move any member of a listed marine species on Commonwealth land or in Commonwealth waters without a permit*. Within the act there is provision for identifying key threatening processes, and implementing threat abatement and conservation plans for listed marine species. Thus the EPBC Act affords some protection to dugongs as a listed marine species.

Queensland's *Nature Conservation (Wildlife) Regulation 1994* lists dugongs as “vulnerable” and under this regulation a stated management intent is *to encourage scientific research programs likely to contribute to an understanding of the wildlife, its habitat and management requirements*. The regulation also notes that *the conservation*

*of the habitat of vulnerable wildlife is critical to ensuring the survival of the wildlife (Queensland Nature Conservation (Wildlife) Regulation 1994, p. 48). Dugongs are afforded similar protection by the Threatened Species Conservation Act NSW 1995, under which they are listed as “endangered”, the Wildlife Conservation Act WA 1950, under which they are listed as “protected”, and the Territory Parks and Wildlife Conservation Act 2000, in which they are considered “near threatened”.*

It is clear that in Australia there are requirements under federal and state laws, and international conventions to provide protection for dugongs. In order to protect them, studies to increase knowledge about the species need to be conducted and critical habitat areas need to be preserved. The conservation of dugongs is also important for the conservation of many other species of flora and fauna within the tropical coastal environment of the Indo-West Pacific. Dugongs are charismatic megafauna, which makes them a popular conservation concern amongst the Australian public. If they are to be protected, then so too must the habitat upon which they rely. Thus dugongs act as umbrella or flagship species, aiding the conservation of the environment and other species within their habitat range (Primack, 1993; Marsh *et al.*, 1999b).

### **1.2.3 Population status and threats in Australia**

Considerable research has been conducted to monitor dugong distribution and abundance in Queensland. Dedicated dugong aerial surveys have been conducted in Queensland, Torres Strait, the Northern Territory and Western Australia and have shown that dugong numbers fluctuate throughout this range. For example, aerial surveys conducted over the southern Great Barrier Reef Marine Park (GBRMP) in 1986/87 (Marsh *et al.*, 1990), 1992 (Marsh *et al.*, 1994a), and 1994 (Marsh *et al.*, 1996), indicated that dugong numbers decreased by approximately 50 percent over the eight year period, and in some areas this decline was as high as 80 percent (Marsh *et al.*, 1996). However, the most recent survey conducted in 1999 showed that dugong numbers in the southern GBRMP and Hervey Bay region had returned to 1986/87 levels (Marsh & Lawler, 2001a). The increase between 1994 and 1999 could not be explained by natural increase in the absence of immigration, but is an indication of the movement of dugongs over a large spatial scale in response to changes in seagrass availability (Marsh & Lawler, 2001a).

Nonetheless, dugong numbers appear to have declined substantially within the southern GBRMP and Hervey Bay region since the 1960s. Marsh *et al.* (in press), analysed dugong bycatch records from a shark control program where shark nets were set at popular beaches for bather protection. The records spanned a 38-year period from 1962 to 1999. The catch rate of dugongs at six locations declined at an average rate of 8.7% per year to an estimated 3.1% of the initial catch rates. If these bycatch rates are considered an index of change in the status of the dugong population, they represent a substantial decrease in dugong numbers on the urban coast of Queensland (Marsh *et al.*, in press).

There are many possible reasons for this large decline. As herbivores feeding almost exclusively on seagrass, dugongs rely on a food source which is very sensitive to human impact (Marsh *et al.*, 1999b). Seagrass die-off is commonly caused by smothering and lack of light as a result of high levels of suspended sediments. Sedimentation can occur naturally, particularly as a result of cyclones, but has been enhanced by clearing of inland and coastal vegetation, which has increased erosion (Heinsohn *et al.*, 1977). Other impacts on seagrass include direct disturbance from dredging, mining or trawling, as well as pollution from agriculture and sewage (Marsh *et al.*, 1999b). However, Marsh *et al.* (1999b) conclude that seagrass loss alone is unlikely to have caused the decline (see also Marsh *et al.*, in press).

Dugong populations have also declined as a result of direct and incidental or indirect takes. Although dugongs have been protected from exploitation since 1969 (Heinsohn *et al.*, 1977), Indigenous Australians are allowed to hunt them. However, most management intervention to control and monitor hunting levels has not been effective. Recent surveys of the Torres Strait and hunting records indicate that the current rate of hunting in Torres Strait and northern GBRMP is an order of magnitude higher than is sustainable by this population (Heinsohn *et al.*, 2004; Marsh *et al.*, 2004).

Incidental takes include dugongs caught in commercial and recreational gill and mesh nets, as well as shark nets set for bather protection. Although this take has not been quantified, commercial set nets are known to have caught significant numbers of dugongs (Marsh *et al.*, 1999b). As discussed below (Section 1.3.1), Dugong Protection Areas (DPAs) implemented in 1997, were designed to reduce dugong bycatch



mortalities in areas that are most heavily used by dugongs. The shark nets used in the analysis described above killed over 800 dugongs between 1962 and 1995 (Marsh *et al.*, 1999b), although catch rates are now low and nets have been replaced with drumlines in most areas (Gribble *et al.*, 1998).

#### **1.2.4 Habitat requirements and population growth**

Fulfilling Australia's international obligations to conserve dugongs means protecting their key habitats. Dugongs are primarily dependent on seagrass, and as a result are mainly confined to shallow and protected areas of high seagrass productivity (Heinsohn *et al.*, 1977; Anderson, 1981a). Anderson (1981a) notes that dugongs are often found along the offshore edges of shoals or around points, as these areas provide ready access to both shallower and deeper waters. Confined bays and narrow inlets are generally avoided, and consistently used areas are often abandoned at low tide when waters are less than 1 to 1.5 m deep, or during rough sea conditions when winds reach above 50 km/hr and swell is above 1 m (Anderson & Birtles, 1978; Anderson, 1981a).

Although dugongs appear to spend most of their time at water depths of less than 3 m (Chilvers *et al.*, 2004), they are also reported to occur in waters up to 58 km from the coast where water depths are up to 37 m (Marsh & Saalfeld, 1989), and feeding trails have been recorded at depths up to 33 m (Lee Long & Coles, 1997). Several species of seagrass are known to occur in these deep waters, with one species, *Halophila decipens*, having been found at depths of up to 68 m. Torres Strait supports an extremely large area of seagrass, including open ocean and subtidal communities that occur at depths of up to 40 m (Poiner & Peterken, 1996). A significant number of dugongs in this area have been sighted in waters over 10 m deep (Marsh & Saalfeld, 1991). Foraging in deeper waters is assumed to cost more time and energy than foraging in the shallows. However, Aragones (1996) suggests that in comparison with intertidal areas, subtidal areas present the advantages of often-warmer temperatures, less drag effects from tidal flows and 24 hour access to forage.

Dugongs are long-lived with the maximum age estimated from counts of growth layer groups in their tusks being 73 years (Marsh, 1980; Marsh, 1995a; Marsh, 1999). They are slow to reach sexual maturity with females having their first calf at 6 to 17 years of

age, and have long calving intervals of 2.4 to 7 years (Marsh, 1995a; Kwan, 2002). This life history results in a slow rate of maximum population increase of less than about five percent per year (Marsh, 1995a). As population increase is most sensitive to changes in the survival probability of adults, dugong populations are vulnerable to even small levels of anthropogenic mortality. This effect is multiplied when habitat quality (i.e., available forage) is reduced and dugongs respond by reducing fecundity (Kwan, 2002).

### 1.2.5 Movements

Aerial surveys and satellite tracking of dugongs have shown that their movements occur at several spatial scales. Large scale movements likely occur as a result of episodic loss of seagrass from events such as cyclones, floods and outbreaks of toxic algae such as *Lyngbya* species (Preen & Marsh, 1995; Marsh *et al.*, 2003b; Gales *et al.*, 2004; Marsh *et al.*, 2004). There is considerable individual variation in dugong movement patterns, with the home ranges of individuals varying from 1.6 to 127.9 km<sup>2</sup> (Marsh & Rathbun, 1990; Preen, 1992; de Jongh *et al.*, 1998). Of six animals tracked by Marsh and Rathbun (1990), one migrated between areas that were over 140 km apart three times in less than seven weeks. Of the remaining five animals, one moved 22 km from the capture site whereas the others stayed within 10 km. The movements of a dugong tracked by Preen (2001) spanned some 800 km of the Queensland coast. This pattern of movement heterogeneity also correlates with and may occur in response to changes in seagrass quality, where animals respond to large scale seagrass loss by either remaining in the area or moving to find seagrass elsewhere (Preen & Marsh, 1995; Marsh *et al.*, 2004). Aerial surveys conducted over a series of years provide further evidence of large scale movements as numbers fluctuate throughout the Torres Strait, Queensland, Northern Territory and Western Australia (Marsh *et al.*, 1996; Marsh *et al.*, 1997; Marsh & Lawler, 2001b; Marsh *et al.*, 2003b; Gales *et al.*, 2004; Marsh *et al.*, 2004).

Movements also occur in response to water temperatures at the limits of the dugongs' range. Preen (2004) sighted large aggregations of dugongs in winter in the Arabian Gulf which contrasted with their dispersed distribution in summer. He suggests that dugongs may aggregate around thermal springs in winter which would involve dugongs migrating approximately 400 km from the main areas used in summer. In Shark Bay (Western Australia), dugongs move from shallow inshore summer feeding areas to

deeper water in winter where the temperature remains higher (Anderson, 1986; Marsh *et al.*, 1994b; Gales *et al.*, 2004). In Moreton Bay dugongs are often found up to 15 km outside the bay during winter, where water temperature remains up to 5°C higher than inside the bay (Preen, 1992).

Local scale movements of dugongs generally coincide with tidal movements where dugongs are dependent on seagrass growing in intertidal and shallow sub-tidal areas (Heinsohn *et al.*, 1977; Anderson & Birtles, 1978; Marsh & Rathbun, 1990).

### **1.3 Assessing and predicting human impacts on dugong populations**

As discussed above, the scientific basis for the conservation of dugongs has centred around analysis of population abundances and distribution. Knowledge of the behaviour of marine mammals is fundamental to these population censuses, as correction factors are used in calculating abundance according to the ‘availability’ of the animals for counting (Sutherland, 1998). For dugongs, availability is determined by their dive patterns and the amount of time spent visible at the surface (Marsh & Sinclair, 1989a; Pollock *et al.*, in press). Knowledge about dugong dive patterns in relation to environmental variables is central to corrections for availability bias and the accuracy of population censuses.

In addition to using baseline behavioural information to improve population monitoring techniques, information on dugong behaviour is an essential addition to conservation efforts. There are two main limitations to basing conservation efforts on population estimates in the absence of behavioural studies: (1) the difficulty in estimating responses to novel circumstance, i.e., impacts that have not yet caused an observed population decline, and (2) the difficulties in assessing trends in marine mammals that are non-sedentary and slow breeding. These limitations make it difficult to assess management initiatives to conserve dugongs, the most controversial of which has been the establishment of DPAs along the urban Queensland coast (Marsh, 2000). In my thesis I explain the design of these protection areas and discusses the merits of marine protected areas in relation to marine mammal, and in particular, dugong conservation. I then discuss the limitations of solely population-based assessment of conservation

efforts, and the way in which behavioural studies can enhance our ability to predict the impacts of human activities.

### 1.3.1 Dugong Protection Areas

A two-tiered system of DPAs was established in 1997 to reduce the number of incidental deaths of dugongs on the urban coast of the GBRMP. Zone-A DPAs include significant dugong habitat areas, i.e., areas which consistently contain over 50% of the dugong population, whereas Zone-B DPAs support 22% of the population. Offshore-set, foreshore-set and drift nets are banned in seven Zone-A DPAs, and netting practices have been modified in the Hervey Bay and Great Sandy Strait Zone-A protection areas. Fishing practices have been modified in Zone-B DPAs in order to reduce the risk of entanglement and increase the chance of release (Marsh *et al.*, 1999b). Aerial surveys revealed that over 50% of dugongs occur in Zone-A DPAs and 10 to 22% in Zone-B DPAs (Marsh, 2000; Marsh & Lawler, 2001a). Assuming that fishing effort in Zone-A DPAs did not differ from that in other areas before, or was not displaced after, implementation of DPAs, and that there is no reduction in dugongs occupying Zone-A DPAs, Marsh (2000), predicted that the establishment of DPAs would reduce dugong deaths in nets along the urban Queensland coast by 42 to 55%. However, as discussed below, it is difficult to detect the impacts of these reduced mortality levels on the population levels in the short term.

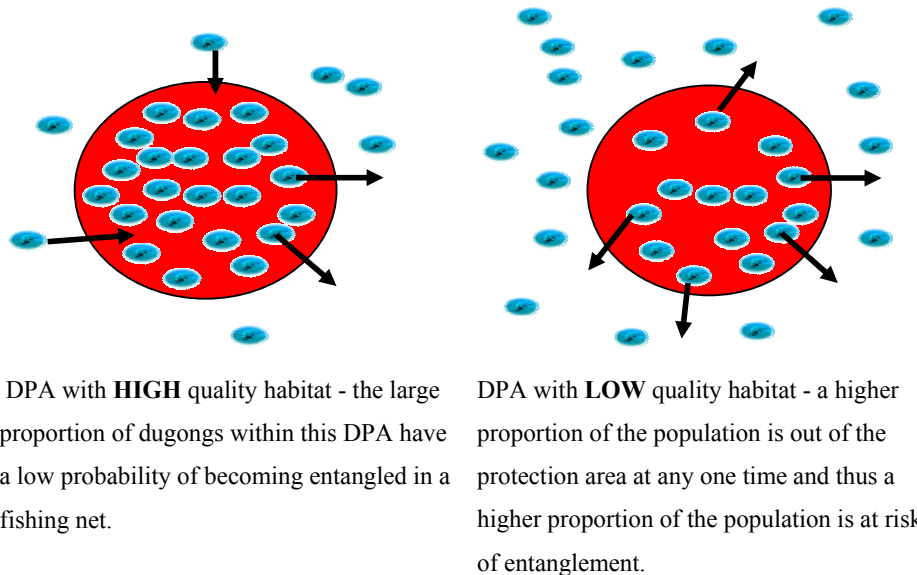
The development of coastal and marine protected areas (MPAs), such as DPAs, has been a popular approach to the problem of managing threatened marine ecosystems and in particular, individual species (Ray, 1999; Hooker & Gerber, 2004). In the past, it has been argued that there should be at least one sanctuary for every species of cetacean (de Klemm, 1979). However, there is considerable debate as to whether this approach produces the optimal result for conservation. In addition, the design, implementation, enforcement and evaluation of many MPAs is governed by a political, economic or social agenda rather than pure biology (Carr, 2000; Reeves, 2000; Hooker & Gerber, 2004). It is therefore difficult to assess the potential effectiveness of MPAs in protecting species.

It is more difficult to determine appropriate boundaries for MPAs than for terrestrial protected areas as the ranging patterns of many marine species are more dynamic than most terrestrial animals (Hooker & Gerber, 2004). Large-scale movements of many marine mammals, including dugongs, mean that it is unrealistic to implement an MPA big enough to encompass the entire home ranges of individual animals (Reeves, 2000). Completely protecting individual dugongs from the threat of entanglement would effectively mean shutting down the whole gillnetting industry in the GBRMP (Marsh, 2000). This problem is exemplified by large mysticetes, such as humpback whales (*Megaptera novaeangliae*). For this species an individual's home range consists of extensive migration routes from feeding grounds in the polar seas, to tropical coastlines of continents and islands for breeding in winter (Bryden *et al.*, 1990). Implementing an MPA encompassing a home range of this size is clearly impractical, while protecting seasonal habitats is of limited value if the animals are threatened elsewhere throughout the remainder of the year.

Many argue that the single-species sanctuary approach is antiquated as many marine mammals are at, or close to, the top of the food chain and depend on an entire ecosystem to survive (Liu & Hills, 1997). It is argued that MPAs should aim to protect whole biotic assemblages and interacting land-seascapes in order to conserve biological diversity (Ray, 1999). An example of the shift of focus of MPAs from species conservation to biodiversity conservation is the Representative Areas Program (RAP), used to rezone the GBRWHA from July 2004. The RAP involved the identification of 70 reef and non-reef bioregions throughout the GBRWHA according to their biological and physical characteristics. The GBRWHA was then rezoned so that one third of the area was classified into a network of "no-take" zones, which represented all habitats and communities within the GBRWHA (Day *et al.*, 2002). It is expected that these "no-take" areas will conserve examples of most species as well as maintain the habitats and ecological processes needed for their survival (Day *et al.*, 2002).

Marsh (2000) supports this approach and states that for the forecasted reduction in incidental deaths of dugongs to occur as a result of the implementation of DPAs, it is essential that the quality of dugong habitat within the sanctuaries is maintained. Currently, a large proportion of the dugong population on the urban coast of Queensland occurs in these DPAs. At any one time, this particular portion of the

population is at low risk of drowning in nets. However, if habitat quality within DPAs is reduced and they are no longer high use areas, then the netting restrictions in these areas will be less effective in reducing the number of dugongs entangled in nets (Figure 1.1).



**Figure 1.1:** The effects of habitat quality on the success of Dugong Protection Areas (DPAs).

Assessing habitat quality relies on empirical studies that obtain baseline knowledge of the population and community processes critical to the survival of the species the MPA is designed to protect (Carr, 2000; Hooker & Gerber, 2004). Knowledge of behaviour associated with critical habitat requirements (preferred diet, home range, migration areas, social structure and mating system) is essential (Salm & Price, 1995; Sutherland, 1998; Ray, 1999).

### 1.3.2 Responses of populations and individuals to novel circumstances

The population-based approach uses knowledge of previous or current population growth, or demographics, to predict the response of animal populations to human impacts and the outcome of removing the negative impact on the population. It relies on observed responses of the population to conditions already experienced (Pettifor *et al.*, 2000; Norris, 2004). Predicting the outcome of changed conditions is difficult, as previously observed population trends may not hold for a new set of circumstances

(Pettifor *et al.*, 2000; Norris, 2004). Population-based predictions generally do not allow for animals responding flexibly to environmental change by adjusting their behaviour (Arcese *et al.*, 1997; Pettifor *et al.*, 2000).

Predicting the impacts of anthropogenic activities on a population and preventing a decline from occurring in the first place, requires knowledge about how individual animals respond to changing environmental conditions and having the capacity to control those changes. This response is dependent upon the plasticity of behavioural strategies available to the individuals of a species. Animals often face sudden natural changes in their environment such as storms which have an immediate impact on their habitats and may have a long term impact on food supply. Animals may have mechanisms such as reducing their reproduction rates or migrating to cope with sudden impacts. (Wingfield *et al.*, 1997). As discussed in Section 1.2.5, dugongs appear to either move in response to seagrass loss or remain and reduce fecundity (Preen & Marsh, 1995; Kwan, 2002). We have no understanding, however, of whether this decision is influenced by the social structure, age or breeding status of individual animals, or their ‘cultural’ knowledge of alternative feeding sites. Knowledge of these mechanisms and understanding the potential for adjustments in behaviour are important for conservation as they will alter the predications of population models (McLean, 1997).

Studies of animal behaviour potentially provide this knowledge by determining how behavioural strategies have evolved according to the phenotypic constraints of the species, and the set of environmental conditions within which the species has evolved (Alcock, 1993). The way in which individuals attempt to maximise their fitness and interact with conspecifics affects the observed dynamics of a population (Pettifor *et al.*, 2000). Thus, an individual-level approach allows predictions to be made about how a population will respond to novel changes in the environment (Pettifor *et al.*, 2000; Norris, 2004).

### **1.3.3 Estimating population trends**

As discussed above, the established methodology for calculating abundance and monitoring population trends of dugongs is to conduct aerial surveys. Though these

surveys are believed to be reasonably accurate in providing a snapshot population census of the areas covered in each survey (Pollock *et al.*, in press), the extent of the dugong's range in Australia (over 15,000 km of coastline) means that to date it has been logistically impossible to survey their entire range during one survey season (Marsh & Lawler, 2001a). Large scale movements of dugongs among survey areas in response to seagrass dieback (see Section 1.2.5) make it difficult to determine an overall population estimate or to determine population trends within Australia.

The large variability in population estimates resulting from large-scale movements (Marsh & Lawler, 2001a), along with the slow rate of population increase for dugongs (Marsh, 1995a; Marsh, 1999), means that aerial surveys need to be conducted over many years in order to detect an increase or decline in numbers. A population that has been declining during this time may have reached a critically low level such that it has become vulnerable or endangered by the time this trend has been detected statistically (Marsh, 1995b). Similarly, a large number of aerial surveys would be needed to determine whether conservation actions are allowing dugong populations to increase. Marsh *et al.* (in press) estimated that 16 annual aerial surveys would be needed to detect an increase of 5% per year within dugong populations of the southern GBRMP and Hervey Bay region. This time-scale is too long for managers to assess their initiatives to conserve dugongs (Marsh *et al.*, in press) in the current political climate.

As an alternative to detecting population trends, Wade (1998) suggests that when human impacts are known to be affecting a marine mammal population, and in particular when these populations are known to be small or vulnerable to extinction, a better estimate of impact would be to monitor mortality rates and determine the Potential Biological Removal (PBR). The PBR is the maximum level of human-caused mortality that can occur in a population, while allowing the population to reach or maintain an optimal sustainable size, and is the product of a minimum population estimate, half the maximum rate of increase, and a recovery factor that allows for population growth and compensates for uncertainties in population estimates or responses to human impacts (Wade, 1998). In the USA, monitoring anthropogenic mortalities rather than population trends is considered a better alternative for assessing the need for management action to protect marine mammal stocks, provided the required statistics are known or inferred with some confidence (Read & Wade, 2000).



The USA *Marine Mammal Protection Act* defines the PBR of each marine mammal stock to be the maximum allowable annual removal limit. Using this criterion for assessing human impacts is considered to have significantly improved assessment of the status of marine mammal populations (Read & Wade, 2000).

Using recovery factors of 0.1 and 0.5, Marsh *et al.* (in press) estimate a PBR of 2 to 40 individuals per annum for dugongs in the southern GBRMP and Hervey Bay region. They suggest that the current carcass salvage program in Queensland (e.g., Haines & Limpus, 2002a) provides a mechanism for recording minimum mortality rates and monitoring the source of mortalities assuming that all carcasses are equally available. The carcass salvage program is therefore an important tool for assessing the success of initiatives to address mortality.

However, predicting impacts such as habitat modification that can directly and indirectly threaten the survival of dugongs presents a greater challenge. Estimating the levels of these impacts requires demographic knowledge of the population, identification of important habitat areas (Marsh *et al.*, 1993; Marsh *et al.*, 2002), as well as quantitative assessment of these impacts on the behaviour of dugongs. Ultimately, the conservation and management of any species are best achieved by combining the approaches outlined here: (1) monitoring population trends and mortality, (2) developing an understanding of the species' population size and demographics to establish a PBR and comparing this with actual levels of anthropogenic mortality, and (3) understanding the ecological and social factors affecting the behaviour of individual animals (Table 1.1). In combination, these tools provide a more complete understanding of the dynamics of a population than found by using one alone. Knowledge of the demographics and population trends is essential for determining how variations in behaviour will affect population levels, while developing a baseline understanding of the behaviour of individual dugongs and the evolutionary processes governing their behaviour allows predictions of population responses that cannot be assessed by simply monitoring population levels or assessing mortality rates.

**Table 1.1** A comparison of the strengths and limitations of the three approaches to assessing and predicting human impacts on dugong populations.

Approach	Strengths	Limitations
Population trends	<ul style="list-style-type: none"> <li>• Linked to IUCN classifications</li> </ul>	<ul style="list-style-type: none"> <li>• Cannot make predictions, triggers action only after decline has occurred</li> <li>• Confounded by movement</li> </ul>
Assess extent and cause of mortality	<ul style="list-style-type: none"> <li>• Permits calculation of PBR</li> </ul>	<ul style="list-style-type: none"> <li>• Cannot predict consequences of declines in habitat quality</li> <li>• Need an accurate assessment of actual mortality levels</li> </ul>
Behavioural studies	<ul style="list-style-type: none"> <li>• Enables predictions of responses to change in habitat quality</li> </ul>	<ul style="list-style-type: none"> <li>• Impossible to estimate long term impacts without knowledge of demography and physiology</li> </ul>

#### 1.4 Using behavioural responses to assess impacts: boats and pingers

The research outlined in this thesis uses behavioural observations of individual dugongs to assess the risk of both direct mortalities from boat strikes, and habitat modification through disturbance from boat traffic and pinger noise. As discussed in Chapter 7, the number of boats registered in Queensland is increasing rapidly, having risen by 35% between 1997 and 2003 (Maritime Safety Queensland, 2004). Dugong watching tours currently occur in Shark Bay, Western Australia, and this industry is likely to increase in popularity in Australia (Birtles *et al.*, 2004). There is concern that disturbance from boats could degrade the quality of dugong habitat areas. This study is the first to quantify the effects of boats on dugongs using a direct approach. Also, in an effort to reduce the number of dugongs caught in gill nets, the Department of Primary Industries in Queensland has been trialling the use of pingers (acoustic alarms) on inshore set nets (Chapter 8). However, the response of dugongs to pingers, and the possible disturbance caused by pinger noise, have not been investigated. Noise disturbance from both boats and pingers has the potential to displace dugongs and alienate them from their required habitats. Although, as outlined above, population surveys of dugongs can reveal changes in the distribution of dugongs, it is difficult to determine the causes of these movements in the absence of behavioural studies. Thus, investigating the behavioural responses of dugongs to boats and pingers is an important first step to assessing the impact these noise sources could have on populations.

### 1.4.1 Quantifying behaviour

The cryptic nature of obligate marine mammals makes observing behavioural responses difficult. It is important that unbiased, quantitative sampling methods be used to observe all animal behaviour (Altmann, 1974), and this is challenging for marine mammals as it is often impossible to observe individuals sufficiently. Thus behavioural observations are often biased towards surface activities (Mann, 1999) and sampling group behaviour (Bejder & Samuels, 2003). Continuous sampling of the behaviour of individuals provides more detailed and less biased information on the frequencies of behavioural events, the duration of behavioural states and time budgets, than group sampling (Altmann, 1974; Bejder & Samuels, 2003). Detailed observations of individuals can also reveal variation in their response to disturbance, and thus vulnerability to impacts, based on age, sex, breeding status, or other factors such as experience and habituation (Constantine, 2001; Bejder & Samuels, 2003).

### 1.4.2 Biological significance of short-term responses to disturbance

Studies have been undertaken of the disturbance impacts of boats on marine mammals other than dugongs (see reviews in Myrberg, 1990; Richardson *et al.*, 1995; Gisiner, 1998), as well as the response and potential effectiveness of pingers for target cetacean species (e.g., Kraus *et al.*, 1997; Stone *et al.*, 1997; de la Mere, 1999). Most of these studies assess the potential impact of boats and pingers according to the short term responses of the animals.

From observed short-term responses, it is difficult to infer the long-term consequences to the individual and population as a whole. Reeves (1992), describes short-term effects as those which can be readily seen and measured, where individuals respond by changing their behaviour. These immediately observable responses demonstrate that the animal can hear and is sensitive to the noise, but do not necessarily imply that the noise is affecting the target animal's biological fitness (Reeves, 1992). Long-term effects are the cumulative effects that occur as a result of repeated or prolonged exposure to noise, and although they are probably the most important effects of noise, they are much harder to measure (Gisiner, 1998). An example would be if a noise were to repeatedly interrupt an individual's foraging and cause a flight response, resulting in an energy

deficit and decreasing the health of the individual. This effect could affect the population as a whole by decreasing the mean and range of life expectancy and/or recruitment rate (Reeves, 1992). The limitations of predicting long-term implications of short-term behavioural responses highlight the need to conduct controlled experiments, in which baseline, relatively ‘undisturbed’ behaviour is measured as well as responses to human activities. The behavioural responses measured should include those that are potentially biologically significant, such as those that reduce foraging efficiency (Gisiner, 1998; Bejder & Samuels, 2003). Hence my research consisted of collecting baseline data on dugong behaviour and using controlled experiments to test how disturbance affected these behaviours.

### **1.4.3 Behaviour and risk of boat strikes**

As discussed further in Chapter 6, collisions between vessels and marine mammals cause death and injury to many species. Boat strikes cause the highest rate of known human-related mortalities of the Florida manatee (*Trichechus manatus latirostris*), and threaten the survival of this endangered species (Wright *et al.*, 1995; Florida Fish and Wildlife Conservation Commission, n.d.). Although deaths of Florida manatees and other marine mammals as a result of vessel strikes are well documented, the causes of collisions are not well understood (Glaser & Reynolds, 2003). There are no documented cases of observed collisions, and it is obviously unethical to conduct experiments to directly test the ability of marine mammals to avoid boats. How marine mammals perceive boats, and the factors that affect their avoidance responses, can be predicted however, from observations of the response of the animals to passing boats. For example, Nowacek *et al.* (2004a) conducted continuous behavioural observations of individual Florida manatees to assess their responses to opportunistic boat traffic and experimental boat passes. They documented for the first time the avoidance responses of Florida manatees to boats. These observations allowed them to provide support for the current management strategy of restricting boat speeds in important manatee habitats (Nowacek *et al.*, 2004a).

## 1.5 Research aims and thesis structure

The objectives of this study were developed according to the research needs and limitations outlined above, including: (1) the difficulties in studying the underwater behaviour of marine mammals and failure of previous attempts to quantify dugong behaviour, (2) the necessity for baseline behavioural information and the lack of this information for dugongs, and (3) the need for unbiased controlled experiments to determine the response of human impacts on individual animals. I recognise that my data are limited to dugongs in clear, shallow water. Dugong behaviour and responses to human impacts are likely affected by habitat characteristics such as water turbidity, depth, and forage availability. Thus the results presented here should be considered a guide to dugong behaviour in the absence of further observations in various habitat types.

My thesis is split into two sections: (1) a description of the blimp-cam developed to observe dugongs and the resultant baseline information obtained on dugong behaviour, and (2) the behavioural responses of dugongs to human activities. My study has six specific objectives. Each objective relates to a chapter of my thesis as outlined below.

### **Objective 1. Develop a technique to conduct continuous observations of individual dugongs and to observe herd behaviour**

In [Chapter 2](#), I describe the study site, Moreton Bay, Queensland, and the reasons this site was appropriate for developing techniques to observe dugongs using a blimp-mounted video camera. I provide the specifications and operational details of the blimp-cam, and compare the system I developed to similar systems previously developed for marine mammal observations.

### **Objective 2. Describe the normal daily behaviour and movements of dugongs on the Moreton Banks, including development of an ethogram and time budget**

In [Chapter 3](#), I describe the movement patterns of dugongs within the study area throughout two field seasons. I use the data collected from continuous behavioural

observations of individual dugongs to: (1) provide the first time budget for dugongs, and, (2) compare the effects of environmental variables and reproductive status (whether with calves) of individuals on their behaviour. I investigate diving behaviour in relation to other behaviours in order to provide a better understanding of the ‘availability’ of dugongs for aerial survey censuses (Section 1.3). Particular emphasis is placed on describing behaviours that may affect the impact of boats and pingers on dugongs.

**Objective 3. Investigate the function of large herds on the Moreton Banks through observations of the behaviour and positions of individual dugongs**

Chapter 4 specifically addresses the question of why dugongs within my study site form large herds given that dugongs are not known to form large herds persistently anywhere else in the world. I investigate this unusual behaviour to promote an understanding of how particular behavioural strategies of dugongs affect their susceptibility to human influences. In the only other study to suggest a function for these herds, Preen (1992; 1995) investigated the dynamics between dugong grazing and seagrass production and developed a hypothesis that the large herds facilitate ‘cultivation’ grazing. I review the possible functions of these herds in light of my behavioural observations, as well as comparisons between the environmental factors that may affect the grouping behaviour of dugongs in my study site and elsewhere, to assess Preen’s (1992; 1995) hypothesis.

To complete the first half of my thesis, and as a prelude to my investigations of the impacts of boats and pingers on dugongs, I review my findings on dugong behaviour in relation to the vulnerability of dugongs to disturbance and boat strikes (Chapter 5).

**Objective 4. Determine what factors affect the risk of boat strikes to dugongs by observing their behaviour while boats are passing opportunistically**

In Chapter 6, I describe qualitative observations of the response of dugongs to boats that passed by opportunistically, and some of which ‘ran over’ dugongs. These observations are used as a framework for developing a hypothesis concerning the factors affecting the risk of boat strikes to dugongs.

**Objective 5. Assess whether disturbance from boats significantly affects the time available for normal behaviours, or has the potential to cause displacement from key habitats**

Chapter 7 describes the controlled experiments I conducted to determine the response of dugongs to boats passing. I assess the impact of disturbance from boats according to the behaviour of individual dugongs as the control boat was passing in comparison to behaviour when there was no boat traffic. I also determine the proportion of time dugongs spend responding to boats within my study site according to the duration of herd and individual responses to boats, and the rate of opportunistic boat passes that occurred during this study.

**Objective 6. Determine whether pingers have the potential to alienate dugongs from their important habitat areas**

Chapter 8 provides the first quantitative assessment of the response of dugongs to pingers. I assess the possibility of pingers causing disturbance to dugongs in a series of controlled experiments where the response of dugong herds to a pinger array was assessed. These experiments do not attempt to test the potential effectiveness of pingers in reducing dugong entanglements in gill nets. However, I review the efficacy of this bycatch mitigation strategy according to my behavioural observations and studies on the responses of target species occurring along the Queensland coast.

Finally in Chapter 9, I discuss my results in relation to their contribution to improving the conservation and management of dugongs. In particular, I use the knowledge gained during this study of dugongs in Moreton Bay to provide a risk assessment framework for managers to determine the potential impacts of human activities in important dugong habitats. I also outline directions for future research on dugong behaviour and human impacts on dugong populations.





# **Chapter 2**

## **Moreton Bay Marine Park and observations using the blimp-cam**

**In this chapter, I describe the study site, Moreton Bay, Queensland, and the reasons this site was appropriate for developing techniques to observe dugongs using a blimp-mounted video camera. I provide the specifications and operational details of the blimp-cam, and compare the system I developed to similar systems previously developed for marine mammal observations.**



## Chapter 2. Moreton Bay Marine Park and observations using the blimp-cam

### 2.1 Moreton Bay

#### 2.1.1 General description

Moreton Bay (153.3° E, 27.5° S) is located in southeast Queensland (Figure 2.1). It is bordered on the seaward side by two large sand islands, Stradbroke Island and Moreton Island, and on the western side by the mainland and Bribie Island. It has a total area of 14,000 km<sup>2</sup> and is approximately 80 km in length. Its narrow southern end contains many small islands, and it widens to the north reaching 32 km across. Most of the bay is relatively shallow, with water depth reaching 30 m at only a few locations.



**Figure 2.1** Moreton Bay in SE Queensland, bounded by Moreton Island, Stradbroke Island, the mainland and Bribie Island.

The western and eastern sides of the bay are very different. The western side is largely influenced by the six rivers and many creeks leading into the bay, with extensive mangrove forests and tidal mudflats. As a result of the large quantities of silt and

organic matter deposited by the rivers and sewage outlets, the waters have high turbidity, with horizontal underwater visibility being 0.1 to 2 m (Preen, 1992). The increase in turbidity since European settlement has led to an estimated 20% loss of seagrass habitat in the western and southern areas of the bay since European settlement (Abal *et al.*, 1998). The eastern side of the bay is dominated by ocean currents, with clean quartz sand and relatively clear waters providing 1 to 5 m horizontal visibility (Preen, 1992) and is still considered to be in relatively pristine condition (Abal *et al.*, 1998).

This area of Queensland has a semi-tropical climate with highest rainfalls occurring between October and May, and a total of 1,500 to 1,600 mm of rain annually (Davie, 1998). Surface water temperatures within Moreton Bay vary between 16 and 29°C, while just outside the bay the range is reduced to 18.5 to 25.5°C. Although the bay is protected by large sand hills on both Moreton and Stradbroke Islands, wave height can occasionally reach 2 m in strong wind conditions, and in some areas, such as South Passage and the deep northerly channel, current flow rate can reach 2 knots (Davie, 1998). The vertical tidal range is approximately 2 m.

### **2.1.2 Status and use**

Moreton Bay is adjacent to Brisbane, the fastest growing capital city in Australia in 2002/03 (2.5% growth), and consisting of approximately 1.7 million people (Australian Bureau of Statistics, 2003). The bay supports over 1,000 full-time commercial anglers, including 200 prawn trawlers and over 1,000 large vessels transit through the port of Brisbane annually (Davie, 1998).

A non-indigenous dugong fishery began in Moreton Bay in 1847, products made from dugong oil, meat and bones, were sold commercially (Johnson, 2002). Dugongs were hunted using harpoons and nets, with the latter method being most successful. The fishery primarily operated from the island of St Helena (approximately 12 km from the Moreton Banks), and was unregulated until 1893. A number of short-term bans on the fishery were implemented as it became apparent that dugong numbers were rapidly declining; however the fishery operated intermittently until 1920 (Johnson, 2002).

The Moreton Bay Marine Park was established in 1993. It covers all tidal lands and waters, and the seaward boundary encompasses Queensland waters which extend three nautical miles offshore. The *Marine Parks (Moreton Bay) Zoning Plan 1997*, states that the purpose of the plan is to provide for the ecologically sustainable use of the marine park, as well as to protect its natural, recreational, cultural heritage and amenity values. Moreton Bay is divided into five zones (Appendix 1), ranging from general use to protection for areas of high conservation value. There are also a series of designated areas that require special management and may be set aside within any of the zones. These include *Turtle and Dugong Areas* which are designated for the purposes of reducing the potential of injury or death to sea turtles and dugongs from vessel strikes, as well as reducing seagrass bed damage. According to the *Marine Parks (Moreton Bay) Zoning Plan 1997*:

*A person must not, in a turtle and dugong area -*  
*(a) operate a speedboat in a planing or non-displacement mode; or*  
*(b) operate a boat, hovercraft or personal watercraft in a way or at a*  
*speed that could reasonably be expected to result in the striking of a*  
*sea-turtle or dugong.*

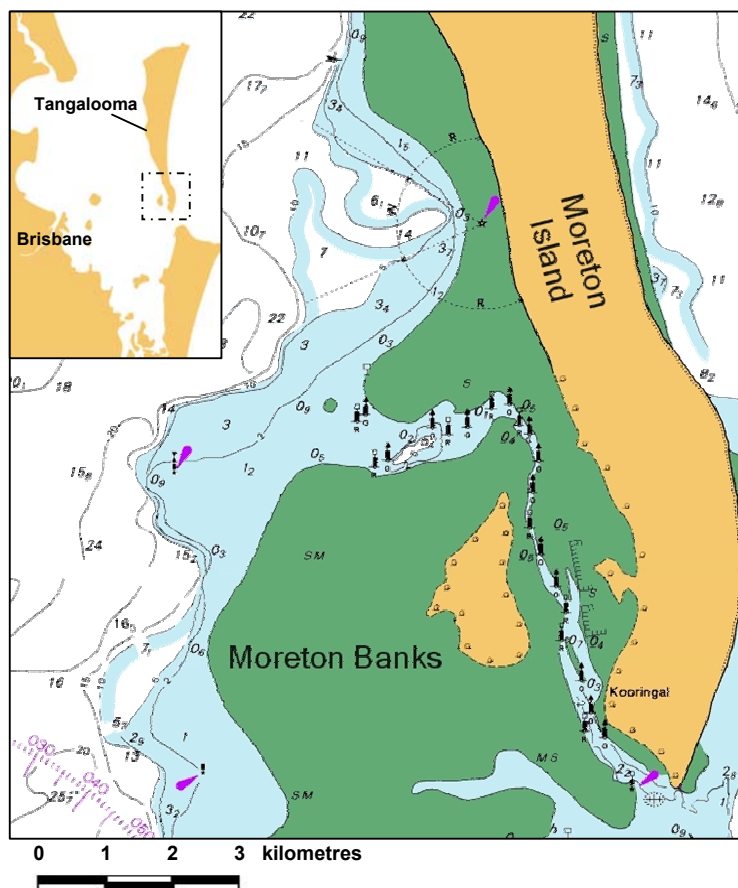
There are five such areas, including the Moreton Banks Turtle and Dugong Area (Appendix 1). Restricting boats to below planing speed rather than a defined speed allows boats to remain within the speed limit without special equipment such as speedometers or GPS units, or having to rely on estimating their speed. While remaining below planing speed, the small recreational boats commonly found on the Moreton Banks are generally travelling at less than 10 knots.

### **2.1.3 The Moreton Banks**

All my observations of dugongs were conducted on the Moreton Banks, located on the southern end of Moreton Island (Figure 2.2). Previous aerial surveys of Moreton Bay have shown that large dugong herds of up to 459 animals, with typical herd size of 147 (an index of the herd size in which the average dugong would occur, Jarman, 1974) regularly inhabit these banks (Preen, 1992) which are covered by seagrass beds dominated by *Halophila* and *Zostera* species. *Halophila* species are the most

widespread, but in some areas produce a relatively sparse covering, whereas *Zostera capricorni* contributes the highest biomass in the area (Preen, 1992). Though seagrass beds on the Moreton Banks are relatively stable over time, density is highly correlated with seasonal changes, in particular changes in day length and water temperature (Preen, 1992). The growing season of *Z. capricorni* begins in winter and peaks in spring, whereas growth of *Halophila* species peaks in summer (Preen, 1992).

The shallow, clear waters of Moreton Banks and their accessibility from the research station (Tangalooma Resort, approximately 18 km north of the banks) made them the ideal location for observations using the blimp-cam. Dugongs frequent other areas of Moreton Bay, but are not as reliably located as those on Moreton Banks. Towing the blimp to areas further afield than Moreton Banks would have taken too long and been too risky in the event sudden high winds. The Moreton Banks were therefore the core location for all my observations.



**Figure 2.2** The Moreton Banks, where all dugong observations were conducted, located at the southern tip of Moreton Island.

## 2.2 Observing dugongs

The challenges inherent in studying obligate marine animals such as sirenians can make behavioural observations difficult or even impossible. Unlike many cetaceans, dugongs exhibit few prolonged surface behaviours with the average time at surface between dives being 1.4 to 5 s (Anderson & Birtles, 1978; Marsh & Rathbun, 1990; Chilvers *et al.*, 2004). Both feeding and resting occur below the surface and although previous studies have differentiated between these two behaviours according to dive type and submergence time, resting behaviour is particularly difficult to record reliably without being able to see below the water surface (Anderson & Birtles, 1978; Anderson, 1998). The only study that details the subsurface social behaviour of dugongs was conducted in an area where particular individuals could be identified and reliably found in shallow, clear water (Anderson, 1997).

Previous studies of dugong behaviour have supplemented boat-based observations with recordings from elevated viewing platforms such as cliffs and aircraft, which allow the observer to see submerged dugongs (Anderson & Birtles, 1978; Anderson, 1982; Preen, 1989; Anderson, 1998). From an elevated position it is possible to obtain accurate counts of individuals and, from cliff-tops, observe individual dugongs for extended periods of time (Anderson, 1982). Anderson (1982) notes that while it is possible to approach dugongs cautiously in a boat or canoe without causing them to take flight, dugongs that subsequently approach or remain close enough to observe, typically exhibit stereotypical investigative behaviour. Underwater observations are similarly hindered by the cautious nature of dugongs and the investigative behaviour they display towards divers and swimmers (Barnett & Johns, 1976; Anderson & Birtles, 1978; Anderson, 1982).

An understanding of dugong behaviour can be developed through the use of remote electronic equipment such as satellite tags (Marsh & Rathbun, 1990; Preen, 1992; de Longh *et al.*, 1998; Preen, 2001) and timed depth recorders (Chilvers *et al.*, 2004). As outlined in more detail in Chapter 3, there are limitations associated with this equipment and the assumptions made in the absence of direct visual observations of the animals. In addition, this equipment is currently used to quantify the behaviour of a limited number

of individuals, and does not provide information about social interactions among animals.

### 2.2.1 Elevated observation platforms

Although cliff-top observations of dugongs were conducted briefly in Shark Bay (Anderson, 1982), there are no known sites in Australia that reliably offer a cliff-top view of dugong herds. Observations from aircraft are limited to a snapshot view of the animals and thus are suited to determining numbers, herd composition, and habitat use patterns, but not detailed behavioural data. While offering longer viewing periods, helicopters produce noise which penetrates the water below (Richardson *et al.*, 1995) and can disturb dugongs at when flown heights below ~ 300 m (*pers. obs.*)

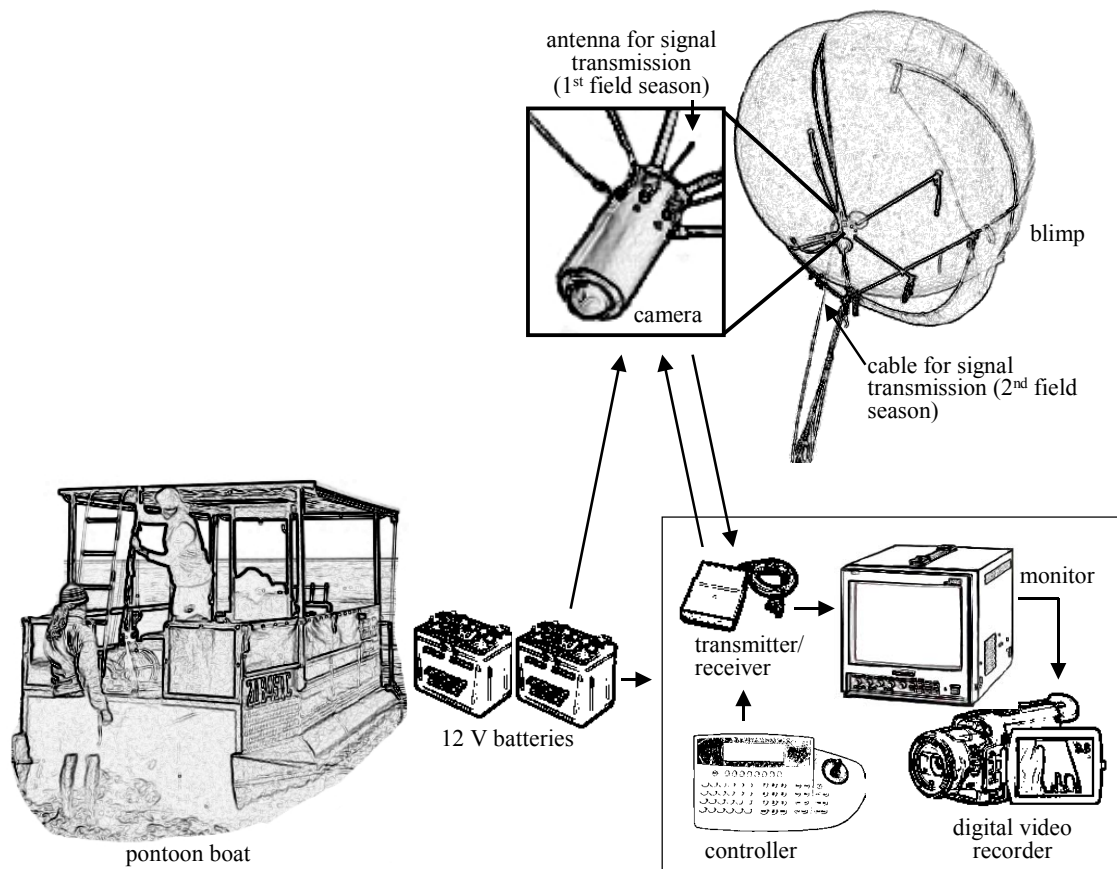
An overhead video system suspended from a helium filled blimp (zeppelin style balloon), was first described by Flamm *et al.* (2000) and then in more detail by Nowacek *et al.* (2001a). They developed the equipment to provide extended aerial observations of marine mammals in their natural habitat. These researchers found that, in comparison with boat-based observations, this system allowed them to record specific behaviours rather than generic behavioural categories, and more accurate counts of behavioural events. Their system has been used to assess life-stage structure of Florida manatees (*Trichechus manatus latirostris*) (Flamm *et al.*, 2000) and the foraging behaviour of bottlenose dolphins (*Tursiops truncatus*) (Nowacek *et al.*, 2001b). This system has also been used to observe the effects of boat traffic on the behaviour of both these species (Nowacek *et al.*, 2001c; Nowacek, 2002). Hain and Harris (2004), developed a similar system to study the behaviour of the North Atlantic right whale (*Eubalaena glacialis*), and they list other known applications of similar blimp systems including the one developed during my study.

### 2.2.2 Blimp-cam

I developed an alternative overhead video system for studying dugong behaviour, termed the 'blimp-cam', which has the advantages of being cheaper and easier to operate than that developed by Nowacek *et al.* (2001a). Both systems are detailed in Table 2.1. The blimp-cam consisted of a helium-filled balloon (blimp), which was



tethered to my research vessel and floated approximately 50 m above the boat (according to tether length) in still conditions (Figure 2.3). Suspended from the blimp was a digital video camera on a pan and tilt system inside a waterproof housing. The footage from the camera was transmitted to the boat where it was viewed on a monitor and selectively recorded on a digital video recorder. The direction, zoom, focus and iris of the camera were adjusted using a joystick controller on board the boat. The system was powered by 12 volt batteries via a power cable attached to the blimp tether. Transmission of the video footage and camera control commands was by either remote transmitter or cable. Here I describe the components of the blimp-cam in detail, the operation procedure, and the methods used to observe dugong behaviour.



**Figure 2.3** Components of blimp-cam: camera (in water-proof housing) suspended from blimp, two signal transmission methods (both remote and via cable), and transmission of video image from receiver to monitor, and finally to digital video recorder. The entire system is run from 2 x 12 V batteries.

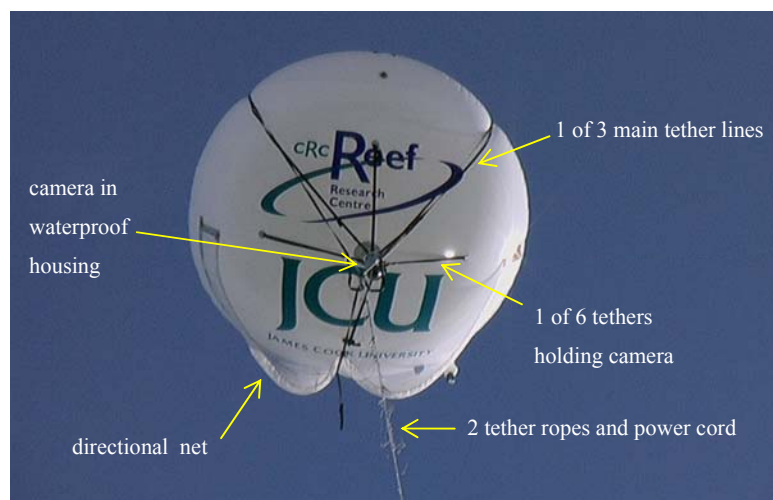
## 2.2.3 Components

### 2.2.3.1 Blimp

The blimp used was a pre-designed ‘Hi-Speed’ blimp (Balloon Promoters, NZ) and was an ovoid shape that can withstand higher wind speeds than the traditional zeppelin style blimp (Figure 2.4). A semi-circular net on its base stabilised the blimp by catching the wind and keeping it directional. Three webbed tether lines (2.5 cm in width) attached to a reinforced apex at the top of the balloon, wrapped around and joined approximately 2-3 m below the belly of the balloon. From this point, two (one as back-up) 4.8 mm polyester braid, hard lay ropes (CJ648), connected the blimp to the boat.

The required size of a blimp is a function of its payload. For the blimp-cam the payload was kept to a minimum (7.6 kg) and required a blimp 2.5 m in diameter with a volume of 11.3 m<sup>3</sup>. The design of the ‘Hi-Speed’ blimp also allows a greater payload (more lift) than a zeppelin style blimp of the same volume, and therefore requires less helium to lift the same weight.

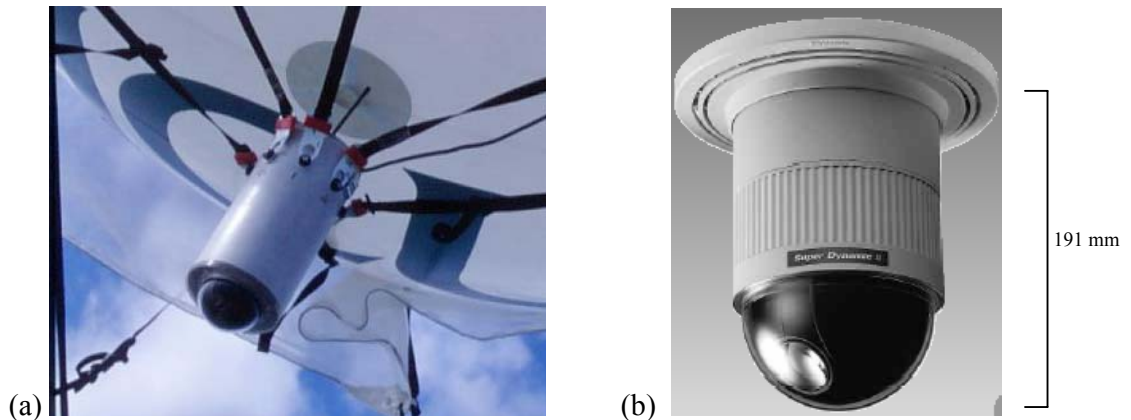
To attach the camera, the blimp had six smaller (2.5 cm webbed) tethers, two extending from the apex and four from the belly of the balloon. They were of equal length with custom made metal clips that hooked firmly over metal bolts on the camera housing.



**Figure 2.4** The blimp-cam, including an ovoid blimp and camera enclosed in a waterproof housing.

### 2.2.3.2 Camera

I used a standard ‘off-the-shelf’ dome, single chip, digital security camera (Panasonic WV-CS854), with 4 to 83 mm zoom, and 480 lines horizontal resolution (Figure 2.5b). The pan and tilt system provided with the camera had 360° continuous pan (to 300°/s) and 180° tilt (with digital flip), which were not mutually exclusive. The camera and pan and tilt system came with a plastic casing and plastic clear dome. This complete package was fitted into a cylinder shaped waterproof housing (30 cm length, 16 cm diameter), such that the dome protruded from the bottom end and was sealed with an o-ring (Figure 2.5a). The cylinder could be opened at the top end and the camera removed. The advantage of using this commercially available product was that parts such as the clear dome (which when scratched could blur video images) could easily be replaced at minimal cost.



**Figure 2.5** (a) Camera inside camera housing, attached to blimp with six tether lines and metal clips, and (b) dome security camera with pan and tilt system in housing.

### 2.2.3.3 Signal transmission

During the first year of operation I used remote video and data transmitters for camera control and receiving video images. The video transmitter (TX921P5V/S) operated at 915 to 928 MHz and the data transmitter (TX151D) operated at 151 MHz. Both used the double conversion receiver (RX921P5V/S). This method was chosen because the components of the remote transmission system were lighter than the alternative method used by Nowacek *et al.* (2001), which transmits via cable. Although this system

provided a continuous video signal most of the time, cable eliminates the possibility of signal interruptions or dropouts entirely. During the second year, improved technology allowed me to replace the remote transmitters with a coaxial cable without increasing the payload.

#### ***2.2.3.4 Camera control***

The controller was a Pacom 2035 Intelligent CCTV keyboard (PC2035K2) that is commercially available and generally used for operating a network of security cameras. It includes a joystick to operate the pan and tilt, and controls for focus, zoom and iris aperture.

#### ***2.2.3.5 Recording video image***

The video image was viewed on a standard colour editing monitor (Panasonic BT-S1050Y). To eliminate the problem of glare, the monitor was housed in a darkened box that had a section cut out and eye goggles fitted. The video image was transmitted from the monitor to a digital video camcorder (Panasonic NV-MX300), and was recorded onto mini digital video (DV) tapes (Panasonic AY-DVM63PQ).

#### ***2.2.3.6 Recording audio***

The blimp-cam operator and observers on the roof of the research vessel were equipped with hands-free radio transceivers. A dedicated transceiver was connected to the camcorder via the microphone/earphone socket so that all communication (including commentary and additional boat-based observations) was recorded with the video footage onto the mini DV tapes.

#### ***2.2.3.7 Power***

The whole system was run on 24 V AC via 2 x 12 V batteries with an inverter. The batteries were recharged nightly. Power was transmitted to the camera via a figure 8 power cord during the first year. When the coaxial cable replaced the wireless transmitters for data and video transfer, power was transmitted via the outer conductor

of the coax cable and an additional single wire. Both the coaxial cable and single wire were taped to the back-up tether to prevent breakage.

#### ***2.2.3.8 Support vessel***

The blimp-cam was operated from a 5.6 m aluminium pontoon boat, with a 40 HP engine. This vessel was chosen because its two large barrel-pontoons and flat deck made it a stable and spacious work platform. It also had minimal draft (~30 cm) which assisted when searching for dugongs on shallow sandbanks. A roof was fitted to provide a higher vantage point for observations additional to those made with the blimp, and to aid the rigging of the blimp.

### **2.2.4 Operation**

#### ***2.2.4.1 Helium, storage and transport***

The blimp was kept inflated during the entire field season as this was the most economical option. After the initial inflation, requiring 4 x E sized (3.6 m<sup>3</sup> each) bottles of helium, approximately one bottle was used per week to keep the blimp topped up.

Overnight and during strong winds, the blimp was stored in a 4 x 4 m tent, which at the apex was approximately 3.5 m high. The blimp was allowed to rest against the roof of the tent, and was attached to sandbags at all times when in storage and transfer to the boat. This transfer required two people to guide the balloon out of the tent and hold the blimp and sandbag. While on the boat, the blimp was attached to both tether ropes. In transit, the blimp was towed at approximately 10 m above the boat without the camera attached (Figure 2.6). Small adjustments to the length of the three main tether lines change the angle of the blimp, while adjusting the tightness of the net changed the stability in different wind conditions, such that the blimp could be ‘tuned’ for different wind conditions.



**Figure 2.6** Blimp attached to the front end of the boat and kept at a height of approximately 10 m while towing during transit.

#### ***2.2.4.2 Locating and approaching dugongs***

On each field day, I searched for dugongs on arrival on the Moreton Banks (Section 2.1.3) by taking into account my knowledge of the dugongs' locations on previous days, as well as the tides. Searches began where I considered the dugongs most likely to be and transects were conducted from this area, gradually expanding to wider areas until dugongs were sighted. The blimp-cam was not used in this search unless the dugongs were particularly difficult to find. The dugongs were generally easy to locate and the time spent rigging the blimp once the dugongs had been approached allowed the animals to settle before filming began.

The dugongs were approached cautiously, where possible by switching off the motor at a distance of at least 50 m and drifting towards them. Once near the dugongs, the vessel was anchored and remained anchored while filming. By approaching the dugongs via drift the vessel was positioned such that any wind would push the blimp closer to the dugongs. Appropriate positioning of the boat and blimp however, was also dependent on the position of the sun's glare on the water, which affected filming. Consequently, dugongs were approached downstream of drift by motoring at only one or two knots, as required.

### ***2.2.4.3 Rigging the blimp***

The blimp was raised from and lowered to the vessel by hand. Both tethers were on hand reels and each was attached by caribinas to the boat at two places. To attach the camera, the blimp was pulled down by cable through the hatch in the roof of the vessel and held by one person who was positioned on the floor, while two people on the roof clipped the camera to the six tethers on the blimp.

The blimp and camera were raised to approximately 50 m above the boat for filming. At this height it was possible to scan large herds of dugongs, as well as to zoom in on individuals and see discrete behaviours without movement from the balloon. Although both the remote transmitters and cable allowed the blimp to be raised to 100 m, there was always some degree of movement from the blimp. This movement was enhanced with height and windy conditions, and affected filming when zooming in on individuals. By limiting the tether length to 50 m, I limited the zoom required to film individuals, particularly in windy conditions where the blimp was blown at an angle from the boat and thus was lower than 50 m.

### ***2.2.4.4 Maintenance***

An important factor to note for all blimp styles is that none will fly well if there is any helium leakage. Although the blimp-cam could lift the camera and was used successfully to film dugongs while it had an extremely small leak, it was much more difficult to fly, and tow behind the boat, in strong winds. This problem is also relevant for zeppelin style blimps (*pers. obs.*). Small holes in the 'Hi-Speed' blimp were easily repaired, however large rips needed to be repaired by the manufacturer.

### **2.2.5 Limitations**

Although the 'Hi Speed' blimp is designed to withstand strong winds, filming was not possible in winds above 15 knots. In adverse conditions the blimp was too unstable, and water clarity too poor, to obtain footage of acceptable quality. It was also difficult to rig the blimp as the higher the wind speed, the more lift the blimp has, and thus it becomes harder to control and reel in and out. The blimp could be towed against winds of up to

20 knots, however this was considered the extreme limit and the blimp could not be pulled down and adjusted in such strong winds. Boat speed was limited to approximately 8 knots because to the size of the boat engine rather than the blimp. The blimp-cam was not used in the rain as electrical equipment on board the boat was too exposed and visibility was too poor.

When looking directly down from 50 m, the field of view from the blimp-cam was 49 m x 36 m. The depth of view and field of view with the camera tilted was dependent on a number of environmental conditions such as water clarity, wind, cloud cover and sun angle (glare). At best, dugongs could be seen well enough to follow continuously and observe their behaviours at a water depth of 4 m and a distance of approximately 200 m (although at these maxima could not be achieved concurrently). Individual focal follows of dugongs were not possible where dugongs were not visible when on the substrate (i.e., in deep or turbid water), as the focal animal was confused with other individuals if it was not continuously visible.

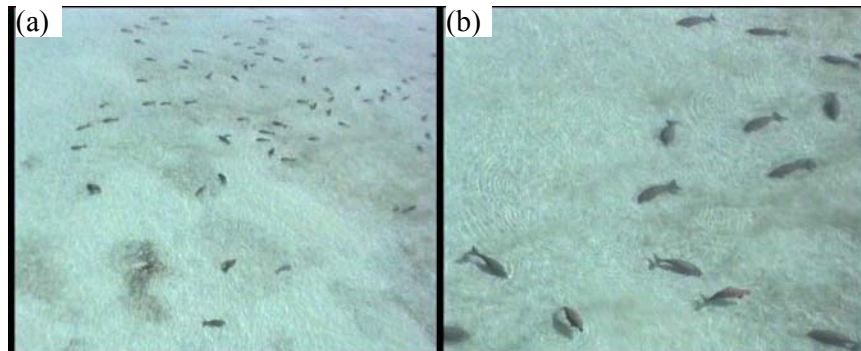
During my study, I did not attempt to follow individual dugongs by moving the research vessel while filming, as I was aiming to minimise disturbance other than from the control pass boat (Chapter 7) and pingers (Chapter 8). Conducting focal follows of individuals of other species such as dolphins would require following the animals in the research vessel, as in the case of observations by Nowacek *et al.* (2001a). Though not used in this manner, in my experience the blimp-cam remains stable enough while being towed by the moving vessel to continue recording animals.

In some areas there may be cultural limitations on using the blimp-cam, either due to restrictions in airspace usage near airports, or in areas that are heavily used by people. Although I did not receive any negative feedback from the general public, it is possible that blimp-mounted security camera could be perceived as a potential infringement on privacy. These two issues need to be considered before using the blimp-cam in other areas.



### 2.3 Comparison of the blimp-cam with Nowacek *et al.* (2001)

The only comparable aerial observation systems similar to the blimp-cam in publication, are the one described by Flamm *et al.* (2000) and Nowacek *et al.* (2001), and a similar one described by Hain and Harris (2004). Their systems and the blimp-cam allow more detailed observations of marine mammal behaviour compared with vessel-based observations, while creating a lower level of disturbance. There are some differences in my system however, and I compare the blimp-cam with specifications provided for the first described aerial observation system, Nowacek *et al.*'s (2001a), with mine in Table 2.1. Nowacek *et al.* (2001) used a 3-chip camera in order to obtain the highest quality footage possible. It is difficult to assess the degree to which a higher quality camera would have improved the visibility from my blimp-cam without a direct comparison. The footage obtained from the blimp-cam was more than adequate to make extensive observations of dugong behaviour as illustrated in Figure 2.7 and Appendix 2. The single chip camera was chosen because it is smaller and lighter, as is its pan and tilt system. This minimised the payload for the blimp and thus allowed me to use a much smaller blimp than Nowacek *et al.* (2001).



**Figure 2.7** Images of dugongs obtained using the blimp-cam showing part of a herd at two different focal lengths.

A smaller blimp can be operated by fewer people and stored more easily. I stored the blimp on land overnight in a hired tent. In comparison to the system used by Nowacek *et al.* (2001), the blimp-cam requires one less person (three rather than four) to operate, and less than half as much helium (therefore halving the cost of helium). Storing the blimp in the tent meant that during periods of strong winds (> 15 knots) when operation of the blimp-cam was not possible, the blimp was well protected and did not need to be

deflated, again reducing helium requirements and overall costs. As well as having comparatively low operational costs, the initial outlay for the blimp-cam was lower; \$AU21,850 (~\$US11,000 at the time of purchase), compared with \$US19,000 for the Nowacek *et al.* (2001) system.

**Table 2.1** A comparison of the components and operation of the blimp-cam with the overhead video system described by Flamm *et al.* (2000) and Nowacek *et al.* (2001a).

Component	Overhead video system described by Flamm <i>et al.</i> (2000) and Nowacek <i>et al.</i> (2001a)	Blimp-cam
Balloon	Traditional zeppelin style blimp – 42.5 m <sup>3</sup> , 8.8 m long, 3.4 m in diameter, 22.7 kg lift (Aerostar TRF-1500)	Hi-Speed blimp – 11.3 m <sup>3</sup> , 2.5 m in diameter, 2.3 m high, 7.6 kg lift (Balloon Promoters, NZ)
Cable / Tether	61 m combined electrical and mechanical tether including a braided Kevlar 49-strength member (680 kg breaking strength)	2 x 50 m of 4.8 mm polyester braid, hard lay rope (CJ648), one combined with figure 8 power cord
Camera	3CCD colour camera, interchangeable (8-80 mm or 12-120 mm) zoom lenses, 750 lines horizontal resolution (JVC KY-F55BU),	Single CCD colour dome camera, 4-83 mm zoom, 480 lines horizontal resolution (Panasonic WV-CS854)
Camera control	Via fibre optic line within tether	Via 151 MHz transmitter (TX151D) and double conversion receiver (RX921P5V/S)
Video signal transmission	Via fibre optic line within tether	Via 915-928 MHz transmitter (TX921P5V/S) and double conversion receiver (RX921P5V/S); or coax cable
Pan and tilt system	360° continuous pan (to 100°/s) and 90° tilt, not mutually exclusive	360° continuous pan (to 300°/s) and 180° tilt (digital flip), not mutually exclusive
Controller	Pelco variable-speed keyboard with joystick to operate pan, tilt, focus, zoom and iris (MPT9500 Series Transmitter/Controller)	Pacom 2035 Intelligent CCTV Keyboard with joystick to operate pan, tilt, focus, zoom and iris (PC2035K2)
Video recorder	Digital video recorder (Sony HR1000)	Digital video camcorder (Panasonic NV-MX300)
Monitor	Sony Trinitron (KV 9PT60)	Panasonic Colour Video Monitor (BT-S1050Y)
Mounting	Water-proof camera housing bolted to aluminium bracket	Water-proof camera housing suspended from balloon with 6 webbed, 2.5 cm width tethers and bracket connectors
Power	24 V AC via tether	24 V AC via tether with 12 V inverter in camera housing for signal transmitter
Initial cost	~ \$US 19,000	\$AU 21,850 (~ \$US 11,000 at 2001 exchange rates)
Helium requirements	8.2 m <sup>3</sup> per week	3.6 m <sup>3</sup> per week
Number of people required	≥ 4	3
Weather conditions	≤ 15 kn and no rain	≤ 15 kn and no rain
Footage quality	Broadcast quality with no dropouts	< Broadcast quality with some dropouts when using transmitter and none when using cable
Support vessel	< 6 m boat, enclosed cabin for monitoring/operation, padded cradle for blimp	5.6 m pontoon boat, 40 HP outboard, open deck
Towing speed while tethered	15 to 20 kn	> 8 kn (restricted by boat engine size)
Storage	In cradle on boat	In tent on land, area = 4 x 4 m, height = 2.7 – 3.5 m

## 2.4 Potential uses of the blimp-cam

The successful implementation of this aerial video system provides further evidence of the feasibility of such systems for the study of other relatively large, yet cryptic marine animals. As a relatively benign research tool the blimp-cam could be used to study pinnipeds on land and in the water near haul-out sites. This approach would reduce the influence of observer disturbance and is therefore ideal for studying the effects of other types of disturbance (for examples of disturbance see Kirkwood *et al.*, 2003). As shown by Nowacek *et al.* (2001), the behaviour of bottlenose dolphins can be observed using an overhead video system. There are also many species of elusive coastal dolphins, such as Irrawaddy dolphins (*Orcaella brevirostris*) (Parra *et al.*, 2002) about which very little is known as they are wary of boats and difficult to approach. While using blimp-cam to observe dugongs, I found that I could also see other species such as turtles, rays, and sharks. This observation technique could be applied to studies of these species and provide previously unobtainable data, as it allows the researcher to remain further away from the animals than when observations are conducted directly from a research vessel.



# **Chapter 3**

## **The diurnal behaviour of dugongs at the southern limit of their range in southeast Queensland**

**In this chapter, I describe the movement patterns of dugongs within the study area throughout two field seasons. I use the data collected from continuous behavioural observations of individual dugongs to: (1) provide the first time budget for dugongs, and, (2) compare the effects of environmental variables and reproductive status (whether with calves) of individuals on their behaviour. I investigate diving behaviour in relation to other behaviours in order to provide a better understanding of the ‘availability’ of dugongs for aerial survey censuses (Section 1.3). Particular emphasis is placed on describing behaviours that may affect the impact of boats and pingers on dugongs.**



## **Chapter 3. The diurnal behaviour of dugongs at the southern limit of their range in southeast Queensland**

### **3.1 Introduction**

As outlined in Chapter 1, quantifying the behaviour of dugongs has been difficult as they occur in turbid waters throughout most of their range, and as bottom feeders spend very little time at or near the surface (Barnett & Johns, 1976; Anderson, 1981a; Anderson, 1982). Boats or other unfamiliar objects often evoke either investigatory or evasive behaviour, neither of which is conducive to studying the undisturbed behaviour of dugongs (Section 2.2; Gohar, 1957; Barnett & Johns, 1976; Anderson, 1981a; Preen, 1989; Whiting, 2002). Generally, when dugongs surface, only the nose (and sometimes the mid-dorsum) emerges, neither of which provides unique characteristics that can be used to identify individuals. Thus even quantifying submergence times can be difficult when more than one individual is present.

Boat- or shore-based observations of dugong behaviour have mostly relied on indicators, such as the way in which the animal submerges, to indicate subsurface activities. For example, roll-diving, where the animal's dorsum appears above the water after its head has submerged, is presumed to occur when a dugong is feeding and needs to angle its body towards the vertical to reach the bottom (Anderson & Birtles, 1978; Anderson, 1994; Anderson, 1998). Using indicators such as submergence style to differentiate behaviours is not always accurate. For instance, foraging dugongs do not always roll-dive, and there are no particular surfacing or submergence characteristics that can be attributed to other behaviours such as resting (Anderson & Birtles, 1978; Anderson, 1998).

As a result of the limitations outlined above, there have been few direct observations of the subsurface activities of dugongs. To date research has been concentrated on life history (e.g., Marsh, 1980; Marsh *et al.*, 1984; Kwan, 2002), estimates of population size (e.g., Heinsohn, 1976; Marsh & Saalfeld, 1989; Marsh *et al.*, 1990; Marsh *et al.*, 1994b; Preen *et al.*, 1997; Marsh & Lawler, 2001b; Lanyon, 2003; Preen, 2004; Marsh

*et al.*, in press), distribution and movement patterns (e.g., Anderson, 1986; Marsh & Rathbun, 1990; Preen, 1992; Anderson, 1994; de Iongh *et al.*, 1998; Preen, 2001), dive times (e.g., Churchward & Anderson, 1999; Whiting, 2002; Chilvers *et al.*, 2004) and the relationship between dugongs and seagrass (e.g., Heinsohn *et al.*, 1977; Preen, 1992; de Iongh *et al.*, 1995; Preen, 1995; de Iongh, 1996; Perry & Dennison, 1996; Anderson, 1998; Aragonés & Marsh, 2000; Masini *et al.*, 2001).

As discussed in Chapter 1, these studies have shown that dugong movements occur at several spatial scales. Large scale movements of populations likely result from changes in seagrass distribution (Preen & Marsh, 1995; Marsh *et al.*, 1996; Marsh & Lawler, 2001b; Gales *et al.*, 2004; Marsh *et al.*, 2004). Individuals show large variation in movement, with some remaining in relatively small home ranges, whereas others travel hundreds of kilometres (Marsh & Rathbun, 1990; Preen, 1992; de Iongh *et al.*, 1998; Preen, 2001). A number of populations occurring at high latitude limits of the dugong's range also move in response to water temperature changes, including dugongs in Shark Bay which have different distributions in summer and winter (Anderson, 1986; Marsh *et al.*, 1994b; Gales *et al.*, 2004), and dugongs in Moreton Bay which move to warm deep water outside the bay during winter (Preen, 1992). At the smallest scale, dugongs move in response to tides that restrict access to seagrass growing in intertidal areas (Heinsohn *et al.*, 1977; Anderson & Birtles, 1978; Marsh & Rathbun, 1990).

Apart from these movements in response to low water temperatures, there has been no quantitative assessment of how water temperatures, or indeed other environmental variables such as wind speed and swell affect the behaviour of dugongs. Early accounts suggest that dugongs seek sheltered areas or deeper water in high winds, which may affect their activity patterns (Jarman, 1966; Heinsohn *et al.*, 1977). Anderson (1998) suggests that resting is restricted to periods of low wind.

The only estimate of a time budget for dugongs has been via dive profiles obtained from timed depth recorders (TDR) fitted to 15 dugongs (Chilvers *et al.*, 2004). Although TDRs provide data on individual animals throughout diurnal and tidal cycles over days to months, the data are limited: (1) to individuals permitted for capture to attach the devices, a restriction which currently excludes females with calves in Australia, (2) by the assumptions made in the absence of visual observations, such as how two



dimensional dive profiles relate to behavior, (3) by the degree of error resulting from technological limitations, particularly in relation to fine scale movements and dive behavior in depths of less than 1.5 m, and (4) the present small sample size of 15 individuals and the high individual variability in dive rates, which make it difficult to detect effects of environmental variables on dive types and thus behaviours (Chilvers *et al.*, 2004).

Studies of dugong social behaviour are mostly limited to qualitative descriptions of mother-calf interactions, social interactions among dugong groups, and mating events (Anderson & Birtles, 1978; Anderson, 1982; Preen, 1989; Anderson, 1998). The only recognised social bond is between mothers and their calves (Prater, 1928; Anderson, 1982). The lactation period is estimated at 15 to 17 months according to examination of female carcasses (Kwan, 2002) and at least 18 months according to the estimated age of a calf caught with a lactating female (Marsh *et al.*, 1984). Apart from this there is little known about dugong social structure. Contrasting reports on mating behaviour suggest that it may vary regionally (Anderson, 2002). Anderson (1997) observed individually identified dugongs patrolling and defending territories, and conducting unique behaviours interpreted as displays in Shark Bay. These activities occurred in a sparsely vegetated cove and two instances of suspected mating behaviour were observed. Anderson (1997) inferred that the individuals regularly occupying these territories are males engaged in a lek mating system. In Moreton Bay and two localities in northern Queensland, mating herds similar to those seen in Florida manatees (*Trichechus manatus latirostris*) (Hartman, 1979) have been observed (Preen, 1989; Marsh *et al.*, 1999b). Compared with Florida manatees, dugongs appear to exhibit more violent competition among males to gain access to oestrous females in mating herds (Preen, 1989).

The blimp-cam (Chapter 2) provided me with the opportunity to expand on these limited records of dugong behaviour by allowing continuous observations of subsurface activities. This study is the first to provide a detailed ethogram of dugong behaviour (Appendix 3), and to quantify dugong time budgets through direct observations. Although I could not identify or determine the sex of individual dugongs using this technique, its benign nature permitted observations of the behaviour of all age-classes, including calves, and comparisons between mother-calf pairs and single individuals.

This information provides a framework on which to base assessments of anthropogenic impacts, including the effects of boats and pingers, as investigated in this study (Chapters 6 to 8).

## **3.2 Methods**

### **3.2.1 Habitat use and herd movements**

Habitat use and herd movements were assessed on the basis of all my sightings of dugongs in both my 2001 (12 July to 24 October) and 2002 (22 April to 11 August) field seasons. The search protocol used to locate dugongs is described in Section 2.2.4.2. The position of the research vessel was recorded each time dugongs were sighted using a Garmin GPS II Plus (maximum error of 15 m according to manufacturer's specifications). While dugongs were kept in sight of the research vessel, GPS positions were recorded every 5 min (during 2001) or every half hour (during 2002) regardless of whether behavioural observations were being made.

Aerial photographs of the Moreton Banks (taken in February 2002) were collaged and warped to fit a georeferenced map of the same area in ArcView GIS 3.3. Land marks were used to fit the photos to the map. All locations of dugongs, including repeated recordings of the same herd on the same day, were added to the georeferenced map.

Environmental data were recorded every half hour when I was on the Moreton Banks, regardless of whether dugongs were present. In addition, water depth was recorded each time the boat was repositioned and anchored close to a dugong herd. Recordings included:

- water depth – measured using a depth sounder attached to the boat (Eagle Fish ID 128, 192 kHz, resolution to 0.1 m)
- surface water temperature – measured using a digital temperature probe (TPS MC81, accurate to within 2.01°C)
- cloud cover – assessed visually in eighths (oktas)
- Beaufort wind scale – assessed visually and checked using a Kestrel K1000 windometer (resolution to 0.1 knots, accuracy  $\pm 3\%$  of reading),

- swell height – assessed visually to the nearest 0.5 m

### 3.2.2 Focal follow protocol

I studied the behaviour of individual dugongs and mother-calf pairs using the blimp-cam from August through October 2001, and June to August 2002. Focal follows (Altmann, 1974) were conducted of individual dugongs or mother-calf pairs randomly chosen according to their visibility. Each follow was conducted for a set time period of 15 min. Calves were never chosen as the focal individual, but were observed as part of a mother-calf pair. These dyads were not always immediately obvious, particularly if they were amongst a large herd and the calf was relatively large. However they became obvious throughout a follow as mothers and calves tended to remain close to one another most of the time. Thus by choosing to follow only adults, the subset of mother-calf focal follows contained a random sample of calves of various sizes. It is possible that individuals were sampled more than once during these series of focal follows as individuals could not be identified. However, herd sizes of up to 200 animals meant the probability of resampling the same individuals on any one day was low, and that the results are unlikely to be biased by resampling the same individual many times. Focal follows were extended if unusual or previously undocumented behaviours were observed, or shortened if the focal individual went out of view.

To aid in keeping the field of view constant, I placed a clear template over the monitor with a square frame in the centre. I continually adjusted the zoom of the camera so that the focal dugong filled the width or height of this frame. The size of the frame was calculated according to the actual width of the monitor, such that if the focal dugong filled this frame, the field of view to each side of the focal dugong was three dugong body lengths. Thus the distance and behaviour of other dugongs within this arena could also be recorded. Distance estimates were limited to a maximum of three body lengths to limit the error caused by camera angle. This unknown angle likely caused dugongs to appear closer or further away than they actually were.

I subsequently made continuous behavioural observations (Altmann, 1974) from the recorded video footage of each focal follow, where the onset and cessation of every behaviour was logged using Adobe Premier. An ethogram of all 54 specific behaviours

observed is provided in Appendix 3. These behaviours were grouped into six broad behavioural categories: feeding, travelling, resting, socialising, rolling and surfacing (Table 3.1). The specific types of feeding, travelling and resting behaviours discussed in this chapter are also described in Table 3.1. It is important to note that the category “surfacing behaviour” differs from actual surface and submergence times (dive cycles), in that surfacing behaviour encompasses the time spent rising to the surface and submerging until the next behaviour was observed (Table 3.1, Figure 3.1).

**Table 3.1** Descriptions of the six broad behavioural categories into which all specific behaviours of dugongs were classified, and the specific feeding, travelling and resting behaviours discussed in this chapter. A full ethogram is provided in Appendix 3.

Behavioural Category	Specific Behaviour	Description
Feeding	Feeding without plumes	Body resting on substrate, slow movement forward, nose turned down and pressed to substrate
	Feeding with plumes	As above but with sediment plumes visible
Travelling	Slow	Movement forward barely detectable but not along substrate, tail pumping not obvious or very occasional, indefinite direction of movement
	Cruising	Swimming at continuous speed with obvious movement forward, tail pumps obvious but not rapid, definite direction
	Fast	Swimming with rapid and obvious pumping of tail, bow wave often seen when animal surfacing
Resting	At surface	Floating still without obvious movement, no pumping of tail, very close to surface although whole body still submerged
	Mid water column	Floating still without obvious movement, no pumping of tail, not obviously near surface or on substrate
	On substrate	Just above or touching substrate but with no movement forward or pumping of tail and nose not pressed to substrate
Socialising		All contact (e.g., tail swipe, nose to nose touch or body to body rub) and non-contact (e.g., approach, follow or flee) interactions between individuals that are within three body lengths of each other
Rolling		Rotating horizontally (90 – 360 degrees) either touching substrate or mid water column, or forcefully pushing ventrum or tail into substrate where cloud of sediment may be visible
Surfacing		Starts ascending to surface by lifting head and/or spreading pectoral fins to steer body upwards, exhales and inhales at surface, descends and returns to former behaviour or begins a subsequent behaviour by pumping tail, ceasing movement, or reaching the sediment to feed

### 3.2.3 Time budgets

To assess the proportion of time dugongs spent within each behavioural category, each focal follow was divided into bouts. A bout consists of a particular behaviour conducted continuously, broken only by surfacing behaviour (Figure 3.1). Time spent surfacing during the bout was included in the bout length, while time spent surfacing in the transition between two different behavioural categories was considered a discrete behaviour. The proportion of time dugongs spend conducting surfacing behaviour was calculated using all surfacings, including those within bouts.

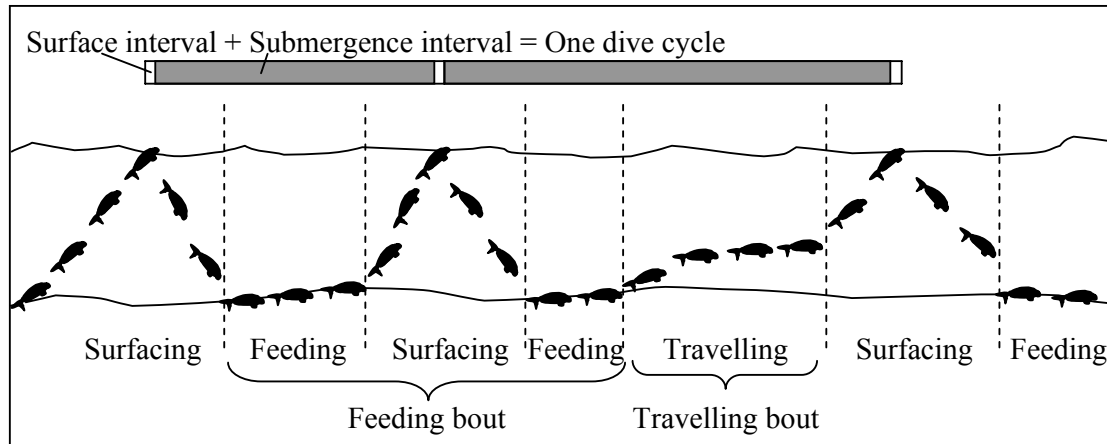
Overall time budgets were calculated according to the mean proportion of time focal dugongs spent in bouts of each behavioural category. The mean proportion of time single dugongs spent performing behaviours in each category was compared to that spent by mothers with calves using t tests. Paired t-tests were used to determine whether the proportion of time mothers were observed conducting each behaviour was significantly different from that of their calves.

### 3.2.4 Dive cycles

Each full dive cycle was divided into surface time and submergence time (Figure 3.1). The surface interval was recorded from the point at which the dugong's nostrils broke the surface, often with an associated mist spray as the animal exhaled, and ending when its nostrils were again submerged. The remaining time was then defined as the submergence interval. The mean dive rate was obtained by adding the mean submergence and surface intervals across all dives and calculating the number of complete dive cycles per hour. When assessing dive times, the video sample used for each focal dugong extended from the beginning of the first observed surface interval to the end of the last clearly identifiable surface interval.

Water depths recorded for each focal follow were categorized as  $< 1.5$  m or  $\geq 1.5$  m to determine whether submergence intervals are different in the shallow depths that cannot be recorded by TDRs (Chilvers *et al.*, 2004). A two-way ANOVA was used to test whether the mean submergence intervals of mothers were different from those of single dugongs for the two depth categories. A paired t-test was used to determine whether the

mean submergence intervals of mothers were significantly different from those of their calves across depth categories. To avoid repeated measures, the response for each of these tests was the mean submergence interval per individual during a focal follow.



**Figure 3.1** The classification of dugong behaviours into categories and bouts of behavioural categories. The duration of each bout included time spent surfacing between successive behaviours in the same category. The total time spent surfacing included surfacing behaviours within and between bouts. The surface interval was considered as the time a dugong's nose remained above the surface of the water, and submergence interval (also representing the respiration interval) was the time between successive surface intervals. One surface and one submergence interval together represent a whole dive cycle.

### 3.2.5 Dive times in relation to behaviour

Each submergence interval was classified into one of the following groups of behavioural categories (behavioural group) on the basis of behaviours conducted during at least 25% of the submergence interval: (1) travelling, (2) feeding, (3) single behaviour other than feeding or travelling, e.g., socializing or resting, or (4) combination of behaviours, e.g., socializing and feeding during one dive. Only single individuals and mothers were used in this analysis as mothers and calves are not independent. The mean submergence time was calculated for each of the four behavioural groups observed during each individual focal follow. A two-way ANOVA was used to test whether the submergence time varied with behavioural groups, and individual type (single individuals and mothers). Different individuals were used for each behavioural group to avoid confounding the effects of individual and behaviour. The response for this test was the mean submergence interval for an individual dugong

exhibiting the relevant behaviour during a focal follow. When there was a significant result, post-hoc Tukey tests were conducted to identify the differences.

### **3.2.6 Calf behaviour**

Calf diving behaviour was classified according to whether it was in synchrony with its mother's surfacing. A calf was considered to have surfaced 'almost in synchrony' with its mother if at least part of the surfacing interval coincided with that of its mother's surfacing interval. If the calf broke the surface and then submerged at the same time as its mother, the surfacing was classed as 'exactly in synchrony' (see Appendix 3).

As mothers and calves were ascending to the surface and descending together, calves exhibited a tendency to move from the mother's side to a position directly over her back. When they both broke the surface or completed their descent, the calf either returned to the same side or crossed to her opposite side. When the calf exhibited this behaviour either while ascending, descending or both, the surfacing behaviour was noted to include a 'cross over' of the mother's back (Appendix 3). While calves were exhibiting other behaviours, I also noted its position relative to the mother (Appendix 3). This information aided in determining the relative vulnerability of dugong age-sex groups to boat strikes (Chapter 5).

### **3.2.7 Suckling Behaviour**

A suckling bout was defined as beginning when a calf put its muzzle to the base of its mother's pectoral flipper, and ended when it broke from this position. The calf's behaviour (other than surfacing) immediately prior to and post suckling, the calf's submergence interval during the suckling bout, the mother's behaviour during the suckling bout, and the mammary gland used (left or right), were also recorded. The submergence times during suckling bouts were compared to submergence times recorded for different calves which were not suckling using an independent samples t-test.

### **3.2.8 Effects of environmental variables on behaviour**

I used Pearson's correlation coefficient to identify which environmental variables were significantly correlated with each other ( $P < 0.05$ ). This approach allowed me to reduce the number of variables incorporated in the multiple regression exploring the relationship between environmental variables and behaviour. One environmental variable was chosen from those that were significantly correlated and that were intuitively related, e.g., for Beaufort wind scale and swell height, I chose Beaufort wind scale.

Forward stepwise multiple regression analysis was used to determine which combination of the chosen environmental factors best accounted for the variation in proportion of time each focal individual spent performing each of the behaviour categories. The criterion for inclusion in the regression model was  $P \leq 0.05$ .

All results are provided as means  $\pm$  standard errors.

## **3.3 Results**

### **3.3.1 Habitat use and herd movements**

#### ***3.3.1.1 Movements across the banks***

Locations of dugongs indicated that the use of the Moreton Banks by dugongs was cyclical, with a gradual but clear northeast shift in dugong sightings throughout both field seasons (Figure 3.2). This shift occurred in both the shallow areas used during high tide and the deeper areas used during low tide. The 2002 field season was conducted earlier in the year (April through August), than the 2001 field season (July through October). Coinciding with this, the extreme ends of the location ranges were more to the northeast during 2001 and more to the southwest during 2002. This pattern may indicate an annual cycle in the movement of dugongs across the banks. However, regular, controlled surveys of the Moreton Banks, along with data from summer months, are needed to confirm this.



### ***3.3.1.2 Tides and water depth***

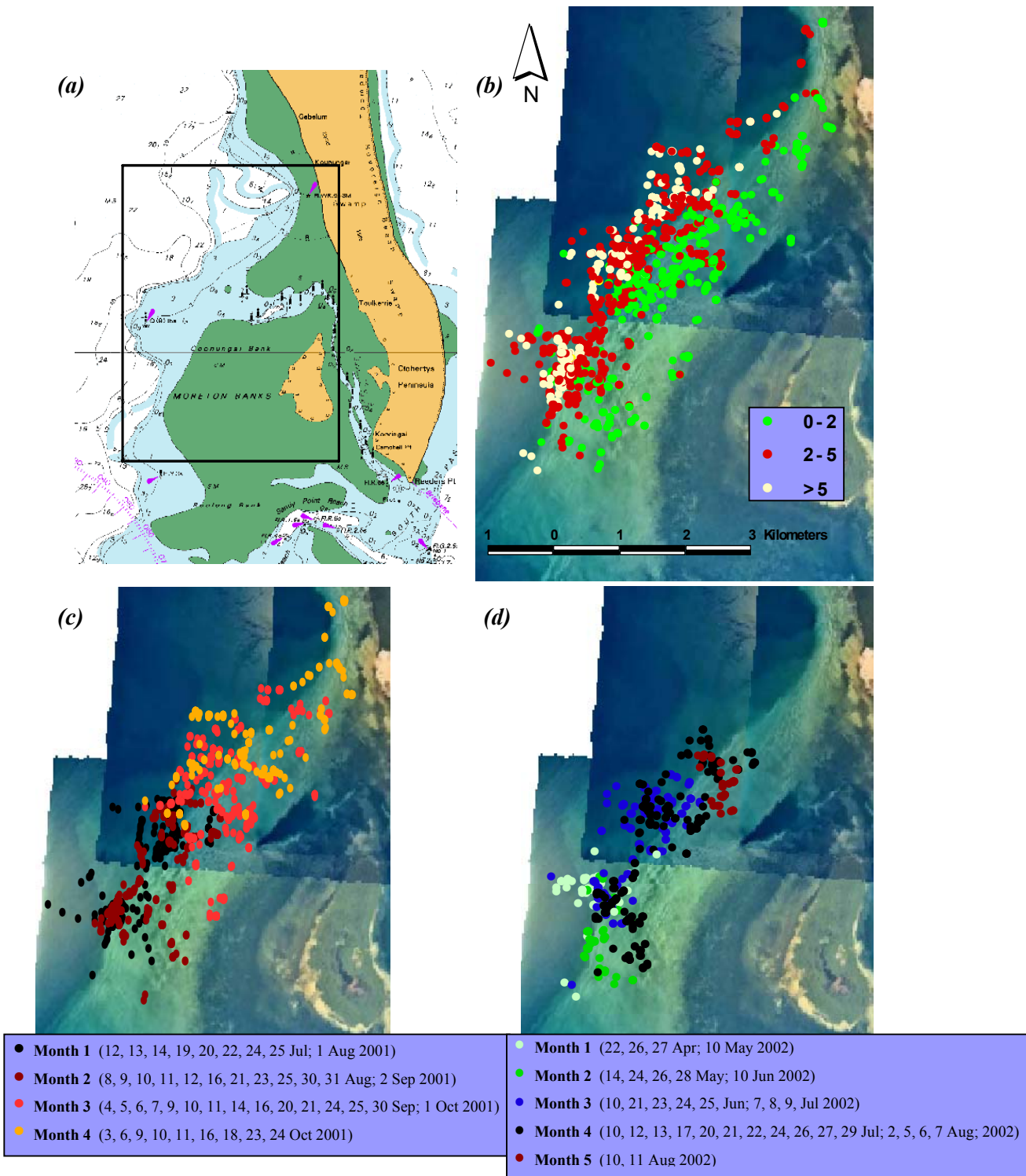
Dugongs could be found on or near the Moreton Banks throughout the tidal cycle (Figure 3.2). During the two hours before and after high tide, dugong sightings were mostly in the shallow areas of the banks at average depths of  $1.7 \pm 0.03$  m (min 0.8 m). During the period two to five hours before or after high tide, dugongs were in slightly deeper water ( $2.4 \pm 0.10$  m) usually along the edges of the shallow banks. At low tide the shallow areas were inaccessible, as the average tidal range in Moreton Bay is about 2 m. Dugongs were normally found along the deeper edges of the banks at low tide at depths averaging  $2.5 \pm 0.11$  m. This estimate is biased towards the shallow depths at which I could view the dugongs using the blimp-cam (Section 2.2.5). I saw dugongs at maximum depths of 25.4 m off the edge of the sandbanks, however they were only rarely seen beyond the edge of the Moreton Banks, which have maximum depths of 5 – 6 m.

### ***3.3.1.3 Water temperature***

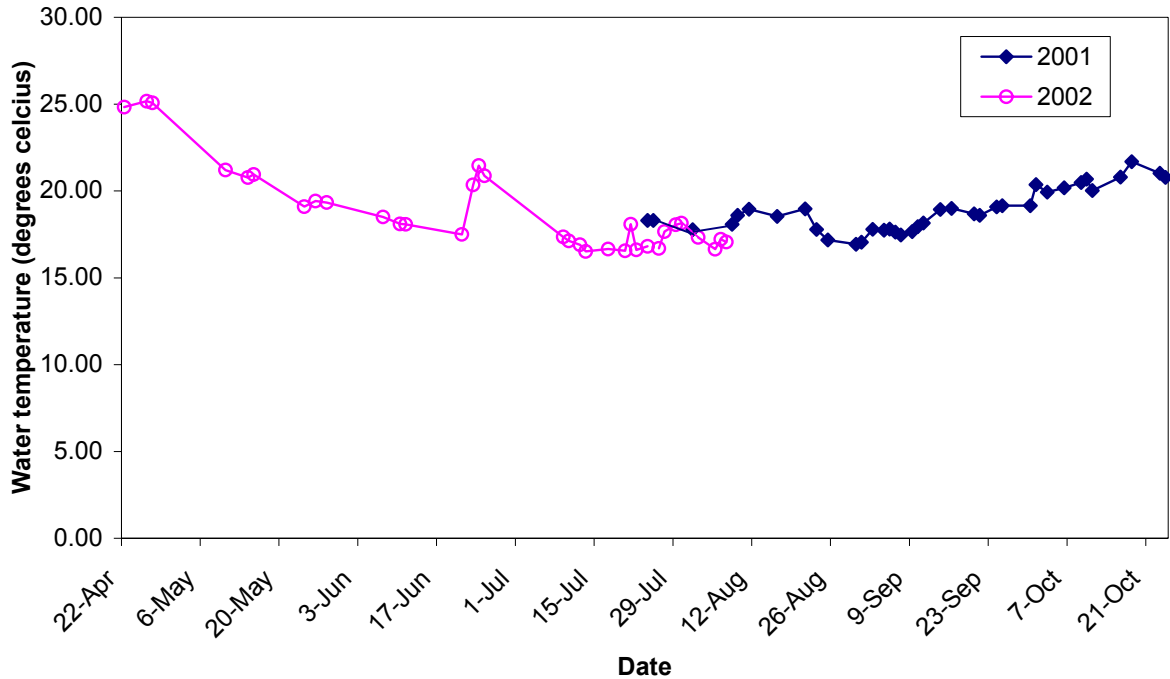
During the 2001 (August to October) field season the mean water temperature measured from the research vessel when dugongs were within sight, was  $18.8 \pm 0.08^\circ\text{C}$  (range = 15.9 to  $22.5^\circ\text{C}$ ). The mean temperature was similar in 2002 (May to August),  $18.5 \pm 0.2^\circ\text{C}$ , but higher maximum temperatures were recorded (ranging 15.7 to  $25.5^\circ\text{C}$ ), reflecting the temporal differences in the two field seasons (Figure 3.3).

## **3.3.2 Focal follows**

Continuous behavioural data were recorded for the focal follows of 126 dugongs (see Appendix 2 for an example), including 94 single individuals and 32 mother-calf pairs. Focal follows lasted from 3 min 26 s to 30 min 11 s, averaging 12 min 32 s. Behavioural observations using the blimp-cam are limited by water depth. Thus more focal follows were conducted during the three hours either side of high tide ( $N = 80$ ) when dugongs had access to the shallower water of the banks, than at low tide (3 – 7 hours before or after high tide,  $N = 46$ ) when dugongs were at the deeper edges of the banks (Figure 3.2).



**Figure 3.2** The study area at the southern tip of Moreton Island highlighted on a map (a) and shown in georeferenced aerial photos (b, c, and d). All points are GPS locations recorded on board the research vessel while dugongs were within sight. These points are categorised according to number of hours before or after high tide (b) and according to months delineated by each new moon in 2001 (c) and 2002 (d).



**Figure 3.3** Water temperatures recorded from the research vessel when dugongs were within sight during the 2001 and 2002 field seasons.

### 3.3.3 Time budgets

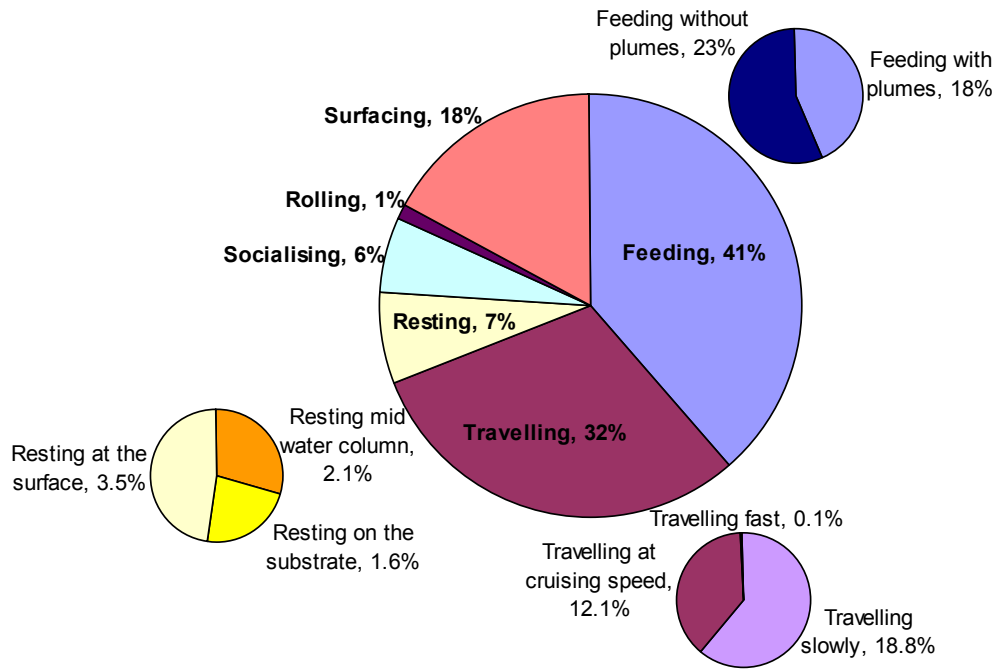
The mean and median length of bouts for each behavioural category is presented in Table 3.2 based on all bouts for all individuals. These data were calculated using only those bouts where both the onset and cessation was recorded (i.e., those that occurred at the beginning or end of focal follows were excluded). According to both mean and median estimates, bouts of feeding tended to be longer than all other behavioural categories, followed by resting, travelling, socialising and rolling. The data for feeding, travelling and resting are biased however as they are right censored (i.e., biased toward shorter bout lengths). When incomplete bouts (those that occurred at the beginning or end of the focal follow) were included in the data set, maximum bout lengths were longer than the average length of focal follows (12 min 32 s). Thus the focal follows were not long enough to obtain an accurate account of the average time spent in bouts of each of these behaviours. It should also be noted that these bout lengths refer to daytime behaviour only.

**Table 3.2** Summary of the length of bouts of each behavioural category, including bouts recorded for all single individuals and mothers during focal follows. Incomplete bouts (those that occurred at the beginning or end of the focal follow) were treated separately and not included in mean, SE, median or range statistics. Maximum bout lengths when including incomplete bouts are provided separately.

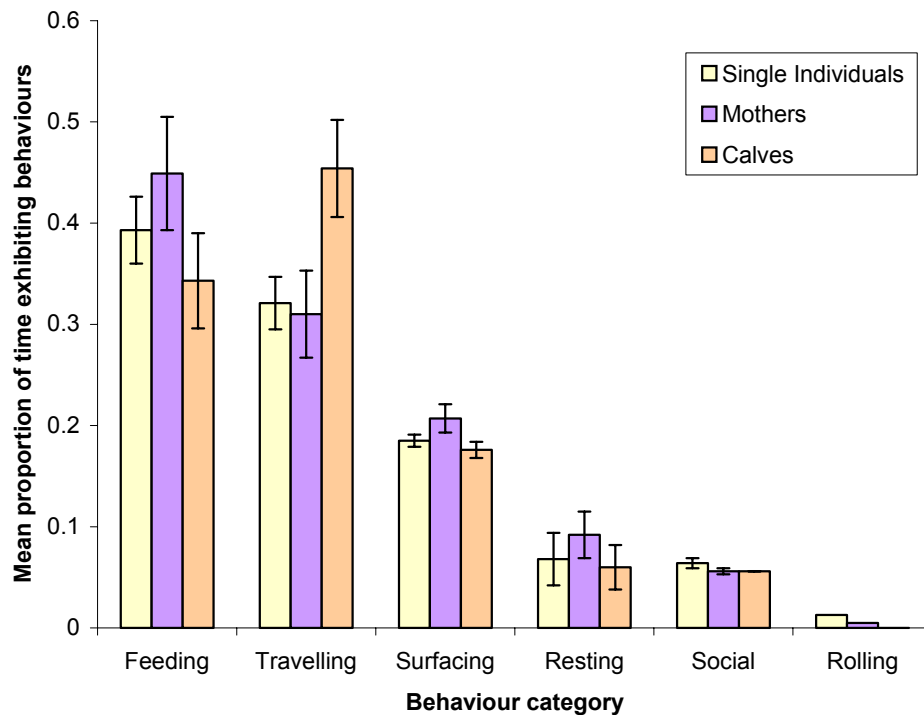
Behavioural category	Mean bout length (s)	SE (s)	Median (s)	Range (s)	Maximum bout length including incomplete bouts (s)
Feeding	93	7	42	2 – 546	1171
Travelling	51	2	33	2 – 392	551
Resting	65	9	39	4 – 621	1136
Socialising	37	3	23	2 – 251	251
Rolling	25	4	19	3 – 115	115

Dugongs spent almost half their time feeding ( $41 \pm 3\%$ ), and were producing obvious sediment plumes during half ( $18 \pm 3\%$ ) of this feeding time (Figure 3.4). Travelling was the second most common behaviour, contributing to approximately one third ( $32 \pm 2\%$ ) of the time budget. The majority of travel was slow ( $19 \pm 2\%$ ), or at cruising speed ( $12 \pm 2\%$ ), with only rare instances of fast travel ( $0.1 \pm 0.001\%$ ). Surfacing also constituted a fairly large proportion of the time budget ( $18 \pm 1\%$ ). The remaining three behavioural categories: resting ( $7 \pm 2\%$ ), socialising ( $6 \pm 1\%$ ) and rolling ( $1 \pm 0.01\%$ ), were exhibited during a relatively small proportion of the observations. Resting behaviour occurred for almost twice as much time at the surface ( $3.5 \pm 0.01\%$ ) than in the mid water column ( $2.1 \pm 0.01\%$ ), and more than twice as much as at the bottom ( $1.6 \pm 0.01\%$ ) of the water column.

The time budget for single individuals did not differ significantly from that of mothers with calves (Figure 3.5); t tests indicated that both types of dugongs spent similar proportions of time in each behavioural category apart from surfacing (Table 3.3). Mothers spent 3% more time surfacing than single individuals and this difference approached significance ( $P = 0.08$ ). Calves spent significantly less time feeding, and more time travelling than their mothers (Table 3.3). Mothers spent 3% more time in surfacing behaviour than their calves and this difference was significant (Table 3.3). Mothers also spent 3% more time resting than their calves and this difference approached significance ( $P = 0.08$ ). Time budgets for the remaining two behaviours, socialising and rolling, were similar for mothers and their calves (Figure 3.5, Table 3.3).



**Figure 3.4** Time budgets based on the mean proportion of time single dugongs and mothers with calves spent within bouts for each behavioural category and for specific behaviours within categories (Appendix 3) during focal follows (N = 126). These proportions do not total to 100% because surfacing behaviour was included within bouts of other behaviours, as well being as assessed separately.



**Figure 3.5** Mean proportion of time ( $\pm$  SE) single individuals (N = 94), mothers (N = 32) and calves (N = 32) spent in bouts of each behavioural category (Appendix 3) during focal follows.

**Table 3.3** Proportions of time single individuals, mothers and calves spent exhibiting behaviours in each category, with the results of t tests comparing single individuals and mothers, and paired t tests comparing mothers with their calves ( $P < 0.05$  in bold).

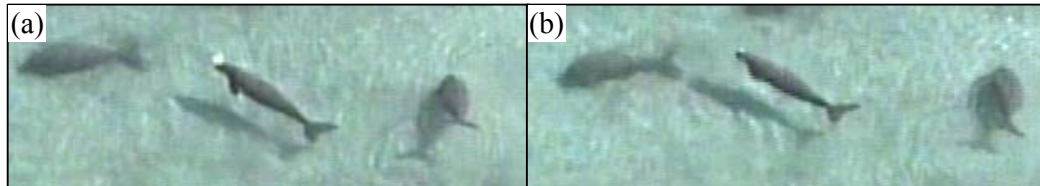
Behavioural category	Singles		Mothers		Calves		T test: singles and mothers			Paired t test: mothers and calves		
	Mean	SE	Mean	SE	Mean	SE	t	df	P	t	df	P
Feeding	0.39	0.03	0.45	0.06	0.34	0.05	-0.85	124	0.40	4.23	31	<b>0.00</b>
Travelling	0.32	0.03	0.31	0.04	0.45	0.05	0.21	124	0.83	-4.09	31	<b>0.00</b>
Surfacing	0.18	0.01	0.21	0.01	0.18	0.01	-1.77	124	0.08	2.70	31	<b>0.01</b>
Resting	0.07	0.02	0.09	0.03	0.06	0.02	-0.64	124	0.52	1.84	31	0.08
Socialising	0.06	0.01	0.06	0.02	0.06	0.02	0.30	124	0.76	0.16	31	0.88
Rolling	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.92	124	0.36	1.52	31	0.14

### 3.3.4 Dive cycles

Dive data were recorded during 87 focal follows of dugongs, including 33 follows of single individuals and 35 follows of each member of a mother-calf pair. Focal follows lasted from 4 min 44 s to 26 min 39 s, averaging 12 min 23 s. A total of 997 submergence intervals was recorded and 1,110 surface intervals. All dive times were recorded in waters ranging from 0.9 – 4 m deep with a mean depth of  $2.1 \pm 0.1$  m.

The precision with which dugong diving behaviour could be timed is exemplified in Figure 3.6 which shows a dugong surfacing and submerging. Submergence intervals ranged from  $< 1 - 317$  s, while the mean time across all dives recorded was  $75 \pm 1$  s and the mode was 108 s. The interaction between the effects of age-sex class (single individual or mother-calf pair) and water depth ( $< 1.5$  m or  $\geq 1.5$  m) on submergence interval was not significant (two-way ANOVA,  $F_{1,64} = 1.64$ ,  $P = 0.20$ ). In addition, the mean submergence interval for single individuals ( $79 \pm 3$  s) was not significantly different from that of mothers ( $82 \pm 3$  s;  $F_{1,64} = 0.10$ ,  $P = 0.76$ ). Also, dugongs in  $< 1.5$  m water depths had only slightly shorter and not significantly different submergence intervals ( $74 \pm 3$  s) than those in  $\geq 1.5$  m water depths ( $83 \pm 3$  s;  $F_{1,64} = 2.55$ ,  $P = 0.12$ ). Furthermore, mothers spent significantly more time submerged than their calves ( $72 \pm 3$  s; paired  $t = 2.96$ ,  $df = 34$ ,  $P = 0.01$ ).

The overall mean surface interval was  $2 \pm < 1$  s with a range of  $< 1 - 5$  s. The mean surface interval across all dives recorded for single individuals ( $2 \pm < 1$  s) and mothers ( $2 \pm < 1$  s) was slightly higher than of calves ( $1 \pm < 1$  s). The overall mean dive rate across all individuals was approximately 47 complete dive cycles per hour.



**Figure 3.6** An example of a dugong surfacing: (a) where the spray from the nostrils can be seen as the dugong exhales slightly below the water surface, and submerging (b) where the ripple of the water indicates when the dugong's nostrils are completely submerged.

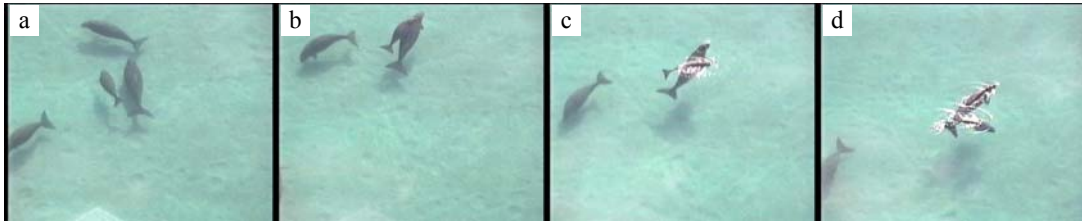
### 3.3.5 Diving in relation to behaviour

Dive times and behaviours were recorded for 28 single individuals and 28 mothers. The interaction between the effects of the behaviour exhibited during a submergence interval and type of individual (single or mother) was not significant ( $F_{3, 48} = 1.29$ ,  $P = 0.29$ ). The effects of behaviour were significant ( $F_{3, 48} = 2.78$ ,  $P = 0.05$ ), while the effects of type of individual were not ( $F_{1, 48} = 2.60$ ,  $P = 0.11$ ). Post hoc analysis showed a significant difference only between submergence intervals where individuals conducted a single behaviour other than travelling or feeding (mean submergence time:  $68 \pm 6$  s), compared with a combination of behaviours ( $92 \pm 8$  s;  $P = 0.04$ ). The mean time spent submerged while feeding only ( $83 \pm 3$  s), and travelling only ( $74 \pm 6$  s), fell between these two values.

### 3.3.6 Calf behaviours

Although, as noted above, mothers and calves had significantly different diving rates, they often surfaced in synchrony. During mother-calf focal follows, calves broke the surface at exactly the same time as their mothers at a mean rate of  $16.9 \pm 0.04\%$  of surfacing behaviours recorded for calves. Mothers and their calves surfaced almost in synchrony (within 2 seconds of one another, Figure 3.7) during a mean of  $37.5 \pm 0.05\%$  of surfacing behaviours recorded for each calf. Calves moved to a position diagonally

above their mother, or crossed over their mother's back while ascending and/or descending during a mean of  $25.8 \pm 0.04\%$  of surfacing behaviours (Figure 3.7).



**Figure 3.7** Mother and calf surfacing behaviour: (a) calf travelling beside the mother, (b) calf beginning to cross over the mother's back while surfacing, (c) mother and calf surfacing almost in synchrony, (d) calf submerging on the opposite side of the mother.

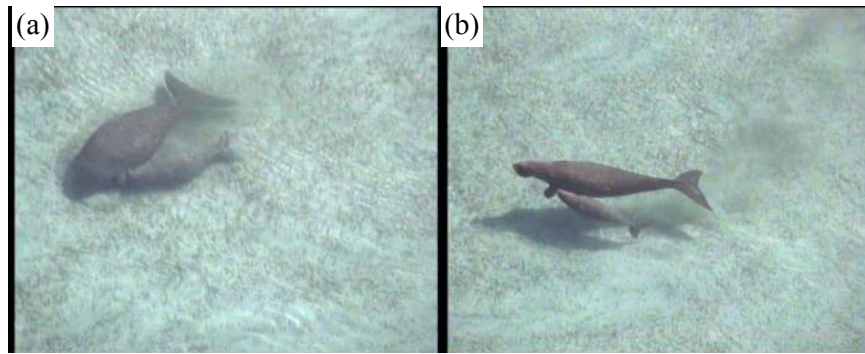
When mothers were travelling, feeding or resting, calves were often positioned directly above their mother's back, while they either followed or rested with her. Of the total time recorded for each mother-calf focal follow, calves spent a mean of  $13 \pm 0.03\%$  above their mother's back, as opposed to near their mother's side.

### 3.3.7 Suckling behaviour

A total of 15 suckling bouts was observed during 15 mother-calf focal follows. Bouts averaged 87 s in length and ranged from 70 to 105 s. While suckling, calves remained in a horizontal position, dorsal surface upright, and angled their head and ventrum slightly towards the mother so that their muzzle could attach to the base of the mother's pectoral fin where the mammary glands are located (Bryden *et al.*, 1998; Figure 3.8; Appendix 2). If the mother was surfacing or travelling, the calf typically 'hung' in this position. However, in one instance where the mother was travelling at cruising speed (continuous and obvious movement forward, tail movements obvious), the calf had to swim rapidly to remain suckling, particularly when the mother was surfacing. If the mother was feeding, her calf lay next to her, angled towards her. Calves suckled from both the left ( $n = 9$ ) and right ( $n = 6$ ) mammary glands.

Before a bout of suckling the calf was usually travelling ( $n = 8/15$  occasions) or resting ( $n = 4/15$ ) with its mother. On one occasion, the calf was observed feeding on seagrass and on two occasions the behaviour was unknown. Post-suckling behaviour by the calf was either feeding on seagrass ( $n = 8$ ) or travelling with the mother ( $n = 7$ ). The





**Figure 3.8** A suckling calf with its muzzle attached to the mother's nipple at the base of her pectoral fin. Calves were always positioned with their dorsum uppermost and their head and ventrum angled slightly towards the mother. Calves continued suckling while the mother fed (a) and surfaced to breath (b).

behaviour of mothers during suckling bouts varied both within and between bouts. Mothers exhibited slow travel (movement forward barely detectable and only occasional tail pumps), cruising (on one occasion as outlined above), resting both at the surface and near the bottom, feeding and diving.

One calf, which was approximately two-thirds the length of its mother, was recorded making unsuccessful attempts to suckle. Based on an average adult body length of 2.5 m, this calf could have been up to 2 years of age (Marsh, 1980). The calf appeared to be angling its ventrum and muzzle towards its mother's pectoral fin, and remained in this position for approximately 30 s, while the mother's flipper was tightly to her side. The calf briefly performed suckling attempts a further four times, each immediately following a surfacing in synchrony with its mother. When not attempting to suckle, the calf rode on the mother's back or fed on seagrass with its muzzle close to her pectoral flipper. The mother was either feeding or exhibiting slow travel during these attempts and turned away from the calf during one attempt. The calf appeared to suckle successfully 6 min 14 s after the first attempt. However following this suckling bout (101 s), it again performed an unsuccessful suckling attempt on the opposite nipple.

Calves did not always surface immediately before or immediately after suckling. The time between surfacing and the onset of suckling ranged from 4 to 72 s, and the time from the cessation of suckling to surfacing ranging from 5 to 67 s. The mean length of the total submergence interval that included the suckling bout was  $127 \pm 8$  s ( $n = 12$ ). This time was significantly longer than the mean submergence intervals for calves that

were never recorded suckling ( $n = 12$ ), which was  $79 \text{ s} \pm 6 \text{ s}$  ( $t = -4.63$ ,  $df = 22$ ,  $P < 0.01$ ).

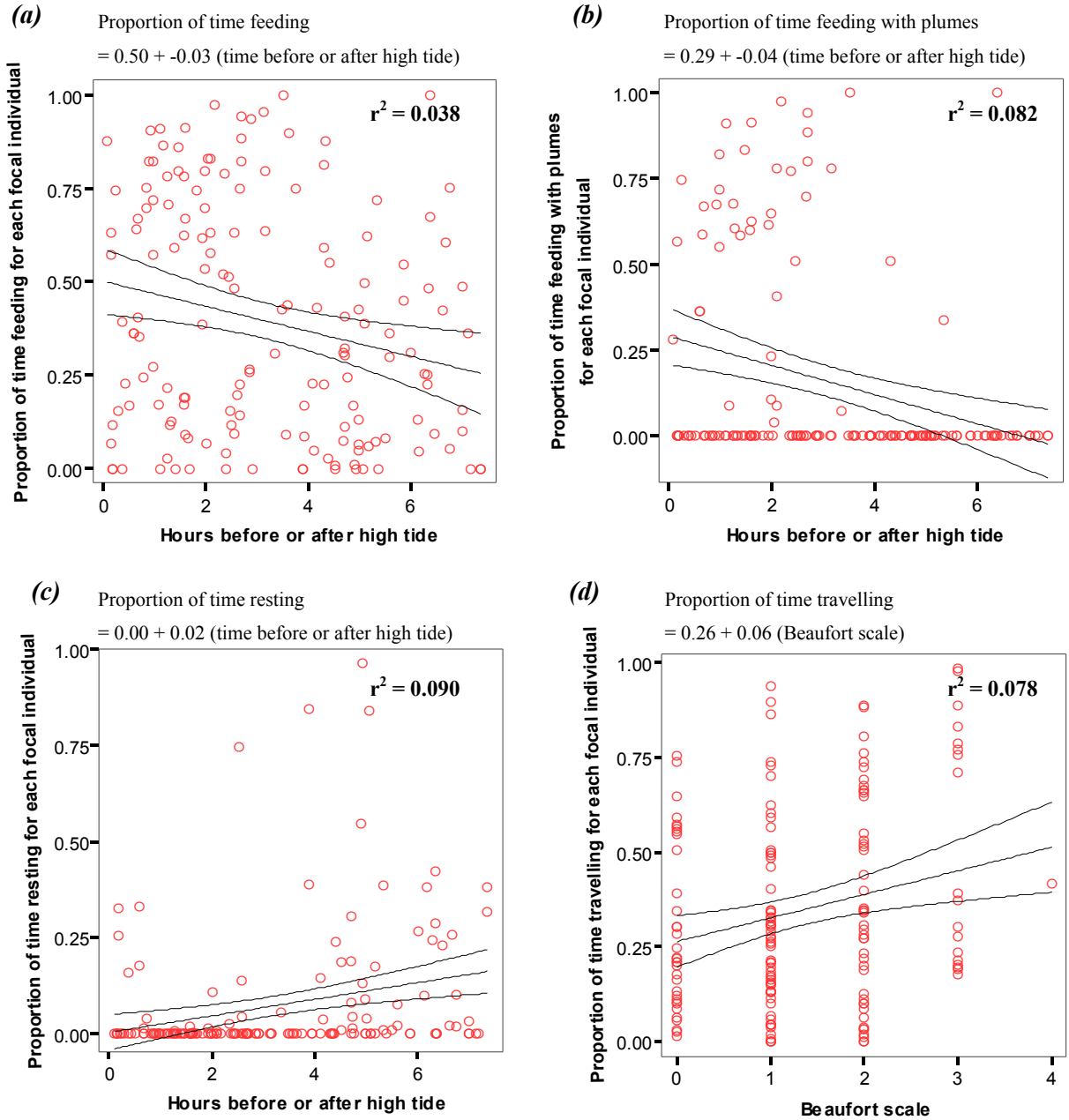
### 3.3.8 Effects of environmental variables on behaviour

Environmental variables that were significantly correlated and intuitively related are presented in Table 3.4. The three environmental variables tested against dugong behaviour were water temperature, time before or after high tide, and Beaufort wind scale, none of which was significantly correlated with one another ( $P > 0.05$ ).

In general, environmental variables accounted for very little of the variability in the proportion of time dugongs spent in each behavioural category. Forward stepwise regression analysis revealed that only one variable (time before or after high tide), was significantly (negatively) correlated with time spent feeding ( $F_{1, 114} = 4.70$ ,  $P = 0.03$ ) and feeding with plumes visible ( $F_{1, 114} = 10.67$ ,  $P < 0.01$ ), accounting for 3.8% and 8.2% of the variation respectively (Figure 3.9 a and b). Time before or after high tide was also positively correlated with time spent resting ( $F_{1, 114} = 11.72$ ,  $P < 0.01$ ) accounting for 9.0% of the variance (Figure 3.9 c). The proportion of time spent travelling was positively correlated with Beaufort wind scale only, which accounted for 7.8% of the variation ( $F_{1, 119} = 10.08$ ,  $P < 0.01$ ; Figure 3.9 d). The proportion of time spent socialising, rolling and surfacing were not correlated with any of the three environmental variables. However, my ability to interpret socialising and rolling data was limited by the small sample sizes of these behaviours.

**Table 3.4** Correlations between environmental variables.

Environmental Variables		Pearson's correlation	P	N	Variable used in multiple regression
Season	% Cloud cover	0.389	< 0.01	158	
Season	Water temperature	0.364	< 0.01	152	Water temperature
% Cloud cover	Water temperature	0.182	0.02	152	
Depth	Time from high tide	0.536	< 0.01	158	Time from high tide
Beaufort wind scale	Swell height	0.510	< 0.01	158	Beaufort wind scale



**Figure 3.9** Scatter diagrams representing the proportion of time each individual dugong spent: (a) feeding, (b) feeding with plumes, (c) resting, and (d) travelling, in relation to the environmental variable which best explained the variance according to forwards stepwise multiple regression. Linear regressions were fitted with 95% prediction intervals, and the  $r^2$  value obtained from multiple regression is given for each.

### 3.4 Discussion

The daily movement patterns of dugongs on the Moreton Banks coincided with the tides, which limit access to approximately 10 km<sup>2</sup> (~ 65%) of the commonly used area on the banks. The tides, however, had a minimal measurable effect on the time budget of individuals over the time periods of my two field seasons. Only a weak positive correlation occurred between the time before/after high tide and the proportion of time dugongs spent feeding, and a weak negative correlation with the proportion of time resting. As the blimp-cam could only be used to record dugong behaviour in water depths of less than 4 m, all behavioural data are biased towards behaviours conducted in this shallow water. Although dugongs were rarely seen beyond the edge of the sand banks (< 6 m) and dugong behaviour was recorded throughout the tidal cycle, I recorded a higher number of focal follows during the three hours either side of high tide than during the remaining tidal cycle. There is also a strong seasonal bias in my data, and as calving occurs mainly between October and December (Preen, 1992), analysis of the behaviour according to dugong 'type' (i.e., single or mother-calf pair) does not incorporate the behaviour of mothers with newborn calves.

#### 3.4.1 Feeding

As herbivores feeding on relatively low quality forage (Lanyon, 1992; Aragonés, 1996), dugongs would be expected to spend a large proportion of time feeding to fulfil their energy requirements. The time budget produced from short focal observations of individual dugongs during daylight hours in Moreton Bay revealed that these animals spent 41% of their time feeding. The time spent feeding with plumes (18% of the overall time budget), represents the minimum time dugongs spent feeding, as this behaviour could be interpreted unambiguously (i.e., dugongs were definitely feeding rather than resting or travelling slowly), as opposed to when plumes were absent and feeding was assumed from the dugong's movement along the sediment (Appendix 3). However, the total time recorded as feeding (with or without plumes) is considered the total feeding budget. The possible significance of feeding plumes created by large herds is discussed in Section 4.4.1.

Assuming that dugongs feed at a similar rate throughout the diel cycle, the rate recorded here equates to approximately 10 hours per day. Nocturnal foraging has been suggested through: (1) direct observations (Anderson & Birtles, 1978; Anderson, 1998), (2) analysis of dive profiles from timed depth recorders (TDRs) fitted to dugongs (Chilvers *et al.*, 2004), (3) a correlation between seagrass availability at night in relation to tides and feeding track numbers (de Iongh *et al.*, 1995), and (4) the adaptation of dugongs to feeding in inshore areas at night to avoid hunters or fishing activities (Jarman, 1966; Brownell *et al.*, 1981; Kwan, 2002).

Although Chilvers *et al.* (2004) state that comparisons between rates of dive types according to time of day are confounded by a high degree of individual variation, they assume that dugongs feed at a constant rate throughout the diel cycle. They estimate from the average rate and duration of feeding dives, that dugongs spend 16.2 hr per day feeding. The time budget estimated in my study is biased towards the three hours either side of high tide. The weak negative correlation between the time before or after high tide and feeding indicate that this may have escalated the predicted feeding budget slightly. However, my estimate of the feeding budget is substantially lower than that of Chilvers *et al.* (2004) which they consider to be a minimum estimate because of limitations in interpreting dive behaviour in water depths < 1.5 m. This difference suggests that some of the dives interpreted as feeding dives by Chilvers *et al.* (2004) may not have been feeding dives (as discussed below and in Section 3.4.2).

Anderson (1982) reports longer submergence times for mother-calf pairs than for single individuals. He relates this to the longer time needed to extract the higher food requirements of lactating females compared to single individuals. However, my observations show that mothers and single individuals spend a similar proportion of time feeding. Calves, by definition, remain close to their mothers and are presumed to nurse. It is not surprising then that calves have a significantly lower foraging rate than their mothers. Similarly, Florida manatees calves feed in less concentrated, intermittent periods than adults (Hartman, 1979; Reynolds, 1981; Domning & Hayek, 1986)<sup>1</sup>.

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<sup>1</sup> The results of these authors refer to West Indian manatees but Florida manatees are now recognised as a morphologically distinct sub-species of West Indian manatees (Domning & Hayek, 1986).

My estimate of the proportion of time dugongs spend feeding is comparable to the feeding times of terrestrial herbivores. Beef cattle, dairy cows and sheep graze for an average of 8 to 10 hours per day (Arnold, 1981; Champion *et al.*, 1994). Owen-Smith (1988) summarises the activities of some larger terrestrial herbivores, but classifies foraging as the time spent eating as well as the movements made in search of food. This definition may, to some extent, explain the higher average forage time given for African and Asian elephants (14 – 18 hr), giraffes and Indian, white and black rhinoceroses (12 - 14 hr, Owen-Smith, 1988). For all these species, the time spent foraging is altered by climatic conditions, and thus foraging rates differ between summer and winter (Arnold, 1981; Owen-Smith, 1988; Champion *et al.*, 1994). However, there is no common response to seasonal changes. For example, African elephants and white rhinoceroses spend more time feeding in the dry season than in the wet season, while the opposite is true for Indian rhinoceroses and giraffe (Owen-Smith, 1988). My study was mainly limited to the winter months. Further studies would be needed to determine whether foraging rates change seasonally according to the growth rate of seagrass, which for favoured species, *Halophila ovalis*, peaks in summer (Preen, 1992).

### 3.4.2 Travelling

I estimated that dugongs spent 32% of their time travelling, which is higher than the 22% estimated by Chilvers *et al.* (2004). The influence of seasonal or location (i.e., availability or quality of forage) differences between the two studies on travelling rates is difficult to assess as the general movement patterns of the dugongs fitted with TDRs is unknown. However, it is possible that dive profiles from TDRs may be interpreted as feeding dives when they are actually travelling dives. Travelling is a behaviour difficult to interpret from TDR dive profiles, especially where the actual water depth is unknown and when there is no information on horizontal movement. In ‘square’ or ‘U-shaped’ dives, where dugongs remain at a constant depth, Chilvers *et al.* (2004) assumed that the animals were feeding at the bottom of the water column. Conceivably, during some of these dives, they may have been travelling at a constant depth. During my observations dugongs often travelled just above the substrate. Satellite tags that give fine scale locations (within 3 – 4 m) using GPS, and which are equipped in TDRs, have shown that dugongs travel along the ocean bottom when travelling long distances of hundreds of kilometres (James Sheppard, *unpublished data*). I observed this bottom-travelling

particularly when dugongs exhibited slow travel, which by definition lacked directionality and did not appear as purposeful movement from one point to the next. Thus, particularly when interspersed with feeding, slow travel could be interpreted as searching for forage. When not searching for forage, slow travel may be interpreted as milling behaviour similar to that recorded for bottlenose dolphins (Shane, 1990). The depths from TDR data were considered accurate to within 1.5 m given the limitations in depth resolution. Therefore, the fine scale variations in depth that occur while dugongs are feeding and searching for forage, would not have been evident in the TDR data, leading to the over-estimate in time spent feeding.

Calves travel significantly more than their mothers, because as mentioned, they do not need to spend as much time feeding on seagrass. While mothers were feeding, calves often exhibited slow travel interspersed with short feeding bouts, seemingly exploring the area around the mother. Florida manatee calves exhibit similar behaviour, often wandering away from their mothers while the mothers feed (Hartman, 1979; Reynolds, 1981). Hartman (1979) notes that manatee calves often play with other calves during this time, however, I did not observe play interactions between dugong calves.

### **3.4.3 Resting**

Resting occurred in long bouts with the maximum length of all full bouts recorded (621 s) being longer than the maximum full feeding bout (546 s). Similarly, Barnett and Johns (1976) observed a dugong resting on the substrate for periods of up to seven minutes during underwater observations. Resting bouts were infrequent however, and thus the estimated time budget for resting was only 7%. Low levels of resting behaviour were also reported by Anderson (1998) from direct observations, and Chilvers (2004) according to dive profiles from TDRs. Dugongs do not appear to spend as much time resting as manatees. Florida manatees usually spend six to ten hours per day resting in bouts of two to four hours, but bouts have been known to last 12 hours during the day (Hartman, 1979). Amazonian manatees (*Trichechus inunguis*) exhibit sleep during 28% of the diel cycle and show circadian rhythmicity, sleeping during the first half of the night (Mukhametoc *et al.*, 1992).

There are accounts from the Yolngu people of northern Arnhem Land that dugongs sleep near the surface at night (Davis, 1985). If dugongs show similar patterns of resting for long periods at night, the true resting budget may be larger than that shown by my daylight observations, and correspondingly, the feeding and travelling budget may be lower. Anderson (1998), however, noted that dugongs rested mostly between the hours of 1000 and 1300, and only once at night during limited nocturnal observations of individuals in a lek, from a catamaran. He also noted that dugongs only rested during calm sea conditions. I found no relationship between the proportion of time spent resting and Beaufort wind scale, though it should be noted that my fieldwork was limited to winds below 15 knots. There was a weak correlation between the time spent resting and tide times. Although not statistically significant, dugongs did tend to have longer submergence intervals in the deeper water they occupied during low tide ( $83 \pm 3$  s;  $\geq 1.5$  m) compared with high tide ( $74 \pm 3$  s;  $< 1.5$  m). Dugongs in deeper water at low tide tended to perform resting bouts at the surface between these slightly longer submergence intervals.

I observed dugongs spending almost twice as much time surface resting (3.5% of the daily time budget) than resting mid water column. Relatively little time was spent resting on the substrate (1.6%). All three types of resting have been reported previously (Barnett & Johns, 1976; Anderson & Birtles, 1978; Anderson, 1982; Anderson, 1998). Florida manatees mostly rest on the bottom, but may also rest suspended just below the water surface (Hartman, 1979). Surface resting may substitute for bottom resting for Florida manatees during cold weather when the surface temperatures may be warmer than at the bottom (Hartman, 1979) or when they bask in the sun (Reynolds & Wolcox, 1994). Dugongs may show similar plasticity in their resting behaviour according to water temperatures, and as most of my observations were conducted during winter, this may explain the high proportion of time I observed them resting at the surface.

Mothers rested for a higher proportion of time than their calves and this difference approached significance. Again, similar to Florida manatees (Hartman, 1979), dugong calves were often observed 'exploring' while mothers were resting.



### 3.4.4 Socialising and rolling

During my observations, dugongs spent relatively little time socialising despite mostly occurring in large herds. Identification and interpretation of social behaviour was limited in this study as I was unable to re-identify individuals or to determine sex, except where calves were present. As a result, some subtle social interactions may have been misinterpreted and classed as other types of behaviour. Rolling allows the animal to scratch its back on the substrate, and perhaps remove external parasites and epiphytes. This behaviour may also have a social function, as it occurred following some social interactions, although often after the other dugongs involved in the interaction were out of sight. Thus the social context of rolling was not confirmed.

Florida manatees interact in a non-sexual manner that is suggestive of play, where small groups of non-specific age and sex, perform mutual kissing, mouthing, bumping, embracing, nudging and chasing (Hartman, 1979). No such affiliative behaviour was observed in dugongs, except between mothers and their own calves. These dyads often rubbed against each other for prolonged periods (refer to Appendix 3 for descriptions of body rubs). Preen (1989) observed three instances of mating behaviour within the dugong herds on the Moreton Banks during late October to early November. My first field season ended on 24 October and the second in August. Thus if dugongs have a distinct mating season on the Moreton Banks I may have missed the period of heightened social activity associated with mating.

### 3.4.5 Dive cycles

No other studies have reported on the time dugongs spend rising to the surface of the water and resubmerging during the dive cycle. As this action is often quite slow for dugongs, it actually accounts for quite a large proportion of the time budget (18%).

The dive rates of dugongs have previously been investigated via boat-, shoreline- and aircraft-based observations (Anderson & Birtles, 1978; Anderson, 1982; Marsh & Rathbun, 1990; Marsh *et al.*, 1997; Anderson, 1998; Whiting, 2002), and TDRs (Chilvers *et al.*, 2004). Visual observations have revealed a variety of dive times, however, these are difficult to compare as submergence, surface and dive cycle times

are defined differently among various studies. Similar results were obtained in two other studies that used the same definition of submergence (overall mean of submergence times: this study,  $75 \pm 1$  s; Anderson and Birtles (1978),  $73 \pm 2.7$  s; Marsh and Rathbun (1990),  $80 \pm 20$  s). The blimp-cam made it possible to observe exact surface times and exhalations were usually obvious, occurring only once per surfacing interval. As a result, the submergence intervals given here can be considered to be respiration intervals.

Chilvers *et al.* (2004) found that dugong dive times are positively correlated with depth. In contrast, my study did not show any significant difference between submergence intervals in water depths  $< 1.5$  m or  $\geq 1.5$  m. However, the restriction of my blimp-cam observations to depths  $< 4$  m (mean  $2.1 \pm 0.1$  m) may have biased the results towards shorter submergence intervals than those recorded using TDRs ( $156 \pm 5$  s), which were restricted to depths  $\geq 1.5$  m (mean  $4.7 \pm 0.2$  m; Chilvers *et al.*, 2004). As dugongs spend 49% of their time within 1.5 m of the water surface (Chilvers *et al.*, 2004), the data provided by the blimp-cam compliment those obtained using TDRs. Together they provide a relatively complete picture of dugong dive behaviour in a variety of habitats. Dugongs are likely to submerge for longer periods in deeper water. The average submergence interval of  $156 \pm 5$  s, and maximum duration of 12 min, according to TDRs in  $\geq 1.5$  m depths (Chilvers *et al.*, 2004), are higher than the average and maximum submergence times recorded in  $< 4$  m depths during this study ( $75 \pm 1$  s and 5 min respectively). Considering the slow diving behaviour that dugongs exhibit, longer submergence times in deep water maximise time spent feeding. Dive data from TDRs are from dugongs in a variety of turbidity levels, whereas the data I report are from dugongs in clear water only. Slowly resubmerging in clear water may provide dugongs the opportunity to locate appropriate forage, and thus doubles as searching behaviour. This searching advantage in clear water suggests that dugong surfacing behaviour may differ in areas of high turbidity.

The surfacing interval for dugongs is extremely short, at only  $2 \pm <1$  s on average during this study, with a range of  $< 1 - 5$  s. This falls between the average time given in the two previous studies that have used the same definition of surface interval as that used in the current study (Anderson and Birtles (1978),  $1.4 \pm 0.1$  s; Marsh and Rathbun (1990),  $2.6 \pm 0.56$  s). Although dugongs spend very little time with their body raised

above the surface, their surfacing and submerging action is slow, and thus they spend a larger amount of time near the surface than is represented by these surface intervals. Whiting (2002) defined the surface interval as the time between dives where the dugong was visible at the surface from a vantage point above the animals on a bridge. This included the time where the animals were just below the surface between breaths, which in this study was defined as resting behaviour. The surface interval given using this definition is  $13.0 \pm 9.9$  (SD) s (Whiting, 2002). The difference between these two definitions of surface intervals should be taken into account when estimating the time that dugongs are available at the surface for sighting during aerial surveys (Marsh & Saalfeld, 1989), and may account for the difficulty aerial survey observers have in defining when a dugong is at the surface (Pollock *et al.*, in press).

Submergence times did not differ between single individuals and mothers with calves, however there was a significant difference in mean submergence intervals between mothers and their calves. In previous studies, longer submergence intervals have been recorded for mother-calf pairs than for single individuals in waters < 5 m deep (Anderson, 1998), but foraging mother-calf pairs had shorter submergence intervals than foraging single individuals in waters 1 – 3 m deep (Anderson, 1982). The results obtained here show that calves respire more frequently than their mothers, but surfaced in synchrony with their mothers in over 50% of surfaces. The proportion of time mothers spent exhibiting surface behaviour (i.e., including the time taken to ascend and descend) was longer than for their calves and single individuals. In my observations, the mother tended to exhibit a slow surfacing action and respire once while the calf respired multiple times.

The common occurrence of calves moving to a position just over their mother's back, or completely crossing over the mother while surfacing or submerging, may indicate that calves receive some hydrodynamic advantage from this behaviour. Similar behaviour is exhibited by manatee calves (Hartman, 1979; Reynolds, 1981). Dolphin calves often 'draft' or swim in close proximity to their mother, producing a hydrodynamic interaction that allows calves to keep up with the mother when swimming at high speed (Weihs, 2004). Dugong calves probably have a lower body fat content than their mothers (Donna Kwan, *pers. comm.*), as indicated by low fat content of pre-pubescent dugongs in comparison to other dugongs (Kwan, 2002). Thus dugong calves may be

negatively buoyant, and swimming towards the surface may be energetically costly. Calves may derive some energetic advantage from positioning themselves in the forward-moving areas of water near the mother as they surface (Daniel Weihs, *pers. comm.*). Being positioned above the mother while surfacing may also offer some protection from sharks, as dugongs are probably most vulnerable to shark attack from below while at the surface (Heithaus *et al.*, 2002).

Submergence intervals for calves while suckling were significantly longer than for calves not observed suckling. Calves did not always surface immediately before or after a suckling bout. This observation supports Anderson (1982) who concluded that dugong respiration intervals in shallow water are not normally determined by oxygen deficit, but are probably determined by factors such as the time taken to extract food, or the food requirements of individuals. This conclusion was also supported by the longer submergence intervals recorded when dugongs were feeding or performing a combination of behaviours (which may have included feeding), rather than travelling or conducting other single behaviours. Dugongs exhibit the latter two behaviours close to the surface where frequent respirations do not require much movement or energy. In contrast however, calves surfaced more frequently than their mothers. This behaviour may reflect high metabolic rates and low oxygen stores in calves. It may also reflect the longer amount of time mothers need to spend feeding on seagrass than their young calves, for which feeding on seagrass merely supplements suckling. Again, resting or slow travel often occurred at the surface while dugongs were taking a number of quick successive breaths between long foraging dives, producing short submergence intervals. Thus in deep water, respiration intervals *are* likely to be determined by an oxygen deficit.

#### **3.4.6 Suckling**

During the 15 suckling bouts observed, calves always assumed horizontal positions with dorsum uppermost, whereas Anderson (1984) reports that during all but one of 18 suckling bouts, calves had their ventrum uppermost. Hartman (1999) reports that Florida manatee calves suckle with their dorsum uppermost. Anderson (1984) suggests that inverted (belly-up) position of suckling calves may be favoured as a result of the structural difference between dugongs and manatees. My observations contrast with

Anderson's report. Without further investigation into the behaviour of mother-calf dugong pairs it is difficult to interpret the apparent differences in suckling technique in Moreton and Shark Bays. Both here and in Anderson's study, calves were aligned horizontally with the mother, and angled towards the base of her pectoral fin. The average suckling bout of 87 s is within the range of the three bout lengths recorded by Anderson (57, 93 and 95 s), but lower than the average time recorded for the Florida manatee (126 s; Hartman, 1979).

All suckling calves fed on seagrass, a result which corresponds with reports that the stomach contents of juvenile dugongs, including neonates, contain seagrass (Marsh *et al.*, 1982; Kwan, 2002). Calves fed on seagrass more often after suckling than before. Further studies would be needed to determine whether there is a significant trend towards foraging immediately following a suckling bout, and if so, whether this behaviour is related to digestion. Mothers were observed conducting a variety of behaviours as calves suckled, including feeding, cruising, travelling slowly, resting and surfacing. These results agree with those of Anderson (1984) for dugongs, but contrast with Florida manatees, where mothers are normally idling or resting while the calf suckles (Hartman, 1979).

Unsuccessful attempts at suckling behaviour have not previously been reported for dugongs. It is possible that the mother was preventing the calf from suckling by holding her pectoral fin close to her side. The mother may have been attempting to wean the calf, which may have been up to 2 years of age given its size in comparison to the mother. The lactation period of calves is thought to be approximately 15 to 18 months (Marsh *et al.*, 1984; Kwan, 2002).

### **3.5 Conclusion**

This chapter provides some basic information about dugong behaviour which, prior to the development of the blimp-cam, was unobtainable. I have focused on the behavioural activities of individual dugongs with the aim of producing a time budget and description of dugong behaviours. In Moreton Bay during the winter, dugongs spend the most of their time feeding and relatively little time socialising or resting. Mothers exhibit similar

daily time budgets to single individuals, but spent significantly more time feeding than their calves. The respiration rate of calves is significantly higher than that of their mother, although it appears that in these shallow waters, respiration rates are determined by the behavioural state of the animals. The following chapter investigates the behaviour of individual dugongs according to their proximity to other dugongs in an effort to determine the function of the unusually large herds of dugongs found in Moreton Bay. Then, to conclude this section on dugong behaviour I examine the implications of these behavioural observations for the potential effects of anthropogenic impacts (Chapter 5).

### 3.6 Chapter summary

- Previous attempts to study dugong behaviour have been inhibited by the difficulties of observing these animals underwater and identifying individual animals. The blimp-cam allowed me to track and conduct continuous observations of individuals, and thus provide the first quantitative study on the behaviour of individual dugongs.
- Two scales of movement by dugongs on the Moreton Banks were observed: (1) herds were found in the shallow areas (average 1.7 m) during high tide, and at the deeper edges of the banks (average 2.5 m) during low tide, and (2) the locations of herds both at low and high tide shifted in a northeasterly direction throughout the duration of both field seasons.
- Individuals spent most of their time feeding (41%), travelling (32%), or surfacing (18%), and relatively little time resting (7%), socialising (6%) and rolling (1%). Time budgets did not significantly differ between single individuals and mothers with calves. However, mothers spent significantly more time feeding and surfacing, and less time travelling than their calves.
- The mean submergence time for all individuals was 75 s. Calves had significantly shorter submergence intervals (72 s) than their mothers (82 s).

Submergence intervals were not affected by depth ( $< 1.5 \text{ m} \geq$ ), but were affected by behaviour.

- Calves surfaced in synchrony with their mothers during over half their surfaces, while during a quarter of their dives, calves ascended or descended by crossing onto their mother's back. Calves also spent 13% of their time travelling and resting over their mothers' back.
- Suckling bouts averaged 87 s. Calves in Moreton Bay suckled while positioned with their dorsum uppermost, which differs from previous reports of calves in Shark Bay suckling with their ventrum uppermost.
- Environmental variables accounted for little of the variability in the proportion of time dugongs spent in each behavioural category.





# **Chapter 4**

## **Why dugongs persistently form herds in Moreton Bay, southeast Queensland**

**This chapter specifically addresses the question of why dugongs within my study site formed large herds given that dugongs are not known to form large herds persistently anywhere else in the world. I investigate this unusual behaviour to promote an understanding of how particular behavioural strategies of dugongs affect their susceptibility to human influences. According to the dynamics between dugong grazing and seagrass production, these large herds are thought to facilitate ‘cultivation’ grazing. I review the possible functions of the herds in light of my behavioural observations, as well as comparisons between the environmental factors that may affect the grouping behaviour of dugongs in my study site and elsewhere, to assess this hypothesis.**



## **Chapter 4. Why dugongs persistently form herds in Moreton Bay, southeast Queensland**

### **4.1 Introduction**

Animals live in groups when various selective pressures result in individuals gaining a greater selective advantage if part of a group than if solitary (Alexander, 1974). This assertion assumes that group living will only occur when the benefits to the individual exceed the costs to that same individual and that individuals seek to maximise reproductive fitness (Emlen & Oring, 1977; Slobodchikoff & Shields, 1988). The trade-offs between these costs and benefits may not always be obvious. There are no universal benefits gained by all species from group living. It is considered however, that the universal costs of group living are increased competition for resources, and increased transmission of disease and parasites (Alexander, 1974; Wrangham & Rubenstein, 1986). Other commonly experienced costs include greater probability of misdirected parental care and infanticide, and increased conspicuousness to predators (Alexander, 1974).

Two main ecological factors select for group living: resource distribution and predation pressure (Alexander, 1974; Wrangham & Rubenstein, 1986). The formation of groups may decrease the risk of predation on individuals by increasing the probability of the group detecting predators, facilitating aggressive group defence and/or allowing individuals to use the group as cover (Alexander, 1974; Elgar, 1989). A further advantage to the individual is a reduction in the time spent in vigilance, leaving more time for other activities (Elgar, 1989)

Individuals may also form groups when this allows more efficient exploitation of resources than a solitary existence (Slobodchikoff & Shields, 1988). A clumped resource leads to a tendency for individuals to feed in aggregations, particularly if this resource is abundant and the cost of defending the resource is higher than the cost of sharing it (Geist, 1974; Slobodchikoff & Shields, 1988; Krebs & Davies, 1993). If the resource is renewable, such as is the case with growing vegetation, an individual may

harvest food and return once the source is replenished, assuming that another individual does not harvest the food in the meantime. In this case it may be advantageous for the individual to defend the resource, but a second strategy may be to use the resource as part of a group so that all individuals harvest the food at the same time (Krebs & Davies, 1993).

When either predation pressure or resource distribution favours group living, social behaviour inevitably evolves for at least one of three reasons: (1) it enhances the original advantage of group living, i.e., predatory defence or the availability of resources, (2) it reduces the likelihood of disease and parasite transmission (e.g., by allogrooming), or (3) it is stimulated by reproductive competition among individuals (Alexander, 1974). Social behaviour within a species may vary according to the environmental pressures that have shaped the distribution and grouping behaviour within each population.

Intraspecific variations in grouping behaviour can occur geographically as a result of different environmental pressures. For example, white-tailed deer (*Odocoileus virginianus*) tend to form larger groups when in open savanna habitats in south Texas than in the forested habitats of Michigan as a result of spatial differences in predator avoidance strategies and perhaps also foraging efficiency (Hirth, 1977). The plains rat (*Pseudodomys australis*) occurs in small colonies in the tropical forests of Australia where food is continuously abundant, but forms breeding pairs in temperate forests where food is more sparsely distributed (Lee & Cockburn, 1985). Jarman (1974) gives examples of how several ungulate species vary their grouping behaviour seasonally as they aggregate while migrating and form smaller territorial groups while sedentary. The Alaskan moose (*Alces alces gigas*) moves between forested and open habitats and increases group size as distance from cover increases in response to increased predation risk (Molvar & Bowyer, 1994). In this species, individuals may choose to join groups or remain solitary according to their reproductive status.

Groups are more conspicuous to predators than solitary animals and young within large groups are a likely target as they are the most vulnerable members of the group. Thus it may be more advantageous for mothers with young to remain solitary and hide rather than seek cover within the group (Molvar & Bowyer, 1994). The benefits of grouping

behaviour can be complicated by variability in anti-predator strategies. In response to the same predator species, animals that depend on a deterrence and confusion strategy gain anti-predator benefits from forming large groups, while those that flee do not gain the same benefits from large groups (Lingle, 2001). Thus animals that flee may be better off forming small groups, which are less conspicuous.

Dugongs are an example of a species exhibiting a wide range of grouping patterns. In early reports dugongs were considered solitary (Jonklass, 1961) or perhaps to occur in small family groups that occasionally join herds (Jarman, 1966). Unusually large dugong herds were observed in Moreton Bay as early as 1893 (Welsby, 1905). Heinsohn *et al.* (1977), speculated that single seagrass beds would not be able to sustain the pressure of such large herds for very long and that dugongs would have to constantly move between areas. Aerial surveys have shown, however, that large herds persistently form on the eastern banks of Moreton Bay (Preen, 1992; Lanyon, 2003). The largest herds reported over these two series of aerial surveys of Moreton Bay were 459 and approximately 300 animals, and up to 85% of dugongs occurred in groups of > 5 animals during both surveys (Preen, 1992; Lanyon, 2003).

Whether large herds of dugongs occur consistently in locations other than in Moreton Bay is difficult to determine as defining what constitutes a 'herd' is problematic. In most areas observations of dugongs have been via aerial surveys, and this perspective may make loosely aggregated individuals appear as a herd depending on the height of the aircraft. Preen (1992), reviewed all known aerial surveys of dugongs up until 1990 that have occurred throughout the Queensland coast and Torres Strait, large sections of the Northern Territory, Shark Bay and sections of north Western Australia, as well as the Arabian Gulf, eastern Red Sea, and Manus in Papua New Guinea. He noted that 'discrete' herds of over 100 animals have been observed in only four areas, including Moreton Bay, Shark Bay (documented as diffuse but spanned over approximately 2-300 m, Helene Marsh, pers. com.; Marsh *et al.*, 1994b), the Arabian Gulf and the Starke River area of Cape York. Since then, herds of over 100 animals have only been seen during aerial surveys of Shark Bay (Ivan Lawler and Dave Holley, *unpublished data*) and the Starke River area (Marsh & Lawler, 2001b). Loose aggregations (termed 'diffuse' herds) have been reported in many places including Shoalwater Bay (Heinsohn, 1976) and Shark Bay (Preen *et al.*, 1997). In these loose aggregations, large

numbers of dugongs are dispersed over many kilometres, however neither Preen (1992) nor I have considered these to be herds because at none of these sites are herds known to form persistently.

For example, although dugongs are at the southern limit of their range in both Shark Bay and Moreton Bay, during four aerial surveys of Shark Bay, large herds of over 100 animals were seen only once in each of two surveys (Marsh *et al.*, 1994b; Preen *et al.*, 1997; Gales *et al.*, 2004, Ivan Lawler and Dave Holley, *unpublished data*). Mean group sizes in these surveys excluding groups of > 10 animals ranged from 1.2 – 1.5. Over 80% of dugongs in Shark Bay were observed as solitary animals.

During aerial surveys of the Arabian Gulf in winter 1989, adjacent groups of 577 and 97 dugongs were observed. In surveys of the same area in summer 1989 and 1999, only smaller groups ranging from 18 to 60 individuals were sighted (Preen, 2004). Preen (2004), suggests that winter aggregations may be a response to low water temperatures. Dugongs may be aggregating near the warmer water of thermal springs, a behaviour that also occurs in the Florida manatee (*Trichechus manatus latirostris*), which form aggregations of 700+ animals near artesian springs and warm effluent water from power plants (Irvine, 1983; Reynolds & Wolcox, 1994).

Preen (1995) investigated the function of the large herds in Moreton Bay via analysis of seagrass dynamics in response to grazing. He suggests that the herds facilitate ‘cultivation’ grazing, where the removal of a large proportion of the seagrass in the area grazed promotes growth of favoured pioneer species with high quality foliage. However, the function of these herds has not been investigated through formal quantitative studies of the behaviour of dugongs. Thus in this chapter I investigate Preen’s (1992) theory of cultivation grazing by comparing the behaviour of individual dugongs within herds and those in smaller groups.

## 4.2 Methods

To determine whether dugong herds in Moreton Bay had a feeding, predatory defence or social function, I considered two questions: (1) whether particular behaviours (e.g.,

feeding or socialising) are favoured by large herds, and (2) whether I could detect any structure within the herds. There were limitations on the way in which the dynamics of these herds could be analysed. Herds were usually too large for all animals to be visible in one frame and I could not reliably calculate distances using the video footage. Therefore, the size and shape of entire herds could not be assessed. Also, dugongs were not individually recognisable, so I could not determine whether particular individuals were always in certain positions within the herd. Thus the structure of herds was assessed based on short focal observations on individuals and their interactions with the dugongs immediately surrounding them.

#### **4.2.1 Herd influence on behaviour**

I compared the behaviour of individual focal dugongs according to the number of dugongs visible and the position of these individuals. Four behaviours were considered: feeding, travelling, resting and socialising (defined in Section 3.2.2). The influence of other individuals in the herd on the proportion of time individuals spent in each of these behavioural states was assessed using three factors: (1) the number of dugongs visible, (2) the position of the focal individual at the start and end of a focal follow, and (3) distance of the nearest neighbour.

The behaviour of individuals was observed by conducting focal follows (Altmann, 1974) using the blimp-cam (Chapter 2). The protocol for filming dugongs during focal follows and analysing behaviour is described in Section 3.2.2. This protocol included a method to maintain a relatively constant field of view in which all dugongs within three body lengths of the focal individual could be seen.

##### ***4.2.1.1 Number of dugongs visible***

The total number of dugongs visible at the beginning of each focal follow was calculated using the video footage. Herds sometimes extended beyond the area visible using the blimp-cam. Thus this factor was only assessed for focal follows if I was confident that the majority of dugongs at my study site could be seen clearly. These counts should be considered minimum estimates. As the accuracy of counts decreased

as the number of dugongs visible increased, I used four broad categories of estimated herd size: 0 – 20, 21 – 50, 51 – 100, and > 100.

#### ***4.2.1.2 Position of focal individual***

The position of the focal individual relative to the rest of the herd was assessed from the video footage: (1) prior to zooming in on the focal individual at the start of the focal follow, and (2) after zooming out at the end. The individual was classed as being in a subgroup or the main herd. In this study the term ‘main herd’ represents the largest group visible. The dugong was in a subgroup if it was either: (a) in a group of dugongs (all within three body lengths of one another) that was not the largest group visible, or (b) more than three body lengths away from any individual.

#### ***4.2.1.3 Nearest neighbour distance***

I identified the neighbour nearest to the focal individual visually using the video footage. The footage was paused at 30 s intervals so that the nearest neighbour distance, identity (whether the same individual as in the previous interval) and type (single individual or mother-calf pair), could be recorded in a manner simulating scan sampling (Altmann, 1974). Although I could not recognise individual dugongs between focal follows, I was able to identify individuals from one scan to the next by visually tracking individuals on the video footage between scans. I considered the nearest neighbour to mother-calf pairs as the dugong closest to the mother, excluding her calf.

Nearest neighbour distances were recorded in body lengths according to the length of the focal individual (<1; 1 - < 2; 2 - < 3; or > 3 body lengths). As dugongs can reach 2 m in length within 5 years of age, and grow to an average of 2.5 m, one body length likely equals 2 – 3 m (Marsh, 1980). The average distance of nearest neighbours was calculated for each individual to use in the analysis described in subsequent sections.

#### ***4.2.1.4 Analysis***

These data did not satisfy the assumptions of homogeneity of variance, even when transformed. Thus I used a series of Kruskal-Wallis tests to determine whether the three



herd factors described above affected the mean proportion of time focal individuals spent feeding, travelling, resting and socialising. Separate tests were conducted for the overall proportion of time spent feeding, and the proportion of time spent feeding with plumes visible as a subset of the overall feeding time. In such a large number of tests (15 overall), there is a high probability of Type I error in at least one or more tests. I have reported actual P values for all tests and interpreted those that were marginally significant with caution. Post hoc analyses were conducted for each Kruskal-Wallis test using Tukey-type multiple comparisons tests with the Q statistic for unequal numbers of data in groups (Zar, 1999).

#### **4.2.2 Herd structure**

If herds had a predatory defence function then individuals might be expected to maintain a particular position within the herd depending on their vulnerability to attack by predators. If there is social structure within the herds, individuals may maintain consistent nearest neighbours. Three aspects of herd structure were investigated: (1) maintenance of constant nearest neighbours, (2) preference for nearest neighbour type (i.e., single individuals or mother-calf pairs), and (3) positions according to these individual types.

##### ***4.2.2.1 Maintenance of nearest neighbours***

I identified the nearest neighbour to focal individuals at regular intervals (scans) throughout focal follows as described in Section 4.2.1.3. For scans in which the identity of the nearest neighbour could be traced from the previous scan, the proportion in which the nearest neighbour remained the same was calculated for each individual. I also tallied the number of consecutive scans that the nearest neighbour remained the same, and the mean of these scores was calculated for each focal individual. Both measures were compared between mothers and calves using t tests.

##### ***4.2.2.2 Preference for nearest neighbour***

The proportion of scans in which the nearest neighbour was a mother and calf was calculated for each focal follow, according to the total number of scans where a nearest

neighbour was recorded. A t test was used to determine whether mother-calf pairs were found next to other mother-calf pairs at a higher rate than single individuals. I also tested preference for nearest neighbour by determining the nearest neighbour type at the middle scan (i.e., the scan conducted closest to the halfway point of the focal follow where a nearest neighbour was recorded) for each focal individual. A Pearson chi squared test was used to determine whether single individuals or mothers were more likely to have either individual type as a nearest neighbour than expected by chance.

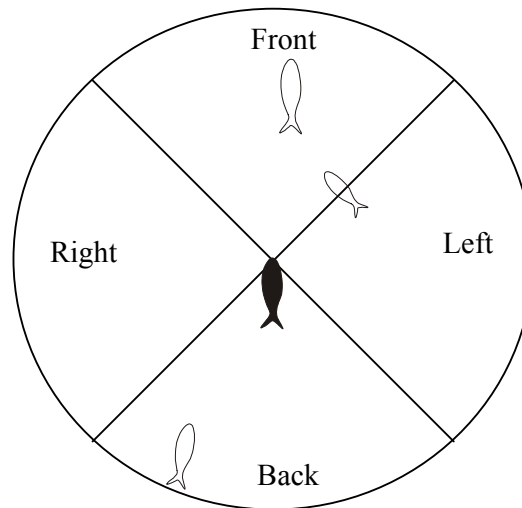
#### ***4.2.2.3 Position of mother-calf pairs***

The total number of dugongs within three body lengths of focal individuals was used to determine whether mothers and calves spent more time in the centre of herds than single individuals. This analysis used different focal follows than the other analyses. These focal follows were filmed as described in Section 3.2.2 but with a wider field of view, i.e., with a wider zoom. Although the behaviour of these individuals could not reliably be determined, all dugongs within three body lengths of both the mother and her calf were in frame. Single individuals were filmed using the same field of view for consistency.

For the first 5 min of each follow, I took 1 min scan samples by pausing the footage. Again, the number of dugongs within three body lengths of single individuals and the calf in mother-calf pairs was assessed visually using the focal individual. A template was placed over the screen (Figure 4.1) to determine how many dugongs within three body lengths were in each of four (front, back, left and right) zones. Each dugong on the line between zones was allocated to the same zone as its head.

Multivariate analysis of variance (MANOVA) was used to determine whether the mean number of dugongs within each zone was affected by focal individual type (single individual or calf). The mean number of dugongs in each zone for each individual was square root transformed to meet the assumptions of this analysis. I used the Pillai's trace MANOVA statistic as it gives the most reliable result for variables that are correlated (Zar, 1999). I then conducted separate ANOVAs for each zone to determine which of the four zones contained significantly different numbers of dugongs according to type

of focal individual. I used a t test to determine whether the number of zones that contained dugongs differed between single individuals and calves.



**Figure 4.1** Template overlaid onto paused video image to determine number of dugongs within three body lengths of the focal individual (filled black), in four zones. In this example there are two dugongs in the front zone and one in the back zone.

All results are provided as means  $\pm$  standard errors.

## 4.3 Results

### 4.3.1 Herd influence on behaviour

Dugongs tended to be closer together and in larger groups while feeding than when exhibiting other behaviours (Figure 4.2 and 4.3). Kruskal-Wallis tests showed a significant relationship between the proportion of time spent feeding and: (1) the number of dugongs visible, (2) whether the focal individual was in a subgroup or the main herd, and (3) the average distance of the nearest neighbour (Table 4.1). The time spent feeding with plumes visible (a subset of feeding behaviour) was similarly affected by all three variables.



**Figure 4.2** A typical dugong feeding herd with sediment plumes which are created, depending on sediment type, when dugongs extract the rhizomes of the seagrass as they are foraging.

Post hoc analysis showed that dugongs spent significantly more time feeding and feeding with plumes when  $> 100$  dugongs were visible compared to  $0 - 20$  (Table 4.1). Focal dugongs also spent significantly more time feeding and feeding with plumes when they were in the main herd at both the start and end of the focal follow compared with those in a subgroup at both the start and end. In addition, dugongs showed a significantly higher rate of feeding with plumes when in a subgroup at the start of the follow but in the main herd by the end, compared with when in a subgroup at the start and end. Feeding and feeding with plumes both occurred at significantly higher rates when the average distance of the nearest neighbour was  $< 1$  body length rather than  $2 - < 3$  or  $> 3$ .

In parallel with decreased feeding rates, dugongs spent more time travelling when in smaller groups and farther away from other individuals (Figure 4.3). Both the number of dugongs visible and distance to nearest neighbour significantly affected the proportion of time dugongs spent travelling, although the latter effect was marginal (Table 4.1). Post hoc analysis showed a significant difference in travelling only when there were  $0 - 20$  dugongs visible compared with  $> 100$ . The difference in the time spent travelling when the focal individual's nearest neighbour was  $< 1$  body length compared to  $> 3$  approached significance (Table 4.1).

Small sample sizes of both resting and socialising behaviour may have limited my ability to detect the effects of the focal individual's position and the number of other

dugongs on these behaviours. Kruskal-Wallis tests indicated no effect of other dugongs on the proportion of time spent resting. However, a significant effect of distance to the nearest neighbour on rates of social behaviour was observed. Dugongs tended to socialise more as the distance to the nearest neighbour decreased (Figure 4.3), and the Kruskal-Wallis test showed that this effect was significant (Table 4.1). Post hoc analysis revealed that there was a significant difference in the time spent socialising if the nearest neighbour was < 1 body length from the focal individual, in comparison with 2 – < 3 or > 3 body lengths (Table 4.1). The effect of the number of dugongs visible on the proportion of time spent socialising approached significance (Table 4.1). The highest rate of socialising occurred when 21 – 50 dugongs were visible, but the rate then declined as this number increased (Figure 4.3).

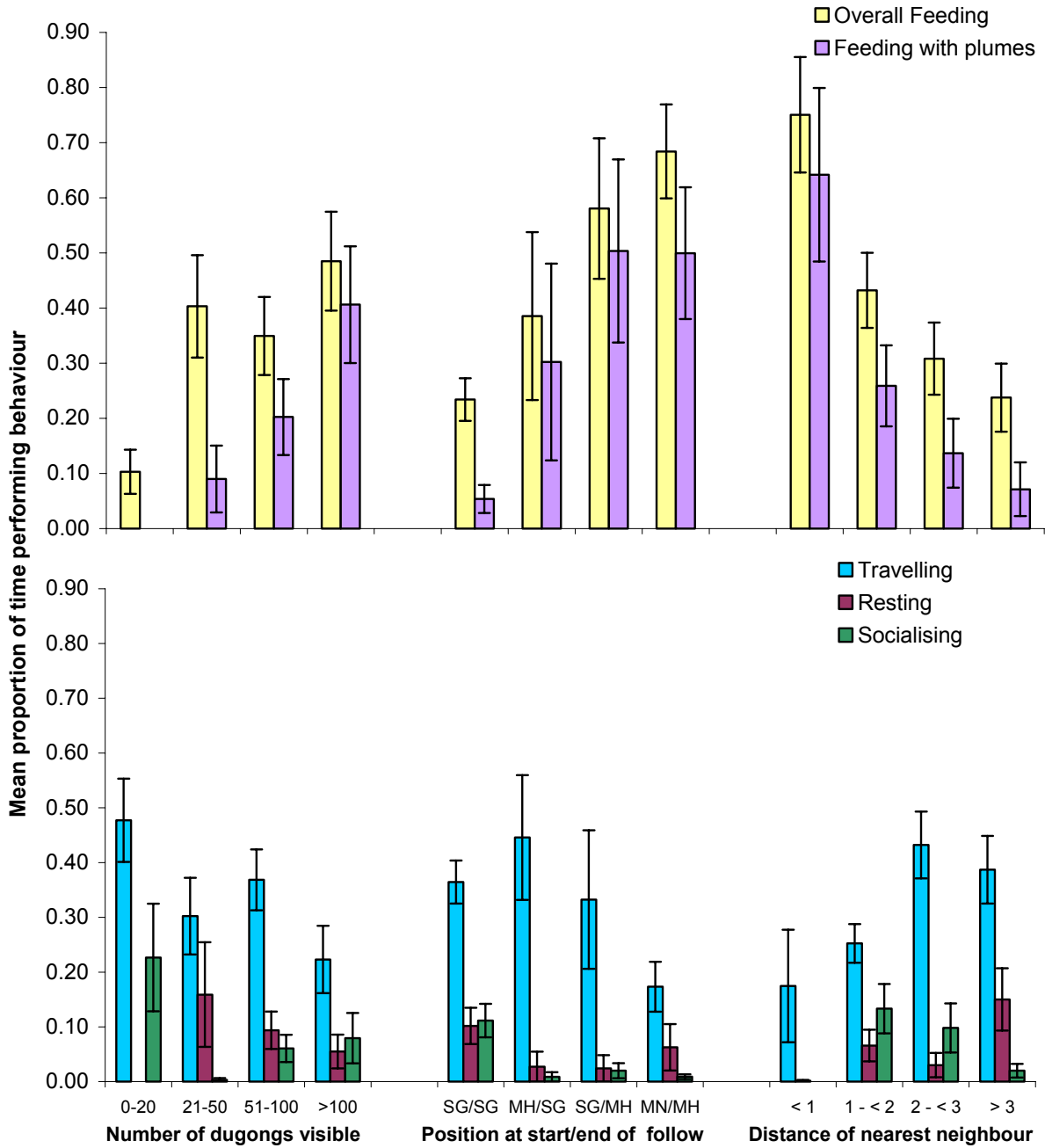
**Table 4.1** Kruskal-Wallis tests to determine the effects of the focal individual’s position and number of other dugongs on the proportion of time focal individuals spent performing each behaviour during focal follows, and Tukey-type multiple comparisons tests using the Q statistic for unequal numbers of data in groups (Zar, 1999). P ≤ 0.05 bolded.

			Feeding	Feeding with plumes	Travelling	Resting	Socialising	
<b>Number of dugongs visible</b> <sup>a</sup>	Kruskal-Wallis (df = 3)		$\chi^2$	9.11	11.05	8.86	6.12	6.53
			P	<b>0.03</b>	<b>0.01</b>	<b>0.03</b>	0.11	0.09
	Post Hoc	0-20 x >100	Q	2.94	2.98	2.83		
			P	<b>&lt; 0.05</b>	<b>&lt; 0.05</b>	<b>&lt; 0.05</b>		
<b>Position at start/end of focal follow</b> <sup>b</sup>	Kruskal-Wallis (df = 3)		$\chi^2$	18.37	22.93	6.52	2.74	2.54
			P	<b>0.00</b>	<b>0.00</b>	0.09	0.43	0.47
	Post Hoc	SG/SG x MH/MH	Q	3.84	4.12			
			P	<b>&lt; 0.01</b>	<b>&lt; 0.01</b>			
			Q	3.00				
			P	<b>&lt; 0.05</b>				
<b>Distance to nearest neighbour</b> <sup>c</sup>	Kruskal-Wallis (df = 3)		$\chi^2$	13.3	14.97	7.98	5.14	11.96
			P	<b>0.00</b>	<b>0.00</b>	<b>0.05</b>	0.16	<b>0.01</b>
	Post Hoc	<1 x >3	Q	3.47	3.61	2.50		2.74
			P	<b>&lt; 0.01</b>	<b>&lt; 0.05</b>	< 0.10		<b>&lt; 0.05</b>
		<1 x 2 - <3	Q	2.78	3.18			2.81
			P	<b>&lt; 0.05</b>	<b>&lt; 0.05</b>		<b>&lt; 0.05</b>	

<sup>a</sup> estimated number of dugongs visible from blimp-cam at the start of the focal follow, classified as 0 – 20, 21 – 50, 51 – 100, or > 100 dugongs

<sup>b</sup> Subgroup = SG, Main herd = MH, i.e., at start/end focal dugong is either in SG/SG, MH/SG, SG/MH, or MH/MH

<sup>c</sup> Estimated in dugong body lengths according to length of focal individual, where the average distance is <1, 1 – < 2, 2 – < 3, or >3 dugong body lengths



**Figure 4.3** The mean proportion of time focal dugongs spent within each behavioural category in relation to the number of other dugongs visible at the start of the focal follow; the position of the focal dugong relative to the main herd at the start and end of the focal follow (where SG = subgroup and MH = main herd); and the average distance of the nearest neighbour throughout the focal follow, measured in dugong body lengths. Error bars depict SE, label on bottom X axis applies to both graphs.

### 4.3.2 Herd structure

#### 4.3.2.1 Maintenance of nearest neighbour

Each dugong maintained its position next to the same nearest neighbour for a very short period. In a mean of  $53 \pm 4\%$  of scans per focal follow, the nearest neighbour was the same individual as in the scan 30 s previous. This measure did not differ significantly between single individuals ( $49 \pm 4\%$ ) and mothers with calves ( $61 \pm 7\%$ ;  $t = -1.49$ ,  $df = 55$ ,  $P = 0.14$ ). The mean number of 30 s scans in each focal follow in which the nearest neighbour stayed the same was  $1.9 \pm 0.18$  scans. Therefore focal individuals maintained positions nearest to particular individuals for an average of only 1 min. Mothers retained the same nearest neighbour for longer ( $2.4 \pm 0.46$  scans) than single individuals ( $1.7 \pm 0.15$  scans) and this difference approached significance ( $t = -1.79$ ,  $df = 55$ ,  $P = 0.08$ ).

#### 4.3.2.2 Preference for nearest neighbour

Neither single individuals nor mothers with calves showed preferences towards particular nearest neighbour types. The mean percentage for scans per focal follow in which the nearest neighbour was a mother and calf when the focal individual was a single dugong was  $37 \pm 6\%$ . When the focal individual was a mother and calf, the nearest neighbour was a mother and calf in  $40 \pm 8\%$  of scans. These values were not significantly different ( $t = -0.34$ ,  $df = 58$ ,  $P = 0.73$ ). There was also no significant difference in the nearest neighbour type at the middle scan (halfway through focal follow) for single individuals and mother-calf pairs (Pearson's  $\chi^2 = 0.44$ ,  $df = 1$ ,  $P = 0.51$ ).

#### 4.3.2.3 Position of mother-calf pairs

Mother-calf pairs had fewer other dugongs surrounding them than single individuals which indicates that they were less likely to be found in the centre of herds. There was a significant overall difference in the number of dugongs within each zone around single individuals and calves (MANOVA: Pillai's trace = 0.37,  $F_{4,37} = 5.54$ ,  $P < 0.01$ ). The ANOVA's showed that single individuals had a significantly higher mean number of

dugongs within all four zones in comparison with calves (Table 4.2). The average number of zones that contained dugongs was also significantly lower for calves ( $1.0 \pm 0.19$ ) than for single individuals ( $2.3 \pm 0.20$ ;  $t = 4.75$ ,  $df = 40$ ,  $P < 0.01$ ).

**Table 4.2** Results of ANOVAs to determine the difference in the number of dugongs within three body lengths of single individuals ( $N = 21$ ) and calves in a mother-calf pair ( $N = 21$ ).

Zone	Single ( $x \pm SE$ )	Calf ( $x \pm SE$ )	df	Error df	F	P
Front	$1.1 \pm 0.19$	$0.4 \pm 0.12$	1	40	11.38	< 0.01
Left	$1.0 \pm 0.19$	$0.4 \pm 0.08$	1	40	11.18	< 0.01
Back	$1.7 \pm 0.29$	$0.5 \pm 0.15$	1	40	19.85	< 0.01
Right	$1.3 \pm 0.28$	$0.3 \pm 0.07$	1	40	16.59	< 0.01

#### 4.4 Discussion

My behavioural observations strongly support Preen's (1995) theory that dugongs in Moreton Bay form herds to facilitate cultivation grazing. Individual dugongs fed at higher rates when in large herds with smaller nearest neighbour distances than when widely dispersed or in small groups. Feeding herds were characterised by high density aggregations of dugongs often producing thick sediment plumes. These plumes were produced during approximately half the time individual dugongs spent what I defined as feeding (Section 3.3.3; Appendix 3). Whether feeding plumes are indicative of intense grazing or of sediment type is unknown, however the possible advantages of creating feeding plumes are discussed below.

In light of my behaviour observations, I will expand on Preen's (1992) assessment of the function of dugong herds in Moreton Bay. In presenting his hypothesis of cultivation grazing, Preen (1992) considered that dugong herds in Moreton Bay may either: (1) form in response to predation pressure, (2) be feeding aggregations, and/or (3) have a social function. My hypothesis on the function of dugong herds summarised in Table 4.3.

##### 4.4.1 Predatory defence

Sharks are assumed to be major predators of dugongs. Assessing the risk of predation on dugongs is difficult because of a lack of data on the distribution, abundance and



feeding habits of sharks in Moreton Bay. Preen (1992) considered the predatory defence function of dugong herds unlikely as attack by sharks on adult dugongs is probably rare even though encounters with sharks may be common. However, in eastern Shark Bay, which has a large population of dugongs, the remains of dugongs were found in the stomach contents of 47% (N = 15) of tiger sharks (*Galeocerdo cuvier*) (Heithaus, 2001a). Fewer sharks (22%, N = 33) contained dugong remains in the western Shark Bay, where there is less seagrass and thus fewer dugongs (Simpfendorfer *et al.*, 2001). This difference is not significant ( $\chi^2 = 2.00$ ,  $df = 1$ ,  $P = 0.16$ ), but indicates that when dugongs are available, they may be a relatively important part of the diet of sharks in Shark Bay. In contrast, dugong remains were found in only 1.4% (N = 553) of sharks caught in Cleveland Bay, Queensland (Simpfendorfer, 1992), which has a much smaller population of dugongs than Shark Bay (Marsh *et al.*, 1990).

Although only small quantities of dugong flesh (< 1 kg) and no bones were found in the tiger sharks surveyed by Heithaus (2001a), he suggests that tiger sharks are active predators of dugongs rather than scavengers of carcasses. He supports this assertion by noting that dugong carcasses are rarely seen and thus probably rarely available. However, carcasses may be scavenged immediately and therefore never seen. If considering that Shark Bay supports 10,000 to 14,000 dugongs (Marsh *et al.*, 1994b; Preen *et al.*, 1997; Gales *et al.*, 2004), there is a relatively high number of carcasses and moribund animals available. The life history strategy of dugongs relies on a high survival rate of adults. Although natural mortality rates are unknown, we can assume a conservative rate (excluding shark attack) of approximately 2.5%, although the rate for calves is likely to be higher (Marsh, 1995a). Therefore, at least 250 to 350 carcasses would be available annually. The actual number including calves must be higher than this. Simpfendorfer (2001) suggests that live dugongs are more likely to be preyed upon by large sharks, although as tiger sharks are designed to cut and take chunks of prey, small sharks may also consume dugongs. Presumably smaller sharks would be likely to scavenge on carcasses or prey on calves and thus calves are more vulnerable to shark attack than adults.

Both great white sharks (*Carcharodon carcharias*) and tiger sharks are known to attack bottlenose dolphins in Moreton Bay (Corkeron *et al.*, 1987; Chilvers, 2001), and thus are also considered likely predators of dugongs in the bay. In large aggregations there is

an increased probability of detection of predators that use stealth as a form of attack, as tiger sharks appear to do (Krebs & Davies, 1993; Heithaus *et al.*, 2002). The increased feeding rates by individual dugongs in large, dense herds, may be attributed to the lower vigilance rates required by individuals in large aggregations compared to when solitary (Elgar, 1989).

However, during 61 days (135 hr) of observations of dugongs using the blimp-cam, I did not observe any sharks on the Moreton Banks. Either the dugongs successfully avoided sharks during this period, or shark abundance on the banks was extremely low. Preen (1992) reported sighting 33 large (2 – 4 m) sharks during 28 aerial surveys of Moreton Bay conducted at three-week intervals. Of these, 91% were sighted on the eastern banks (which include the Moreton Banks) during December to March which is the post-calving period for dugongs (Preen, 1992). Summer is the pupping season for tiger sharks, and studies in Florida and Cleveland Bay indicate that females migrate to inshore waters during this time of year (Springer, 1940; Simpfendorfer, 1992). During winter in Shark Bay, tiger shark abundances decrease with lowering water temperatures (Heithaus, 2001a). Both of my field seasons were conducted during winter and therefore during my observations shark abundances may have been at their yearly low.

Studies of other herbivores show that herds tend to be smaller or disband in response to low predation risk (Jarman, 1974) and thus dugong herds may be expected to do the same. However, during my winter observations when shark abundance was low, I saw herds of more than 100 animals. Previous research has shown that herds in Moreton Bay are smaller during the cooler months than during the summer post-calving season. For example, Lanyon (2003) recorded mean group sizes of 4.2 in May with 45% of individuals occurring in herds (groups > 10 dugongs), while in December mean group size was 14.4 with 85% of animals in herds. Though Preen (1992) found no significant affect of season on herd size, the largest herd observed during his study was recorded during summer. However, rather than being a response to low predation risk, the decrease in herd size in winter can be attributed to the periodic movement of dugongs to warm waters outside of the bay, and the resulting lower abundance of dugongs within the study area (Marsh & Sinclair, 1989b; Preen, 1992; Lanyon, 2003).

Despite the apparently low predation risk during my field seasons, if the risk of predation was high in Moreton Bay relative to other areas where dugongs occur, it might still be hypothesised that herds in Moreton Bay are a predatory defence mechanism. In Shark Bay, large dugong herds are less common than in Moreton Bay (Preen, 1992; Marsh *et al.*, 1994b; Preen *et al.*, 1997; Lanyon, 2003; Gales *et al.*, 2004), however as mentioned, dugong remains are commonly found in the stomach contents of tiger sharks in Shark Bay (Heithaus, 2001a; Simpfendorfer *et al.*, 2001). There are no records of the diet of tiger sharks in Moreton Bay with which to compare, however the rates of shark scars on bottlenose dolphins are higher in Shark Bay (74% of dolphins with scars; Heithaus, 2001b) than in Moreton Bay (47% of dolphins that feed behind trawlers and 37% of those that do not; Chilvers, 2001). So it is reasonable to assume that the risk of predation to dugongs is at least as high in Shark Bay as Moreton Bay, while dugongs in Shark Bay do not appear to regularly form herds as a predatory defence.

Preen (1992) considered the possibility that the high density feeding plumes created by large herds create a form of cover from predators both visually and through olfactory noise in the unusually clear waters of the Moreton Banks. He subsequently rejected this hypothesis as dugongs occurring in clear water elsewhere, such as in Shark Bay, do not appear to persistently form large herds (Marsh *et al.*, 1994b; Preen *et al.*, 1997; Gales *et al.*, 2004). Dugongs in Shark Bay migrate between summer and winter feeding grounds (Anderson, 1986; Preen, 1992). At the summer feeding ground, dugongs create feeding plumes as they remove both the above- and below-ground sections of *Halodule uninervis*. One large herd sighted in Shark Bay during summer was associated with feeding and plumes were clearly visible (Ivan Lawler and Dave Holley, *unpublished data*). The other aerial survey where a large herd (> 100) was sighted was conducted in winter (Marsh *et al.*, 1994b). Forage at the winter feeding ground consists mainly of *Amphibolis antarctica* and dugongs remove only small leaf clusters without disturbing the sediment (Anderson, 1986). Thus a large herd in winter is unlikely to create the dense feeding plumes seen in Morton Bay and use feeding plumes as a predatory defence strategy.

Resting behaviour in animals is generally associated with low vigilance in comparison to other behaviours. Animals that form groups as an anti-predator strategy may be

expected to be more likely to form groups while resting than while conducting other behaviours, or to choose relatively safe places to rest. Bottlenose dolphins form larger groups while resting than while foraging in Shark Bay where predation risk is considered to be relatively high (Heithaus & Dill, 2002). Yellow baboons (*Papio cynocephalus*) choose resting sites according to group size, with small groups resting high in trees as they are more susceptible to predators than large groups, which may rest on the ground (Stacey, 1986). Dugongs spent little time resting and my small number of observations of resting made it unlikely that I would detect any significant effects of other dugongs on this behaviour. However, there was a general trend towards higher rates of resting as group size decreased and distance to nearest neighbour increased. This is the opposite of what would be expected if the formation of dugong herds was an anti-predator behaviour.

I also found a weak positive correlation between the proportion of time dugongs spent resting and the time before or after high tide, thus showing a tendency to rest more at low tide in slightly deeper water (2.5 m) than at high tide (1.7 m; Chapter 3). Heithaus *et al.* (2002) believe that dugongs are more vulnerable to attack from sharks in shallow water as they have fewer escape routes, while in deep water dugongs can probably outmanoeuvre sharks. In this sense, deep water may represent 'cover' from sharks, and dugongs' distance from deep water increases their vulnerability to predation. At low tide in Moreton Bay, dugongs are still in water defined by Heithaus *et al.* (2002) as shallow (< 4 m), but are on the edge of the sand banks and so closer to deep water (refer to Chapter 3). Thus dugongs may prefer to rest on the edges of the sandbanks where they are closer to the relative safety of deep water, in a similar way to other animals regulating their behaviour according to distance from cover (Geist, 1974; Elgar, 1989; Molvar & Bowyer, 1994).

The degree of risk associated with water depth however, may not be clearly defined in the case of the dugong. Anderson (1981b) reports a case of a dugong pressing its ventrum against the substrate in defence against a shark. A dugongs' dorsum offers better protection than its ventrum as it has thicker skin, and its heavy, closely spaced ribs protect vital organs. Thus dugongs are probably most at risk from predation when surfacing to breath when they likely exhibit reduced vigilance, visibility is restricted by light attenuation, and sharks can attack their ventrum from below (Heithaus *et al.*,

2002). The depths occupied at low tide may have in fact represented the highest predation risk, as dugongs resting at the surface were vulnerable to attack from below, and in only 2.5 m of water, they still have little room to manoeuvre and escape from sharks. A clearer understanding of the level of predation risk relative to depth is needed to verify whether these factors combine to affect dugong resting behaviour.

If herding in dugongs reduces the risk of predation (Alexander, 1974), we might expect that calves, being smaller and thus presumably more vulnerable to attack by sharks, would be more commonly found in larger herds than adults (e.g., Carbyn & Trottier, 1987). Calves may also be assumed to be positioned in the safest place within the herd: the centre (Hamilton, 1971). In this study, however, calves had fewer dugongs surrounding them within three body lengths (i.e., in all four zones: front, back, left and right) than single individuals. The average number of zones containing dugongs was also significantly lower for calves. Thus mother-calf pairs are likely to be further from other dugongs than single individuals, and are unlikely to be found in the centre of herds. Preen (1992), found a linear relationship between herd size and calf counts, indicating that large herds do not attract high numbers of mother-calf pairs. Both findings suggest that mother-calf pairs are unlikely to seek large herds for protection.

#### **4.4.2 Feeding aggregation**

If dugong herds are a feeding aggregation, then individual dugongs must be gaining substantial fitness through increased foraging efficiency by being a member of the herd (McNaughton, 1984). That is, the benefits of increased foraging efficiency must be greater than the costs of competition, both directly through exploitation of forage, and indirectly from interference from other individuals (Krebs & Davies, 1993). This conclusion is reinforced by my findings that dugongs aggregate in tighter, larger groups to feed than when conducting other behaviours. My finding contradicts the expected decrease in opportunity to forage that generally occurs through the increase in competition as animals become closer to one another (Beecham & Farnsworth, 1999).

Preen (1995) provides evidence that dugongs in Moreton Bay gain benefits from feeding in large herds by ‘cultivating’ the seagrass. There are two basic aspects of his theory: (1) regular feeding by large herds changes the species composition of the

seagrass beds, favouring the seagrasses which are the preferred species for dugongs, and (2) regular grazing of preferred species improves the nutritional quality of seagrass. Together these two effects maximise the energy intake of dugongs feeding on the Moreton Banks (Preen, 1992).

Many other herding animals exhibit a similar relationship between grazing intensity and forage quality (McNaughton, 1984; Frank *et al.*, 1998). However, in contrast to other grazing animals which improve forage quality by increasing above-ground biomass of highly nutritious vegetation (McNaughton, 1984; Frank *et al.*, 1998), dugong herds remove 65 – 95% of the above-ground and 73 – 96% of the below-ground biomass (Preen, 1992). Individual dugongs in large herds leave meandering and intersecting feeding trails, while small tufts of seagrass remain interspersed at short distances. These reserves allow recovery of the seagrass within months. In Moreton Bay recovery rates of seagrass are high in comparison to seagrass beds further north (Preen, 1995; McMahon, 2003). Preen (1992) speculated that as new shoots of *Halophila ovalis* have higher nitrogen content than older shoots, intense grazing can promote growth of nutritionally superior new seagrass stands. His suggestion was supported by experiments and nutritional analysis by Aragones (1996). Perry and Dennison (1996), showed that intensive grazing by dugongs in Moreton Bay increases rates of microbial nutrient cycling in seagrass sediments, resulting in elevated nitrogen and phosphorous levels in new seagrass shoots in comparison with new shoots where grazing does not occur.

The other important benefit of removing most of the above- and below-ground biomass is that the preferred seagrass species of dugongs in Moreton Bay, *H. ovalis*, is a sparsely growing early pioneer species (Brouns, 1987; Preen, 1992) and has a greater capacity to recover quickly from grazing than many other seagrass species (Aragones & Marsh, 2000). In Moreton Bay, the climax species is *Zostera capricorni*, the least preferred species of dugongs (Preen, 1992). In experiments initiated just prior to winter, Preen (1995) showed that light grazing in Moreton Bay led to the recovery of *Z. capricorni*, while intensive grazing by large herds promoted growth of *H. ovalis*. Aragones and Marsh (2000) conducted similar experiments at two sites north of Moreton Bay at the same time of year as Preen (1995). In contrast to Preen's (1995) results, both light and intensive grazing changed the community composition of the plots from

*Zostera/Cymodocea* dominated to *H. ovalis* dominated (Aragones & Marsh, 2000). De Longh (1996) also suggested that regular cropping by small herds in East Indonesia, promotes new, nutritionally rich growth of swards of *H. uninervis*, another species favoured by dugongs.

Though grazing by small herds can produce the same changes in species composition and nutritional value of seagrass as grazing by large herds (Aragones, 1996; de Longh, 1996; Aragones & Marsh, 2000), dugongs in other areas do not persistently aggregate in large feeding herds like those observed in Moreton Bay. I suggest there are a combination of factors that select for these large feeding herds in Moreton Bay, each of which I discuss below.

### *1. Distribution of seagrass*

Favoured seagrass beds are limited to a relatively small proportion of Moreton Bay. Approximately 75% of dugongs in Preen's (1992) study area were located over seagrass beds dominated by *Halophila* species, the preferred forage of dugongs in the bay. Within the eastern banks area of Moreton Bay surveyed by Preen (1992), which includes my study area, *Halophila*-dominated communities cover 59 km<sup>2</sup>. This compares with only 9 km<sup>2</sup> of *Halophila* on the western side of the bay (Preen, 1992). Seagrass on the western side of the Bay has declined as a result of an increase in sediment loads in runoff from adjacent cleared and urbanised land (Abal & Dennison, 1996). Thus the localised distribution of seagrass in Moreton Bay influences the herding behaviour of dugong by forcing large numbers of dugongs to occupy a limited space. In contrast, seagrass in Shark Bay occurs over a relatively large area. *H. uninervis*, the preferred summer forage, occurs with *Halophila* species over approximately 500 km<sup>2</sup>, while *A. antarctica* meadows used in winter cover 3676 km<sup>2</sup>.

### *2. Differences in seagrass growing seasons*

The need for dugongs to graze in large herds in Moreton Bay may be explained by the longer winter/spring growing season of *Z. capricorni* in the sub-tropics, in comparison to the shorter, spring growing season of this species in the tropics (Aragones & Marsh, 2000). Dugongs in Moreton Bay have a longer time period over which only intensive

grazing will maintain stands of *H. ovalis* in comparison with dugongs in the tropics. Dugongs consume more *Z. capricorni* during winter when the low growth rates of *H. ovalis* limits the availability of this preferred species (Preen, 1995). Perhaps this pattern of dugong grazing also serves to restrict growth of *Z. capricorni* during the winter/spring seasons.

### *3. Accessibility of below-ground biomass according to sediment type*

The nutritionally important rhizomes of seagrass are probably more difficult for dugongs to extract when they are growing in hard sediment such as the coarse sandy substrate in Moreton Bay, than in soft soils such as the muddy substrate that occurs throughout most of the inshore waters of tropical Australia (Aragones, 1996). Though dugongs show no preference for feeding areas with particular sediment types within the range of sediment available in eastern Moreton Bay (Preen, 1992), the feeding trails produced are shorter and narrower than at Shoalwater Bay which has muddy sediment (Anderson & Birtles, 1978; Preen, 1992). Preen (1992) suggests that dugongs constrict their rostral disk to push through coarse sediment, while in soft mud they can maintain a flared upper lip and maximise their cropping width.

Dugongs feeding at the back of the dense herds I observed during my study may have to incur the cost of having less seagrass available to them than those at the front. However, this cost of feeding at the back of a large herd may be compensated by the effect of the dugongs in the front disturbing the sediment. While removing seagrass dugongs may loosen the surrounding sediment and make the remaining seagrass, and in particular the rhizomes, easier for those behind to remove. Thus foraging efficiency may be relatively equal at the front and back of the herd, negating any disadvantage of forming dense herds.

### *4. Prevalence of natural disturbance of seagrass*

Preen (1992) notes that other sources of disturbance of seagrass in the tropics (as opposed to subtropical Moreton Bay) may maintain the seagrass at a low seral stage and reduce the need for large dugong herds to produce this effect. In comparison with Moreton Bay, tropical Australia experiences more frequent cyclones, which can be a



major structuring force in seagrass communities and promote the growth of favoured species for dugongs (Poiner *et al.*, 1989). Intensive grazing by large dugong herds is not consistently observed in sub-tropical Shark Bay. This may, in part, be due to the fact that dugongs feed mostly on meadows of *H. uninervis* which are maintained by other physical factors, namely sporadic fresh-water inflows and sediment deposits (Masini *et al.*, 2001).

#### *5. Movements and ranging habits of dugongs*

The steady movement of dugong herds across the Moreton Banks over both my field seasons shows that the dugongs forage on the banks using a systematic regime. They appeared to move in a northeasterly direction during the months of my observations (April to October), returning to the same locations from one year to the next (2001 to 2002). Because of the lack of information for the period November to March it is difficult to know whether the dugongs revisited areas more often than is shown here. I suspect that the gradual movement of dugong herds across the banks probably occurs more than once per year, a conclusion supported by Preen's (1995) observations of dugongs revisiting an area after five months.

The dominant factor preventing seagrass meadows being maintained by large herds in Shark Bay is the movement of dugongs between separate feeding grounds in winter and summer in response to low winter temperatures in eastern Shark Bay (Anderson, 1986; Gales *et al.*, 2004). Considering that dugongs probably crop seagrass patches at least twice per year in Moreton Bay to maintain stands of their favoured seagrass species, the annual migration of dugongs in Shark Bay between the two feeding grounds probably prevents them from cropping the seagrass at the rate required for cultivation grazing. Thus, without the benefit of cultivation grazing, dugongs in Shark Bay do not persistently form large herds.

#### *6. Feasibility of defending territories*

It may be argued that cultivation of seagrass in the manner described could be achieved by lone dugongs occupying spatial territories. Territoriality is only feasible if the food resources required by one individual occurs in a defendable area (Geist, 1974). Dugongs

would need to defend extremely large areas if they were to each maintain a grazing lawn large enough to sustain them through the continual process of destruction and regeneration of the seagrass. The energy cost of defending such a large area would likely be much greater than the benefits, through the foraging time lost to this activity. The inaccessibility of the favoured shallow-water feeding areas of the Moreton Banks during low tide would also make it difficult to maintain these territories (Prins *et al.*, 1980).

#### 4.4.3 Social Function

Once selective forces have resulted in the formation of groups, evolution of social behaviour is inevitable (Alexander, 1974). Through this process, dugong herds in Moreton Bay may have developed a social function that increases the benefits of these aggregations.

The information collected on the social behaviour of dugongs during this study was limited by the fact that individual dugongs could not be identified. Nevertheless, the variability of group sizes and the apparently open, unstable nature of dugong herds (Preen, 1992; *pers. obs.*) suggests a loose social structure. Individual dugongs only maintained particular nearest neighbours for an average of 1 min, which is close to the average submergence time for dugongs in shallow water (75 s, Section 3.3.4). This result suggests that the herds are extremely fluid and that each dugong moves to different places within the herd after each surfacing. There is little evidence for strong bonds between individuals other than mother-calf pairs.

Herds were maintained while dugongs were not feeding and at low tide (Preen, 1992; *pers. obs.*), but with larger nearest neighbour distances than while feeding and at high tide. Rather than resulting from social behaviour, dugongs may remain in large herds simply to facilitate the coordination of their feeding regime. Although dugongs are known to vocalise (Anderson & Barclay, 1995), vocalisation rates are low (*pers. obs.*) and it is unlikely that communication occurs over long distances. By remaining in visual contact and moving on and off the shallow sandbanks as a group, individual dugongs can easily locate feeding sites and form dense feeding aggregations at high tide.

Observations of dugongs at night would determine whether vision is an important factor in herding behaviour and thus test this hypothesis.

Dugongs exhibit coordinated responses to some within-herd stimuli and to some boats (Anderson, 1982; *pers. obs.*; Section 7.3.2; Preen, 1992). Such coordination may allow dugong herds to remain in close contact, and easily resume feeding in dense herds if foraging is interrupted. Disturbance from boats and aggressive interactions within herds also at times resulted in the scattering of individuals (*pers. obs.*). Aggressive interactions amongst individuals in feeding herds occurred regularly (*pers. obs.*), and it may be assumed that this behaviour reduces the time available for feeding. If this were the case, dugongs would incur a cost as a result of the increased opportunity for social interactions provided by feeding aggregations. However, the proportion of time I observed dugongs performing social behaviours was low (6% of daily time budget; Section 3.3.3), and socialising tended to occur at higher rates in average sized herds (21 – 50 individuals) than in larger herds (> 50 individuals). The coordinated flight response of dugongs to boats lasts for an average of 2 min before dugongs resume feeding (Section 7.3.2). If the scattering response of herds to aggressive interactions has a similar duration, the interruption to feeding is probably minimal.

Mother-calf pairs were more likely than single individuals to be greater than three body lengths away from other dugongs. This behaviour may help maintain mother-calf dyads, as in large groups they may become separated more easily. I observed at least two occasions where calves were separated from their mothers while in large herds that were highly mobile. Rhesus macaques (*Macaca mulatta*) in captivity show a higher frequency of infant kidnapping by other adults in groups of high density compared to enclosures with a low density of macaques. In response, parenting styles change, with mothers staying in closer contact with young when in high density groups (Maestripietri, 2001). Dugong mothers may similarly change their behaviour in response to the risk of separation from calves by remaining in smaller groups or staying at distance from large herds. A larger scale segregation occurs in humpback (*Megaptera novaeangliae*) and southern right whales (*Eubalaena australis*), where cows with calves often use different habitat areas to other age-sex classes (Payne, 1986; Smultea, 1994). While this again may reduce the possibility of cows and calves being separated, the maternal females are

also thought to be avoiding harassment from males (Smultea, 1994). Dugong females may remain away from herds to avoid contact with males.

As discussed in Chapter 3, dugongs in Moreton Bay did not exhibit the non-sexual social behaviour observed in Florida manatees by Hartman (1979; see also Appendix 3). Although manatees are considered essentially solitary, they may socialise for long periods of over three hours while in winter aggregations (Hartman, 1979). No such social interactions were seen within the large herds of dugongs in Moreton Bay. As discussed in Section 3.4.4, I conducted few observations during October which is when Preen (1989) described mating behaviour amongst these herds in Moreton Bay in 1988. I rarely observed behaviour that was indicative of courtship behaviour (Appendix 3), suggesting that mating may be seasonal. In Preen's (1989) description, dugongs form mating herds and fight vigorously for access to a single female. If the formation of herds facilitates this mating behaviour, herd formation would only be expected to occur during the mating season. Overall, considering the limited social behaviour I observed, there is little evidence to suggest that the large dugong herds in Moreton Bay form primarily to facilitate social interactions.

#### **4.5 Conclusion**

These findings suggest that the selective pressures that have resulted in persistent herds forming in Moreton Bay are most likely to be related primarily to foraging efficiency rather than to predation pressure. The dugongs formed tighter, larger aggregations while feeding than while exhibiting other behaviours. Herding appears to facilitate cultivation grazing, which both improves the nutritional quality of forage, and changes the species composition to promote growth of a favoured species (*H. ovalis*). Small herds can achieve similar effects in other areas within the dugongs' range. However, grazing in large herds is favoured on the Moreton Banks as a result of a combination of factors including seagrass distribution and growing seasons, sediment type, a lack of other types of disturbance, and year-round presence of dugongs on the banks.

The predation risk in Moreton Bay does not appear to be particularly high in comparison to Shark Bay where dugongs only occasionally form large herds. Although

**Table 4.3** The three possible function of the large persistent dugongs herds in Moreton Bay, the possible indicators that might prove or disprove each of the three functions which are presented with a ✓ if observed or X if not.

Function of Herds	Indicators →	Observed or not	Comments
Predatory Defence	High predation risk from high abundance of sharks	X	Risk presumably lower than in Shark Bay where dugongs only form herds occasionally
	Herds disband during periods of low predation risk	X	Herds of > 100 animals still form during winter when shark abundance probably low
	High predation risk with low turbidity so dugongs use dense feeding plumes as cover	X	Similar low levels of turbidity in Shark Bay where dugongs only form herds and create feeding plumes occasionally
	Individuals seek shelter in herds while exhibiting particularly low vigilance, i.e., while resting	X	Dugongs showed tendency (though not significant) to be in smaller groups and further from nearest neighbours while resting
	Calves, being smaller and thus more vulnerable to predation, seek shelter in the middle of herds	X	Calves were surrounded by fewer individuals than single individuals (i.e., adults)
Feeding Aggregation	Increased feeding rates with increased herd size	✓	Dugongs form larger, tighter aggregations while feeding than while conducting other behaviours
	Clumped resource	✓	Most of the favoured seagrass in Moreton Bay occurs on the eastern banks (including my study site)
	Increased foraging efficiency in large herds		<ul style="list-style-type: none"> <li>• Intensive grazing promotes growth of nutrient rich young shoots of <i>H. ovalis</i> while retarding growth of least favoured species such as <i>Z. capricorni</i></li> <li>• Rhizomes may be easier to extract when feeding behind other animals than when alone as sediment is loosened by those in front</li> </ul>
	Increased foraging efficiency could not be achieved by defending territories	✓	Impossible for individuals to defend areas large enough to sustain them, particularly as dugongs must move with the tides
Social Function	Stability of herds	X	High variation in numbers and herds appear open
	Individuals maintain their position within the herd relative to other individuals	X	Nearest neighbours changed at a rate that approximates the average submergence interval, thus herds are fluid in structure
	Herds persist when individuals not feeding	✓	Rather than indicating a social function, herding facilitates coordinated feeding regimes

the benefits of dugongs herding in Moreton Bay may include a reduction in predation risk, the behaviours normally observed in animal aggregations that form primarily as predatory defence were not observed in dugong herds. These herds did not disband during periods of low predation risk (i.e., low predator abundance), and dugongs were less likely to be in large herds when particularly vulnerable to predation such as when resting in mother-calf dyads. The social function of herds in Moreton Bay is poorly understood. The herds appear open and unstable, where individuals rarely maintain proximity to particular nearest neighbours. Loose herds are maintained while dugongs

are exhibiting behaviours other than feeding. Rather than indicating social structure, I suggest that herding behaviour helps in the coordination of their feeding regime.

#### 4.6 Chapter summary

- Preen (1995) surmised that dugong herds in Moreton Bay are feeding aggregation where dugongs cultivate seagrass by promoting the growth of young, nutritionally rich stands of favoured pioneer species, *H. ovalis*.
- I found that the behaviour of individual dugongs was affected by their proximity to other dugongs. The feeding rates of focal individuals increased as the number of animals visible increased, as they spent more time in the main herds, and as the distribution to nearest neighbours decreased. These results suggest that dugong feed more efficiently in large herds than in small groups.
- Dugongs did not seek large herds or have shorter nearest neighbour distances while resting, and calves were less likely to be surrounded by dugongs other than their mother than single individuals. These observations suggest that dugongs do not shelter in large herds when most vulnerable to shark attack. Thus the herds do not appear to have a predatory defence function.
- The structure of herds was fluid with individuals maintaining positions next to particular individuals for an average of only 1 min. Neither single individuals nor mothers with calves showed an obvious preference for a particular type of nearest neighbour. The social behaviour of individuals was not affected by herd size. These results suggest that dugong herds do not primarily have a social function.
- My results support Preen's (1995) theory of cultivation grazing. Though dugongs can cultivate seagrass in other areas when in small groups, large herds are favoured in Moreton Bay because of: (1) a localised distribution of seagrass, (2) an extended growing season of the least favoured *Z. capricorni*, (3) difficulty in extracting rhizomes from coarse sediment and the advantage of feeding

behind other dugongs that have already disturbed the sediment, (4) a lack of other natural causes of seagrass distribution, (5) the presence of dugongs on the Moreton Banks year round, and (6) the impracticality of cultivating seagrass within defended territories.





# **Chapter 5**

## **Dugong behaviour in Moreton Bay: considerations for managing human impacts**

**To complete the first half of my thesis, and as a prelude to my investigations of the impacts of boats and pingers on dugongs, in this chapter I review my findings on dugong behaviour in relation to the vulnerability of dugongs to disturbance and boat strikes.**



## **Chapter 5. Dugong behaviour in Moreton Bay: considerations for managing human impacts**

Chapters 3 and 4 provided new insights into the behaviour of dugongs through direct observations. These observations are the first attempt to produce a daily time budget for dugongs and a description of the behaviours exhibited by these animals, including the interactions between mother-calf pairs. Together these observations provide the baseline information from which the biological significance of the dugong's behavioural response to disturbance can be assessed. I have also produced further evidence to suggest that the dugongs in Moreton Bay exhibit a unique foraging strategy. The formation of large dense herds coincides with higher rates of feeding than observed for solitary dugongs, but does not appear to be a response to predation pressure. This conclusion is supported by Preen's (1995) theory of cultivation grazing where these large feeding aggregations promote the growth of favoured seagrass species and increase the nutritional quality of the seagrass. I make some inferences from these direct observations of the 'undisturbed' behaviour of dugongs in relation to how they might be affected by anthropogenic disturbance below.

### **5.1 Interruption of feeding**

Dugongs spent a substantial proportion of their day feeding, and fed throughout the tidal cycle. Thus any form of anthropogenic disturbance has a high probability of interrupting foraging. Without measuring the energetic consequences of short-term interruptions, it is difficult to determine the frequency and duration of disturbance that would lead to negative long-term effects (Richardson *et al.*, 1995). The energetic cost is likely to depend on several factors such as seagrass productivity, meadow size and isolation, and accessibility according to tides and season. Each of these factors is discussed in more detail below.

In areas where the tidal range is large, for example in Shoalwater Bay, which has a tidal range of up to 8.5 m, limited access to seagrass beds may provide limited opportunity for dugongs to feed (Anderson & Birtles, 1978). The feeding areas used at high tide in

Shoalwater Bay are accessible only during approximately 39% of the day, and although dugongs also feed during low tide, the seagrass beds available are less extensive than those used at high tide (Anderson & Birtles, 1978). Similarly in Moreton Bay, there were some areas on the Moreton Banks that dugongs only used during the four hours at the top of the tide. Dugongs fed during low tide, but at slightly lower rates. The quality of seagrass in the low and high tide feeding areas was not compared. However if there is less seagrass available, or the seagrass is of lower quality in the low tide feeding area, then the time available to feed during high tide is extremely important. Thus dugongs may incur a higher energetic cost if disturbed during high tide than if disturbed during low tide. If this is the case, then limiting disturbance of dugongs in these high tide feeding areas may be more important than in the low tide areas.

I suggest that the impact of disturbance also depends on the size and isolation of seagrass beds. If, when moving in response to disturbance, dugongs are forced off seagrass beds and then have to move back to their feeding ground when the disturbance ceases, they would expend more energy than if they could move to another area and continue feeding. Thus the smaller and more isolated the seagrass bed, the more energetically costly disturbance is likely to be. This result may in turn enhance the effect of the disturbance, as the cost of disturbance may outweigh the benefits of a particular feeding ground, and the area may be abandoned altogether.

Preen's (1995) theory of 'cultivation' grazing by dugongs on the Moreton Banks supports the behavioural observations described here, and is an adaptation to maximise foraging efficiency at this site. The systematic grazing by large herds on the Moreton Banks allows the dugongs to create seagrass meadows of preferred forage with high nutrient content. Disturbance of these foraging activities and the displacement of the herds could therefore not only reduce the time available for feeding, but also eventually cause changes in the composition and nutritional quality of seagrass beds. Combined, these two effects would decrease the foraging efficiency of dugongs, the effects of which may be particularly severe in winter when dugongs in Moreton Bay lose condition (Preen, 1992). Reproduction in dugongs seems dependent on energy intake (Kwan, 2002). Thus, if disturbance increases, the ultimate result could be reduced reproduction rates, and thus anthropogenic disturbance may be unsustainable at the population level.

## 5.2 Disturbance of travel behaviour

Often the purpose and importance of travelling behaviour of marine mammals is unknown. Thus, other than quantifying changes in directionality and speed (e.g., Au & Perryman, 1982; Bejder *et al.*, 1999; Williams *et al.*, 2002), it is difficult to assess the effects of interrupting travel. However, dugong feeding behaviour is often interspersed with slow travel and in this context I suggest that travel represents searching for forage within these sparse seagrass beds. Disturbing dugongs when they are conducting this searching behaviour may decrease foraging efficiency if the animals are forced to relocate in a new area and recommence searching.

Fast travel with obvious and rapid fluke movements was seen rarely, constituting only 0.1% of the time budget. This behaviour is likely to be energetically costly to dugongs, if as predicted, they have low metabolic rates similar to manatees (Preen, 1992). As a result, high speed travel is only exhibited as flight behaviour in response to threats such as aggression by other dugongs, or boats approaching. The energetic cost of fast travel should be considered when assessing the response time of dugongs to an approaching boat.

## 5.3 Vulnerability while resting

Resting is an important behaviour for conserving energy. For dugongs, resting is also an integral part of feeding in relatively deep water. I often saw dugongs rest at the surface between long feeding dives in deep water (Section 3.4.5). Sperm whales reduce the time they remain at the surface by 17% in response to whale watching boats in Kaikoura (Gordon *et al.*, 1992). If assuming that this results in an equivalent reduction in dive times, and accounting for a constant period of descent and ascent during a foraging dive, this would relate to a 36% reduction in the time available for foraging (Gordon *et al.*, 1992). A similar approach could be applied to dugongs, particularly when foraging at depths greater than observed in this study. Thus the energetic cost of disturbance during inter-foraging rest is multiplied if it reduces the energy available for the animal to exhibit long feeding bouts at depth.

In addition, resting behaviour may increase the vulnerability of dugongs to boat strikes if they are less vigilant during rest, or rest at the surface. Although dugongs rested throughout the water column, they spent the highest proportion of time (3.5%) resting at the surface. As indicated above, surface resting may be related to water depth, as it often occurs between feeding dives in deep water. My observations were limited to water depths of less than 4 m, and were biased towards high tide when dugongs were in average depths of 1.7 m. Thus estimates of the time budget for this behaviour may be less than for dugongs in a wider range of depths. The tendency for dugongs to rest at the surface while foraging in deep water suggests that the vulnerability of dugongs to boat strikes may be affected by water depth.

#### **5.4 Vulnerability of calves**

Dugong calves appeared able to adapt to their mother's increase in travel speed by swimming and suckling concurrently. Thus suckling may not be as readily terminated by a mother's movement in response to disturbance, as for Florida manatees where the mothers idle or rest while calves suckle. Dugong mothers were never observed travelling fast during suckling bouts, however, and I consider that a suckling bout would be terminated if the mother were disturbed and exhibited a flight response.

The behaviour of calves makes them particularly vulnerable to boat strikes. Calves exhibit shorter submergence times than their mothers, and thus spend more time at or near the surface. Calves also spend 13% of their time either travelling or resting above their mothers' back, and often cross onto or over their mothers' back while surfacing and submerging. Timed depth recorders show that dugongs spend 47% of their time within 1.5 m of the water surface, where they may be exposed to the propellers of boats. A calf positioned above its mother's back is in a more vulnerable position than the mother with respect to passing boat traffic.

## 5.5 Direct observations of anthropogenic impacts

Direct observations of dugong behaviour provides insights into the likely effects of anthropogenic impacts. While interpreting the behaviour of dugongs in this Chapter, I have considered how they may be affected by disturbance, and what factors may influence their vulnerability to boat strikes. The second half of this thesis combines these observations with direct observations of the response of dugongs to boats and pingers. This approach allowed me to assess the current threat of boats, and the potential adverse effects of pingers on dugongs with a focus on Moreton Bay. To date, this is the only study to consider these impacts on dugongs, and thus provides the best knowledge currently available on the effects of disturbance and the risk of boat strikes to dugongs.

## 5.6 Chapter summary

- The basic understanding of dugong behaviour gained from my observations of undisturbed dugongs provides insight into the possible effects of disturbance on dugong populations and their vulnerability to boat strikes.
- Any form of anthropogenic disturbance has a high probability of interrupting feeding as dugongs feed for a large proportion of the day. The cost incurred by dugongs if disturbed while feeding is likely to depend on the productivity, size, isolation and accessibility of the seagrass meadow.
- Dugongs are presumably most vulnerable to boat strike while at the surface of the water. Most resting occurs at the surface, which contributes 3.5% of the daily time budget.
- Mothers, and particularly calves when positioned over their mother's back, spend more time at the surface than single individuals and thus are probably most vulnerable to boat strikes.





# **Chapter 6**

## **Confirming the obvious: boat speed affects the risk of boat strikes to dugongs**

**In the chapter, I describe qualitative observations of the response of dugongs to boats that passed by opportunistically, and some of which ‘ran over’ dugongs. These observations are used as a framework for developing a hypothesis concerning the factors affecting the risk of boat strikes to dugongs.**



## Chapter 6. Confirming the obvious: boat speed affects the risk of boat strikes to dugongs

### 6.1 Introduction

In the waters of urban coastlines, marine mammals are faced with a wide range of human-related impacts and various forms of habitat modification, including ever-increasing levels of boat traffic. Boat traffic presents the obvious and direct risk of injury or death from boat strikes for a range of marine mammals, including at least 11 whale species (Laist *et al.*, 2001), particularly North Atlantic right whales (*Eubalaena glacialis*) (Kraus, 1990; Kennedy & Kraus, 1993; Knowlton & Kraus, 2001), and most known dolphin species such as bottlenose (*Tursiops truncatus*) (Wells & Scott, 1997; McFee & Hopkins-Murphy, 2002) and Hector's dolphins (*Cephalorhynchus hectori*) (Stone & Yoshinaga, 2000). Marine mammals are also faced with the indirect effects of disturbance, such as energy costs (Baker & Herman, 1989). Both boat strikes and disturbance may affect the survival of marine mammal populations. This chapter relates the response of dugongs to boats, in an assessment of the risk of boat strikes. Boat disturbance is investigated in Chapter 7.

The direct effects of boat traffic on marine mammals are most apparent in Florida, where deaths of Florida manatees (*Trichechus manatus latirostris*) as a result of collisions with watercraft accounted for 25% (N = 1224) of all known mortalities between 1978 and 2003 (Marine Mammal Commission, 2004). The number of boat strikes increased between 1974 and 1992 at a rate of 9.3% per year in conjunction with increasing vessel registrations (Ackerman *et al.*, 1995). Most manatees in Florida bear scars from boat propeller blades or keels (Reid *et al.*, 1991; O'Shea *et al.*, 2001). Over 1,000 live manatees have been photographically identified using these scars, and 97% of these individuals have sustained injuries from multiple boat strikes (O'Shea *et al.*, 2001). An extreme example was a manatee examined at necropsy that had scars from 50 separate boat strike incidents (O'Shea *et al.*, 2001). Thus boat strikes not only raise concern for the conservation of this species, but also for the ethical issue of animal welfare. However, the pain and suffering caused by boat strike injuries has received

little attention, despite Florida statutes and federal laws that legislate against injuring these animals (O'Shea *et al.*, 2001).

Levels of boat traffic in Australia are lower than those in Florida (approximately 180,500 in Queensland (Queensland Transport, 2003) compared to 920,000 in Florida (Florida Dept of Highway Safety & Motor Vehicles, n.d.)). To date, boat strikes have contributed to a relatively small proportion of human-related dugong mortalities (Marsh *et al.*, 2002). Dugongs appear to be less vulnerable to boat strikes than manatees as the former occur in open waters, while manatees are often found in narrow inland waterways closer to urban centres (Anderson, 1981a). In 2002, however, the number of reported dugong mortalities attributed to boat strikes along the Queensland coast reached its highest level, with seven individuals, accounting for 64% of anthropogenically caused dugong strandings and mortalities reported that year (excluding mortalities from Indigenous hunting). Five of these boat strikes occurred in Moreton Bay (Limpus *et al.*, 2003a). These figures represent minimum numbers, as they include only those dugongs that were found and on which recent pre-death boat injuries were clearly and unambiguously identifiable. Dugong populations, particularly along the urban Queensland coast, have already been severely depleted as a result of human activities (Marsh *et al.*, 2001). According to aerial surveys estimates of the Moreton Bay dugong population (Lawler, 2001; Lanyon, 2003), the sustainable level of mortalities using the Potential Biological Removal method (Wade, 1998; Section 1.3.3) is between 1 and 11 (Appendix 4). Thus, as boat strikes are not the only source of human-related mortalities of dugongs in Moreton Bay (known mortalities also occur through traditional hunting), this rate of boat strikes is unsustainable for this population.

Detailed reports about the incidence of human-related mortalities are not available for countries or states within the dugongs' range other than Queensland. However, high levels of boat traffic from ecotourism in the Red Sea, China and Vanuatu, and in harbours and shipping channels in Indonesia and Palau, pose a potential threat from boat strikes. Evidence of propeller wounds have been reported in Thailand, Malaysia, Brunei, and New Caledonia (Marsh *et al.*, 2002). Thus the threat of boat strikes is a widespread problem, affecting dugong populations in many countries (Marsh *et al.*, 2002).

The high incidence of manatee deaths caused by boat strikes in Florida has promoted research on how manatees respond to boats in an effort to provide management agencies with strategies to reduce the risk. Behavioural observations revealed that manatees only begin to respond when boats are within 25-50 m (Nowacek *et al.*, 2001c). This response is characterised by an increase in swim speed and a change of heading towards deeper water, often taking manatees across the path of boats (Nowacek *et al.*, 2001c). In a preliminary study, Nowacek *et al.* (2001d), used ‘digital acoustic data logger tags’ (DTAGs), which are attached to Antillean manatees (*Trichechus manatus manatus*) and record sound as well as movements of the animal, such as pitch, roll, fluke strokes and compass heading, to record responses to experimental boat approaches. Only one manatee was tagged and three boat approaches conducted, however, the DTAGs showed a response to the boat at greater distances than had been detected using visual observations. An increase in activity levels, which may include an increase in depth and fluke stroke rate, and change of heading, suggested that the manatee detected the boat about 800 m away.

Prior to my study, there has been no dedicated research on the behavioural responses of dugongs to boats or on the risk of boat strikes. Anderson (1982) reports an incident where dugongs showed a delayed response to a boat travelling at high speed, observed from a cliff-top location. In this case the boat was travelling at 27 knots and passed within 2 m of some individuals. Only when the boat was passing through the herd did dugongs stop performing roll dives indicative of feeding, and begin surfacing with their heads high out of the water (Anderson, 1982). Preen (1992) gives some qualitative reports of dugong and boat interactions observed during aerial surveys. He noted that dugongs are more likely to respond by taking evasive action to avoid boats in water less than 2m deep, than when in deeper water. Preen (1992) also suggested that, similar to Florida manatees, dugongs have a tendency to head for deeper water in response to boats. According to Anderson (1981a), during daily approaches with a catamaran, dugongs appeared to detect the slowly moving or anchored boat at 100 to 200 m. Preen (1992) observed responses to speed boats at up to 1 km but does not describe these responses.

Boat speed is intuitively considered to be the most likely factor influencing the risk of boat strikes to marine mammals. The faster the vessel is moving, the less time the

animal has to take avoidance action. In addition, the force of impact is a product of mass multiplied by velocity. Thus, once struck by a boat, the probability of the animal being seriously injured or killed must increase as boat speed increases. The most obvious action for management authorities is thus to implement speed restrictions, as has been done in Florida to protect manatees (Frohlich, 1994), and in Moreton Bay to protect dugongs (Appendix 1).

Experimentally testing the factors that might influence the risk of marine mammals being hit by boats is difficult without risking harm to the study animals. As such, the risk of boat strikes was not tested directly in this study. However, the large amount of time spent studying dugong behaviour using the blimp-cam provided me with the opportunity to observe the responses of dugongs to a variety of opportunistic boat passes. These passes represent more realistic boat-dugong interactions than experimental passes. Few other research techniques provide such graphic detail of the response of marine mammals to boats. From these observations I have been able to examine the most likely factors that influence the risk of boat strikes to dugongs, and provide recommendations to managers for how to minimise this risk.

## **6.2 Methods**

The response of dugongs to independent boats passing opportunistically, was recorded over 60 days during two field seasons, from August to October 2001, and from June to August 2002. All observations were conducted using the blimp-cam (Chapter 2), and all data were extracted from video footage at the end of the two field seasons.

While dugong behaviour was being recorded using the blimp-cam, observers recorded all boats that passed opportunistically within 1 km of the research vessel (e.g., recreational boats) including the distance, bearing, and method of propulsion (inboard or outboard motor, jet, sail or drift). The distance of the vessel from the research boat was either estimated, or if close enough, obtained using a laser range finder (Bushnell TPEB800, range 23 – 732 m). If possible, the blimp-cam was panned to the boat to determine its location relative to the dugongs.

The protocol for filming opportunistic observations was to pan the camera around so as to observe as many dugongs as possible. If the passing boat was close enough it was kept in frame so that the actual distance of the boat from the dugongs could be estimated using the video footage. The average length of dugongs was used as a guide for these distance estimates. Each boat was classified as either within 50 m or beyond 50 m of the nearest dugong as it passed the herd.

Throughout this chapter I refer to boats ‘running over’ dugongs. This terminology does not imply that the dugongs were hit or injured by the boats. I use the term ‘run over’ to describe events where one or more dugongs remained in the path of a boat, and the boat passed directly over the top of them, such that the dugong(s) briefly disappeared beneath the hull and/or motor of the boat.

### **6.3 Results**

During my field seasons in 2001 and 2002, totals of 135 and 78 boats respectively were observed within 1 km of the research vessel while I was recording dugong behaviour. This tally equated to approximately 1.8 boats per hour of video footage in 2001, and 1.1 boats per hour in 2002, giving an overall average of 1.5 boats per hour. The average number of boats per hour on weekends and public holidays was 2.3 (N = 37 hrs) and on weekdays was 1.2 (N = 108 hrs)

A total of 25 boats passed within 50 m of the dugongs during 145 hours of video recordings. Of these 25 boats, 16 (64%) were travelling above planing speed (the designated speed limit within the study area). Six of those slowed down just as they reached the dugongs, presumably a response to seeing them surfacing. On four occasions, boats travelling above planing speed ran over dugongs (Table 6.1; Appendix 2) These dugongs were seen travelling away from these incidents, however it was not possible to determine whether any of these animals sustained any injuries (Figure 6.1a).

**Table 6.1** The four cases of dugongs being run over by boats, including the number of dugongs run over, water depth, propulsion type (inboard or outboard motor, jet, sail or drift), and speed (<> planing) of the boat.

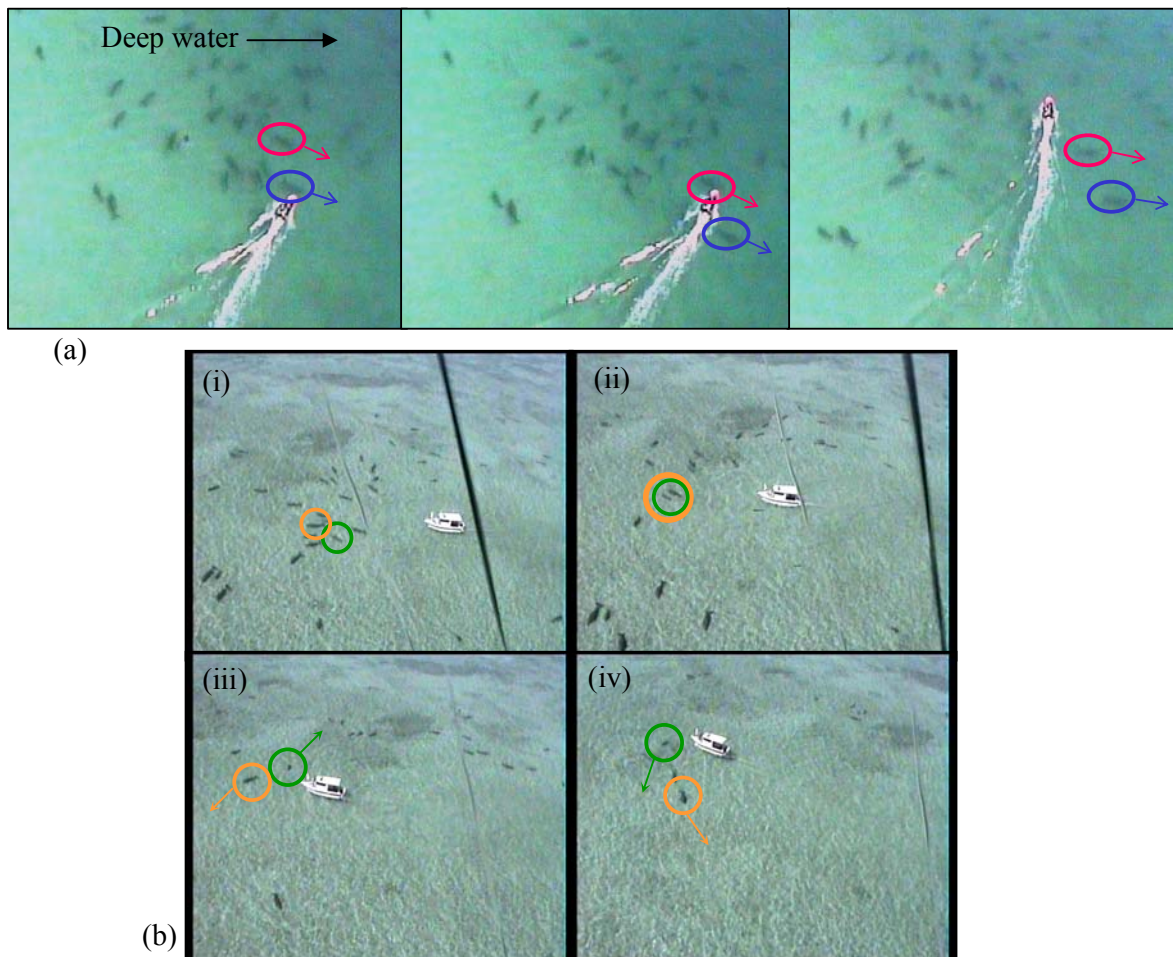
Case	Date	Dugongs Run Over	Water Depth (m)	Propulsion Type	Speed
1	24/09/01	2 adults	1.3	Outboard motor	> planing
2	18/10/01	2 adults, 1 calf	2.4	Outboard motor	> planing
3	02/07/02	1 adult	1.3	Outboard motor	> planing
4	27/07/02	2 adults	4	Outboard motor	> planing

Dugongs were observed crossing the path of the moving vessel on nine of the 25 occasions when the boat was within 50 m. In one instance, two catamarans were motoring slowly and dugongs crossed the paths of the boats 24 times, with at least seven dugongs crossing twice. I also observed a mother-calf pair split when moving away from a non-planing, outboard powered boat. The calf then swam directly across the path of the boat to join the mother (Figure 6.1b; Appendix 2). As with all other occasions when boats were travelling below planing speed, none of these dugongs was run over. However, in Case 2 (Table 6.1), the three dugongs run over were fleeing when they swam across the path of the boat (Figure 6.1a). The calf in Case 2 was following its mother, which succeeded in avoiding the boat while the calf was run over.

In seven of the nine cases where dugongs crossed the path of the boat, the dugongs appeared to be heading towards the deeper water at the edge of the sandbanks. This observation is difficult to verify however, as the animals were not always heading directly to the closest point of deep water. Also, in most cases the edge of the sandbanks was hundreds of metres away from where the dugongs initially responded and the animals stopped responding (i.e., travelling) before they reached the deep water. In Case 2 described above, the boat passed through the dugong herd while the animals were on the edge of the banks and the dugongs that crossed the boat's path were clearly attempting to flee to deeper water (Figure 6.1a). In four cases the dugongs appeared to cross the path of the boat to join the majority of the herd, which was on the other side of the boat. Thus in some cases, dugongs were heading for both deeper water and the main herd, and the actual motivation for crossing the path of the boat could not be distinguished. Also, in two cases, dugongs crossed the path of the boat in both directions, so again, the motivation for the choice of direction was unclear.



In general, dugongs seemed able to detect the boats but did not have time to swim away from boats moving at high speed. The eight dugongs that were run over by boats either: (1) were in the direct path of the boat and responded too late to move far enough to avoid the boat, or (2) responded by swimming across the path of the boat (Figure 6.1a). As dugongs swam across the path of the boat they appeared to detect the boat and further increase their swim speed. If the boat was moving slowly, the dugongs then still had time to swim away from the path of the boat, however if the boat was moving fast, the dugongs could not swim fast enough to avoid the boat.



**Figure 6.1** (a) Example of a boat travelling above planing speed and driving over the top of two dugongs (circled, arrows indicate swim direction). (b) Example of boat travelling below planing speed and dugongs fleeing from the vessel, note mother (circled in orange) and calf (circled in green) in (iii) swim in opposite directions and in (iv) calf swims across front of boat to join mother.

## 6.4 Discussion

My observations of the response of dugongs to independent boats passing opportunistically support the assumption that boat speed is the most significant factor affecting the risk of boat strikes. Over the period of the study, 25 boats passed within 50 m of the dugongs. Only boats that were travelling above planing speed were observed running over dugongs, while dugongs were always observed moving away from the path of boats travelling at below planing speed. Although the eight dugongs seen run over by high-speed boats showed no obvious signs of injury, the risk of boat strike must be extremely high for dugongs that remain in the path of a boat in shallow water. Three dugongs were run over in only 1.3 m of water. I assume that in these cases, the dugongs managed to avoid the propeller, or the boats involved had a shallow enough draft to allow the dugongs to pass underneath.

The dugongs did not appear to adjust their response to account for different boat speeds. In interpreting the observed response of the dugongs, there is a complex array of influences to consider. In this study I was unable to quantify the response distances of dugongs to boats, as boats were not usually within the field of view of the blimp-cam and distances could not be reliably estimated from the video footage (Section 3.2.2). Nonetheless, the delayed flight response that dugongs exhibited and the vulnerability of dugongs to fast boats, can be examined theoretically as discussed below.

### 6.4.1 Optimal escape theory

A dugong's response to a boat involves a decision-making process similar to that made by animals in response to predators. Several authors have suggested the response to non-lethal disturbance by animals can be directly related to anti-predatory behaviour (Berger *et al.*, 1983; Gill *et al.*, 1996; Frid & Dill, 2002; Cooper *et al.*, 2003).

Encounters between dugongs and boats are particularly suited to this analogy, as boats not only cause disturbance, but can be lethal to dugongs. There is evidence that animals are able to assess the risk of being preyed upon and that this information influences their behaviour (Lima & Dill, 1990). As dugongs have been forced to adapt to the potential threats posed by boats over a very short time period in evolutionary terms, it is

reasonable to suggest that their response incorporates the same decision-making process as that used in response to predators.

It cannot be assumed that animals flee immediately upon detecting a boat. This assumption that the distance at which animals will flee from a predator is constrained by their ability to detect the predator is termed the ‘perceptual limit hypothesis’ (Ydenberg & Dill, 1986). In contradiction to this hypothesis, many studies have shown that animals respond to a predator by becoming vigilant well before initiating the flight response, indicating detection of the predator (e.g., Estes & Goddard, 1967; Ewer, 1968; Dill, 1974). This delayed response supports the ‘economic hypothesis’ or ‘optimal escape theory’ which proposes that animals make choices about when to flee once a predator has been detected (Ydenberg & Dill, 1986). Perceptual constraints then become a limiting factor in this decision. If detection is restricted, prey may flee as soon as predators are detected (Ydenberg & Dill, 1986). There may be behaviours that are directly related to detection and which are distinct from flight (Ydenberg & Dill, 1986).

Costs of fleeing include energy expenditure, and lost foraging or social opportunities (Ydenberg & Dill, 1986). These costs mean that continually responding to boats not posing a direct threat, i.e., boats that are not about to run over the dugongs, may have similar detrimental effects on the dugong population as those caused by actual boat strikes (Morse, 1980). Dugongs using Moreton Bay are likely to have encountered boats on numerous occasions. I estimated that boats pass within 1 km of dugongs approximately 1.5 times per hour. During summer, and particularly during the summer holiday season, the level of boat traffic is probably higher than during the winter period of my study. It is likely that these dugongs have become habituated to boats, as has been documented for other marine mammals such as bottlenose dolphins (Acevedo, 1991). Habituation is consistent with the optimal escape theory, as the animal is assessing risk based on past experience with a particular predatory stimulus (Ydenberg & Dill, 1986). In this sense, habituation may only be partial, as the animal may respond to a predator, or disturbance from a boat, but will not waste energy fleeing until the risk from the predator (or boat) is greater than the perceived cost of fleeing (Frid & Dill, 2002).

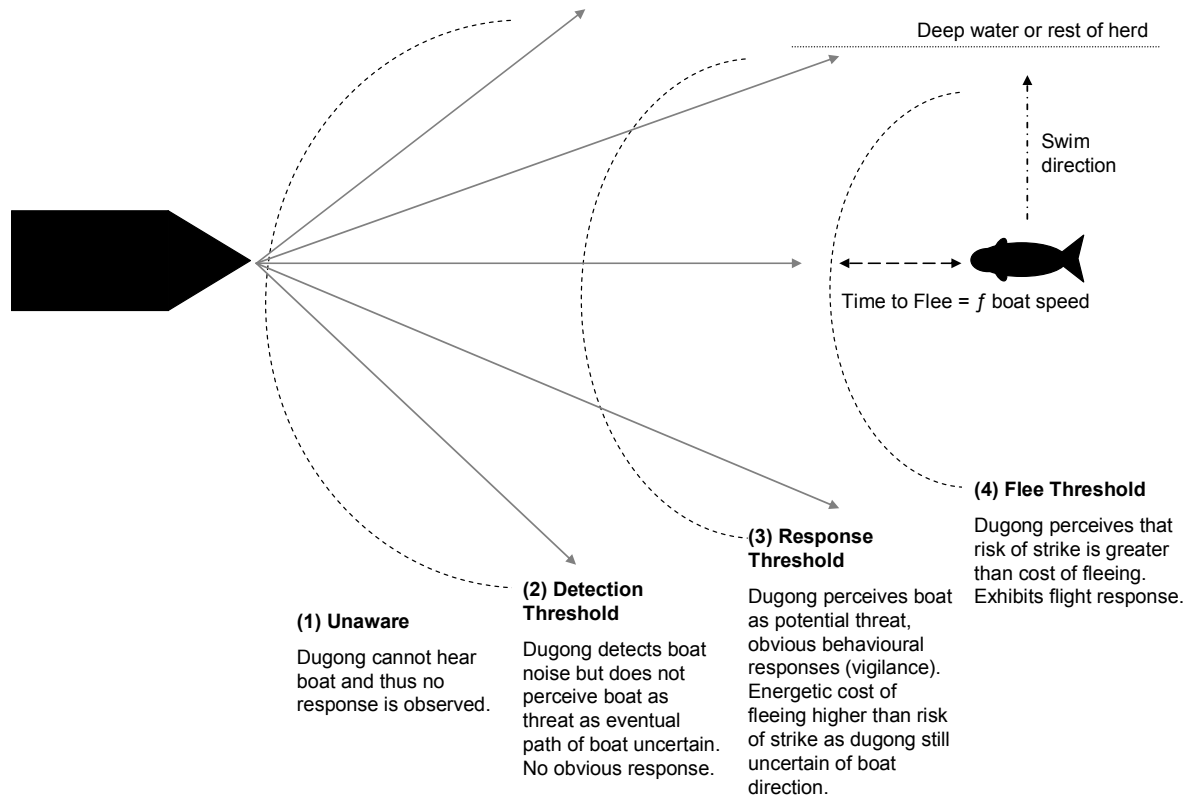
If dugongs make ‘economic’ decisions about when to flee from boats, then their vulnerability to boat strikes cannot be assessed based on their ability to detect boats. In

addressing the high frequency of Florida manatee deaths as a result of boat strikes, Gerstein (2002) notes that manatees have better hearing abilities in the range of frequencies emitted by fast moving boats than those emitted by slow boats. Thus he proposes that they have a better chance of evading fast boats as they can detect them at a greater distance. He calculates that the advantage of hearing boats at a greater distance gives manatees more time to evade the boat, even accounting for boat speed. The observed response distance of manatees, however, is not affected by the speed of the approaching vessel (Nowacek *et al.*, 2001c) suggesting that either manatees can hear both fast and slow boats at equal distances, or that manatees respond to boats at a given distance regardless of detection distance.

In explaining the vulnerability of dugongs to fast boats, I have divided the response of dugongs into four stages according to the distance of the boat (Figure 6.2). I hypothesise that: (1) initially a dugong is unaware of a boat's presence, and thus is conducting 'normal/undisturbed' behaviour, (2) once the boat is detected, or is within the 'detection threshold', the dugong may not exhibit an observable response, (3) once the boat is close enough to be perceived as a threat, or is within the 'response threshold', the dugong may become vigilant and produce an obvious behavioural response, but will not yet flee as it is still uncertain about the location and eventual path of the boat, i.e., the energetic costs of fleeing from the boat are still perceived to be greater than the risk of boat strike while remaining or being vigilant, and (4) the boat reaches a distance where the dugong can determine that it is in the direct path of the boat, or the 'flee threshold'. At this point the boat is close enough for the dugong to determine its actual location. Thus the animal has a high chance of successfully avoiding the boat, so the cost of remaining is higher than the cost of fleeing.

#### **6.4.2 Detection threshold**

To assess the risk of boat strikes to dugongs, the main factor to be determined is whether dugongs can detect boats at a distance that allows them time to escape. Detection is determined by the hearing abilities of the dugongs, and the propagation of the boat noise. Propagation distance depends on the frequency and sound pressure level of the noise (determined by the type and speed of the boat) and the surrounding environment (Richardson *et al.*, 1995). As all of these factors varied throughout the



**Figure 6.2** The hypothesised four stages of response by dugongs to boats according to the perceived risk of boat strike. Dugongs delay fleeing until the risk of boat strike is greater than the energetic cost of fleeing. Ultimate avoidance of the boat is dependent on the time the dugong has to respond once the boat has reached the strike threshold. This time is a function of the boat's speed. Thus boat speed is the main factor affecting the risk of boat strike to dugongs.

opportunistic observations of this part of my study, and as sound was not recorded, the sound levels actually received by the dugongs are unknown. It is important to recognise however, that sound propagates very poorly in shallow water, a factor that influences the distance at which dugongs can detect boats. Thus future studies would benefit from recording the sound levels being received by the dugongs in various water depths.

Assuming that detection does not necessarily elicit a response, then the only reliable measure of detection would be to measure the dugongs' neural responses (Ydenberg & Dill, 1986). Dugongs may have detected boats before exhibiting an obvious response. As discussed in Section 6.1, an Antillean manatee showed a subtle response to a boat hundreds of metres away, which was detectable using a DTAG but not by visual observations (Nowacek *et al.*, 2001d). However in this study, I used response, or a

change in behaviour, to assess the detection abilities of dugongs, so the initial detection of the boat may have occurred at larger distances than recorded here.

### 6.4.3 Response threshold

Many marine mammals exhibit changes in behaviour other than fleeing, which are considered indicative of a disturbance response to boats. As discussed further in Section 7.1, these responses include longer dive times (e.g., Baker & Herman, 1989; Evans *et al.*, 1992; Nowacek *et al.*, 2001b) increased breathing synchronicity (e.g., Hastie *et al.*, 2003) and reduced interanimal distances (e.g., Au & Perryman, 1982). Dugongs exhibited obvious mass movements in response to boats, including boats passing over 500 m away (Section 7.3.2). These movements could not be considered a flight response, as dugongs were typically travelling at ‘cruising’ speed (Appendix 3). This response to boats indicates that they are able to detect boats at large distances. It also shows that dugongs do not immediately initiate a flight response upon detecting a boat, but that they may begin to move away from the general direction of the boat noise.

There are two important factors influencing the way dugongs respond to boats: (1) their ability to determine the boat’s exact direction and approach speed, and (2) the predictability of boat movements. The ability of dugongs to localise (determine the direction of) sound is unknown. It is suggested that as the zygomatic process (‘cheekbone’) of manatees contains lipids similar to the lower jaw of bottlenose dolphins, and thus may perform the same function in detecting directionality (Ames *et al.*, 2002). Dugongs do appear to detect boats that are hundreds of metres away and move away from the general direction of boats (Anderson, 1981a, *pers. obs.*). However, they may not be able to pinpoint a boat’s exact location until the boat is within sight, or perhaps is detected via pressure waves. Anderson (1982) suggests that hairs distributed over the dorsum on dugongs may serve a sensory function, allowing them to detect the pressure waves of moving objects nearby. Kamiya and Yamasaki (1981) described the short stiff hairs on the dorsum as sinus, or tactile, hairs. Manatees have similar sparse hair distributed over the body, which are also believed to be tactile hairs that could sense approaching animals or water currents (Reep *et al.*, 2002). The tactile hairs on dugongs may enhance their ability to localise a boat once it is relatively close.

The exact path of a boat is unpredictable as it is not restricted to a predetermined track as is the case with a car on a road (Figure 6.2). Therefore, even if a dugong is able to localise a boat, determining whether it is in the direct path of the boat is impossible until the boat is relatively close. These two factors introduce a large degree of uncertainty about the direct risk posed by an approaching boat. They also mean that if the dugong does move during this uncertainty, it may actually move into the direct path of the boat.

Dugongs possibly incur a cost of lost foraging time when moving in response to boats, as discussed in Section 7.4.4. However, this travel behaviour can be considered a form of vigilance, during which the dugong is more aware of its surroundings and more prepared to flee. There is a much greater cost related to flight behaviour in comparison to travelling at cruising speed, particularly for dugongs. During behavioural observations, fleeing was considered fast travel, and dugongs only spent 0.1% of their daily time budget in this behaviour (Section 3.3.3). Anecdotal observations suggest that dugongs can exhibit fast travel for only a short time, after which they tire and begin to surface frequently, thus becoming more vulnerable to boat strike. Knowledge that dugongs become exhausted quickly when pursued is used when hunting or capturing dugongs (Marsh *et al.*, 1981; *pers. obs.*). Once the animal has been chased it is easier to catch, but researchers will also abort a chase if unsuccessfully pursuing a dugong for too long, as a precaution against endangering the animal (two animals have died after being chased and captured in Moreton Bay; Marsh *et al.*, 2002). Thus, I propose that dugongs delay fleeing from boats until the risk of boat strike is greater than the energetic cost of flight, that is, the boat is within the flee threshold.

#### **6.4.4 Flee threshold**

If dugongs are to make differential responses to boats that are travelling at various speeds, they must make a decision about when the boat poses a threat based on both distance and speed. To respond at a safe distance they must be capable of determining the boat's speed from the noise levels received, as well as to perceive fast boats as a threat when they are at a greater distance than slow boats. Gazelle and wildebeest herds exhibit an alarm response to wild dog packs at a greater distance when the dogs are running than when the dogs are walking or trotting. However, the flight distance is independent of the approach speed of the dogs (Estes & Goddard, 1967). Similarly

dugongs appear to flee at a set distance regardless of boat speed, although this has not been formally tested.

As discussed above, I assume that dugongs delay their flight response until they perceive the location of the boat and can determine that they are in its direct path. If dugongs can locate boats more reliably than I am predicting, it is still reasonable to assume that their assessment of risk is based on distance rather than speed. The decision of when to respond to a boat may be compared to safe crossing decisions made by both human pedestrians and drivers in relation to traffic. Both require judgement of the car or vessel's time-to-impact, distance and speed (Connelly *et al.*, 1998). By testing the threshold point at which children would no longer cross a road in front of traffic, it was determined that the distance gap threshold was not affected by car speed (Connelly *et al.*, 1998). When asked, children admitted that they used distance rather than speed to judge the safe gap at which they could cross the road, a strategy which produced a proportionally high number of unsafe decisions. Adults also use distance cues rather than speed when deciding when to over-take, join or cross traffic while driving (Hills, 1980). Whether dugongs can determine the boat's exact path and speed is irrelevant if they flee when a boat reaches a particular distance.

#### **6.4.5 Risk as a function of speed**

If the flight threshold remains constant, then the time the dugong has to respond is a function of the time it takes for the boat to get from the flee threshold to the dugong. Once reaching the flee threshold, a fast boat may offer only an instant for a dugong to flee. As observed in this study, this is not enough time for a dugong to avoid the boat. If, for example, a boat was travelling at 20 knots and the flee threshold was 20 m, then the dugong would have approximately 2 s to move from the path of the boat. Avoidance may be possible if the dugong is already travelling in the appropriate direction. However if the dugong was resting or respiring at the surface and needed to submerge before initiating flight, or chose the wrong direction to flee and went into the path of the boat, then it would not have enough time to avoid the boat. In this example I assume that the dugong is not visible to the boater. Glaser and Reynolds (2003) provide a similar example to show that high speed also reduces the time boaters have to respond if



sighting an animal. Ultimately, boat speed is the most important factor affecting the risk of boat strike for dugongs.

This theory probably applies to other marine mammals. Accounts of collisions between ships and whales suggest that whales often exhibit a last-second flight response even though whales should be able to detect ships at a distance. Most fatal collisions involve ships travelling at 14 kn or faster (Laist *et al.*, 2001). Terhune and Verboom (1999) also suggest that boat noise propagates least in the area directly in front of a ship and near the water surface. Thus whales in a ship's path may not perceive the ship as a threat according to the sound detected, but may flee once the boat is close enough to detect visually. Bottlenose dolphins, which are also subject to boat strike (Wells & Scott, 1997; McFee & Hopkins-Murphy, 2002), show increased responses in correlation with increased boat speed (Cope *et al.*, 1999; Nowacek *et al.*, 2001b). However, there is no relationship between the speed and distance of the boat, and the response of bottlenose dolphins (Nowacek *et al.*, 2001b). This increased disturbance as a result of increased boat speed may simply be related to the effects of increased noise, such as the masking of other important sounds, rather than an increase in the perceived threat from boats.

In further support of this theory, Florida manatees also appear to initiate an obvious avoidance response only once a boat is within a particular distance. Nowacek *et al.* (2001c) did not observe changes in the swim speed of manatees until passing boats were within 25 m of the animals. During their experiments, Nowacek *et al.* (2001c) did not observe an effect of boat speed on either of the two common responses to boats: increased swim speed and a change of heading towards deeper water. Similar results were obtained during a pilot study on manatee responses to boats, where manatees initiated their response at a distance of approximately 50 m regardless of boat speed, which ranged from slow speed to over 25 knots (Weigle *et al.*, 1993).

#### **6.4.6 Individual variation, and response of other individuals**

Nowacek *et al.* (2001c) noted that Florida manatees exhibit a high degree of individual variation in their response to boats. Reasons for variation may include age, reproductive state or exposure to boats (Nowacek *et al.*, 2001c). This individual variation in response may affect the vulnerability of individuals to boat strikes. For example, the risk of boat

strikes to dugong calves may be greater than to adults. Two calves crossed the path of boats to join their mothers during this study, and one of these calves was run over. Similarly, Wells and Scott (1997), noted that mother and neonate bottlenose dolphins appeared more at risk of boat strikes than single animals, while the only two records of boat strike mortalities of Hector's dolphins are both calves (Stone & Yoshinaga, 2000). My behavioural observations suggest mother-calf pairs spend more time close to the surface than single individuals (Section 3.3.4), and that calves are often positioned above the mother while travelling, resting or surfacing (Section 3.3.6). Thus mother-calf pairs, and calves in particular, may be more vulnerable to boat strikes than single individuals.

Observations of dugongs indicated that the response of individuals to boats is often influenced by the behaviour of other dugongs. In particular, when a few individuals were separated from the main herd, the separated individuals would cross the path of the boat to join the herd. Coordinated herd responses to boats, as described in Chapter 7, suggest that dugongs on the edge of the herd closest to the boat are more vulnerable to boat strike if distance is the key factor determining their response. If a dugong on the edge of the herd responds at the individually determined flee threshold and stimulates the response of the rest of the herd to respond at the same instant, the rest of the herd has more time to avoid the boat.

## **6.5 Conclusions and current situation**

Given that boaters usually cannot actively avoid dugongs, it is important to provide the animals with the maximum opportunity to avoid boats. The qualitative evidence given here suggests that dugongs have greater opportunity to avoid boats travelling below planing speed than boats above planing speed. Boat speed also reduces the impact of a boat strike and thus reduces the probability of dugongs being seriously injured or killed by boats. Thus speed limits in important dugong habitat areas are an appropriate management strategy for reducing the risk of boat strikes for dugongs.

This conclusion is supported by evidence in dugong mortality records. The majority of dugongs killed by boats in Moreton Bay have been found around the populated southern

Moreton Bay islands (Yeates & Limpus, 2002). Although this area supports a much smaller number of dugongs than the Moreton Banks, the area is frequented by water taxis, barges and larger (> 8 m) recreational vessels, which travel at high speed through boat channels (Yeates & Limpus, 2002; Groom *et al.*, 2004). The dugong carcasses found in this area display wounds that are most likely to have been inflicted by these large motorised vessels (Yeates & Limpus, 2002).

Images of dugongs being run over by boats in shallow water offer graphic evidence of their lack of response to boats travelling at high speed. No such evidence has previously been obtained for any marine mammal. This imagery has important implications for the management of dugong habitat areas and minimising mortality rates of dugongs. It provides clear evidence of the risk posed to dugongs by high-speed boats. A high rate of boater non-compliance with the speed limits on the Moreton Banks was recorded during this study (64% of boats seen speeding). It is important that managers find solutions for this problem and address possible reasons for non-compliance. I have made detailed recommendations in Chapter 9.

## 6.6 Chapter summary

- The number of dugong mortalities from boat strikes has increased in Moreton Bay over the last two years. As the number of boats along the Queensland urban coast increases, it is important that boat strikes of dugongs do not continue to increase as has occurred with manatees in Florida
- Twenty-five boats were observed passing within 50 m of dugongs herds. Four boats travelling above planing speed (i.e., above the legal speed limit on the Moreton Banks) were observed passing directly over the top of dugongs. A total of eight animals were run over in water depths ranging from 1.3 – 4 m.
- Dugongs crossed the path of nine boats, and appeared to be either heading towards deeper water or attempting to join the rest of the herd.

- I propose that the distance of the flee threshold for dugongs in response to approaching boats is independent of the speed of the vessel. Thus the time dugongs have to avoid boats is dependent on boat speed. This delayed response explains the vulnerability of dugongs to boat strike from high-speed boats.

# **Chapter 7**

## **Response of dugongs to boat traffic: the risk of disturbance and displacement**

**This chapter describes the controlled experiments I conducted to determine the response of dugongs to boats passing. I assess the impact of disturbance from boats according to the behaviour of individual dugongs as the control boat was passing in comparison to behaviour when there was no boat traffic. I also determine the proportion of time dugongs spend responding to boats within my study site according to the duration of herd and individual responses to boats, and the rate of opportunistic boat passes that occurred during this study.**



## **Chapter 7. Response of dugongs to boat traffic: the risk of disturbance and displacement**

### **7.1 Introduction**

Marine mammal populations continue to be threatened by direct human impacts such as hunting and incidental takes in fisheries, and are under increasing pressure from the indirect effects of habitat modification (Twiss & Reeves, 1999; Gales *et al.*, 2003). These indirect effects include pollution, reductions in food availability, disturbance and displacement from key habitats. As discussed in Chapter 6, boat traffic is an example of human activity which has the potential to both disturb and displace marine mammal populations. The behaviour of marine mammals is disturbed when they respond to the unfamiliar noise or perceived risk of boat strikes. Marine mammals can be displaced from their habitats when the cumulative effects of boat traffic produce a greater cost than the benefits of the resources available in the area. These effects include: (1) risk of death or injury from boat strikes (e.g., Ackerman *et al.*, 1995), (2) energy costs of disturbance interrupting feeding and social behaviours such as courtship and mating (Baker & Herman, 1989), and (3) noise preventing detection of other important sounds such as calls from conspecifics (Richardson *et al.*, 1995).

The greatest impact from boat traffic is not necessarily displacement. Animals can move to alternative habitat areas only when resources are available elsewhere. If animals can move to suitable habitat they may be less affected than animals forced to remain and tolerate the effects of disturbance (Gill *et al.*, 2001). Both the reduction of habitat availability and the costs of disturbance can affect the survival of individual marine mammals and therefore entire populations.

Most studies on the effects of boats have used short term behavioural changes in response to boats to predict long term impacts on marine mammal populations (Richardson *et al.*, 1995). In comparison with other marine mammals, there is a relatively large amount of literature on the behavioural responses of cetaceans to boats. These responses range from avoidance to approach (Richardson *et al.*, 1995). Some

typical reactions include changes in swim direction (e.g., Nowacek *et al.*, 2001b; Williams *et al.*, 2002), increased swim speed (e.g., Kruse, 1991), shorter surfacing times (e.g., Gordon *et al.*, 1992; Blane & Jaakson, 1994), longer interbreath intervals (e.g., Stacey & Hvenegaard, 2002; Lusseau, 2003a), reductions in inter-individual distances (e.g., Bejder *et al.*, 1999; Jelinski *et al.*, 2002), changes in the types of surface behaviours exhibited (e.g., Baker & Herman, 1989; Corkeron, 1995), a reduction in resting behaviour (e.g., Lusseau, 2003b; Constantine *et al.*, 2004), and an increase in breathing synchronicity between individuals (e.g., Hastie *et al.*, 2003).

Cetaceans display both inter- and intraspecific variability in both the nature and severity of their responses to boats. For example, belugas (*Delphinapterus leucas*), when disturbed by ice-breaking ships, take flight, form herds, perform shallow dives and emit alarm calls. In contrast, narwhals (*Monodon monoceros*) tend to freeze, submerge by sinking and remain silent (Finley *et al.*, 1990). Intraspecific variation in response to boat traffic is demonstrated by humpback whales (*Megaptera novaeangliae*) in Hawaii, where small pods and pods with calves are more likely to alter their behaviours than large pods or pods without calves (Baur, 1993). In New Zealand, sperm whales (*Physeter macrocephalus*) are more likely to respond to boats if they are non-resident, whereas resident individuals appear tolerant of boats, suggesting that the latter have habituated to them (Gordon *et al.*, 1992).

Behavioural responses often vary with the distance, number and behaviour of boats. For example, bowhead whales (*Balaena mysticetus*) are most likely to flee when a boat heads directly towards them at high speed (Richardson & Malme, 1993). Responses of bottlenose dolphins (*Tursiops truncatus*) increase when boat disturbance is repeated at short intervals (Evans *et al.*, 1992) and interbreath intervals increase as the distance to a passing boat decreases (Nowacek *et al.*, 2001b). The disturbance behaviours in belugas (Blane & Jaakson, 1994) and dusky dolphins (*Lagenorhynchus obscurus*) (Barr & Slooten, 1999) increase when boat numbers increase. In general, marine mammals tend to be most tolerant of boats moving at a consistent speed, and least tolerant of fast, erratically moving boats (Richardson *et al.*, 1995; McCauley *et al.*, 1996).

It is, therefore, important to distinguish between disturbance from boat traffic, and disturbance from tourist boats. General boat traffic consists of boats that are in the



vicinity of marine mammals with a purpose other than viewing these animals, and boat operators may not be aware of the animals' presence. Conversely, dedicated marine mammal tour boats actively search for marine mammals and seek to remain near them for extended periods of time. Thus the behaviour of these two types of boats is very different, and animals may perceive them differently.

As discussed in Section 6.4.1, parallels can be drawn between behavioural responses of animals towards disturbance from human activities such as vessel traffic, and anti-predatory behaviour (Berger *et al.*, 1983; Gill *et al.*, 1996; Frid & Dill, 2002; Cooper *et al.*, 2003). Studies have shown that animals adjust their response according to perceived risk of predation (Ydenberg & Dill, 1986; Lima & Dill, 1990; Bouskila & Blumstein, 1992; Abrams, 1994), which may be determined by the predators' speed (e.g., Estes & Goddard, 1967) and directness of approach (e.g., Dill, 1974), and the distance of the prey from a refuge (e.g., Cooper, 2003). If the perceived threat of boats differs according to the boat's behaviour, then the response of marine mammals to general boat traffic may differ markedly from the response to tourist boats. Such differences have been demonstrated in bottlenose dolphins, which are more likely to respond to boats following them, i.e., dedicated tour boats, than other boats (Acevedo, 1991; Janik & Thompson, 1996).

While short term behavioural responses to boats are relatively easy to assess, few studies quantify the long term effects of vessel traffic, such as displacement from areas of heavy boat traffic (Richardson *et al.*, 1995). Some exceptions include the movement of belugas in Bristol Bay, Alaska, from a river to a nearby bay when disturbed by boat noise (Stewart *et al.*, 1982). Vessel traffic may also have caused the disappearance of belugas in Cook Inlet, Alaska (Speckman & Piatt, 2000). Bottlenose dolphins in Florida show a preference for deeper channels rather than their primary foraging habitats on weekends when boat traffic densities are higher (Allen & Read, 2000). Declining catch rates of Baird's beaked whales (*Berardius bairdii*) have also been attributed to the whales changing their migration routes in response to vessel traffic in Japan (Nishiwaki & Sasao, 1977), although whale numbers may simply have reduced as a result of whaling.

Although most of the work on boat disturbance has concentrated on cetaceans, there is equal, and perhaps even greater potential for boat disturbance to affect sirenians. As herbivores, sirenians have a restricted habitat range that makes them particularly vulnerable to boat traffic. Their distribution is limited to the shallow and protected coastal or riverine areas where their forage is found (Heinsohn *et al.*, 1977; Hartman, 1979; Anderson, 1981a; Reynolds & Odell, 1991; see also Section 1.2.4). Similarly, most recreational boat traffic occurs in protected coastal areas, and through modifications in design, boats are increasingly able to travel in shallow water at high speed (Wright *et al.*, 1995). As discussed in Chapter 6, concern about the impact of boat traffic on sirenians has largely centred around the high incidence of boat strikes of the Florida manatee (*Trichechus manatus latirostris*). Approximately 25% or more of all known mortalities of manatees in Florida are caused by boat strikes (Marine Mammal Commission, 2004). Similarly, along the urban coast of Queensland, boat strike mortalities of dugongs are becoming increasingly common (Limpus *et al.*, 2003a; refer to Chapter 6) and dugongs are particularly vulnerable to boats travelling at high speed (Chapter 6).

Of the manatee species and subspecies, Florida manatees appear the most vulnerable to disturbance from boat traffic (Reynolds, 1999), as there are currently over 920,000 vessels registered in Florida (Florida Dept of Highway Safety & Motor Vehicles, n.d.). Boat traffic is also considered a potential threat to dugongs throughout a large proportion of their range, including at least 11 of the 37 countries and territories in which dugongs are found. In most of these places this threat includes both disturbance and displacement (Marsh *et al.*, 2002).

Both dugongs (Preen, 1992) and manatees (Nowacek *et al.*, 2001c; Nowacek *et al.*, 2001d) exhibit short term behavioural responses when boats are up to hundreds of metres away. Manatees appear to increase their activity level when initially detecting boats at large distances, indicating that they are disturbed by boats, but do not exhibit a dramatic avoidance response (Nowacek *et al.*, 2001d; discussed in Chapter 6). Obvious responses from manatees when boats are within 25 – 50 m are to increase swim speed and move towards deeper water (Nowacek *et al.*, 2001c). As discussed in Chapter 6, to date only qualitative observations of the response of dugongs to boats have been recorded (Anderson, 1981a; Preen, 1992). During cliff-top observations, Anderson

(1982) estimated that a dugong herd moved 500 m in response to a boat with an outboard motor passing slowly at a distance of 150 m from the herd. Preen (1992) suggested that dugongs could detect a speed boat from at least 1 km, but does not describe the behavioural responses indicative of detection.

Changes in the distribution of Florida manatees have been attributed to boat traffic (Provancha & Provancha, 1988; Buckingham *et al.*, 1999). Florida manatees appear to seek areas of low boat traffic, increasing their use of sanctuaries where boating is prohibited in correlation with increased boating outside sanctuaries (Buckingham *et al.*, 1999; Reynolds, 1999). There has, however, been no research on potential for the displacement of dugongs as a result of boat traffic, despite the persistent anecdotal reports from Indigenous hunters that such displacement has occurred in response to boat traffic in Torres Strait (Johannes & MacFarlane, 1991; Kwan, 2002). Preen (1992) also suggests that boat traffic may have reduced dugongs' use of the western side of Moreton Bay, however, seagrass loss has also occurred in this area (Abal & Dennison, 1996).

As explained in Chapter 6, in 2003 there were over 180,500 boats registered in Queensland, 97% of which were recreational boats (Queensland Transport, 2003). This represents a 35% increase in boat numbers since 1997 (Maritime Safety Queensland, 2004). This rapid increase in boating emphasises the importance of examining the potential for dugongs to be disturbed and/or displaced by boats, particularly as most recreational boating activity is concentrated in coastal areas to which dugongs are constrained by the nature of their feeding habits. In this chapter, I investigate the impact of boats on dugongs by observing their response to both experimental and opportunistic boat passes. These observations are then related to the 'undisturbed' behaviour of dugongs, described in Chapters 3 and 4, in an effort to assess the biological significance of disturbance responses.

## 7.2 Methods

I aimed to use experimental boat passes to test the effects of traffic density by varying the repetition of passes, and to determine whether sudden changes in engine noise

increases disturbance by varying the boat's driving pattern. However, my experimental boat passes were limited by the non-planing speed restrictions at the study site imposed by Queensland Parks and Wildlife Service, the cautious distance limits that I set to minimise the risk of my experimental boat hitting dugongs, and the use of a single boat type. Thus I also describe the responses of dugongs to independent or opportunistic boats (that is, boats that were not under my control, but that passed the monitored dugong herd while I was recording) as described in Chapter 6. These boats varied in type and approached the dugongs at a range of speeds and distances. These observations were useful for determining the risk of boat strikes to dugongs, as boaters were often unaware of the dugongs and passed through the middle of herds.

Experimental boat passes were conducted from 23<sup>rd</sup> June to 29<sup>th</sup> July 2002. All observations were conducted using the blimp-cam (Chapter 2). Data were extracted from video footage at the end of the field season. The methods used to observe responses to opportunistic boat passes are described in Section 6.2.

## **7.2.1 Controlled boat pass experiments**

### ***7.2.1.1 Protocol***

All boat pass experiments were conducted using a single boat (aluminium dinghy with 20 HP engine) to eliminate confounding variables and to enable me to achieve the required replication. The dinghy was towed to the study site behind the research vessel. Once the dugongs had been located and approached in the research vessel (Section 2.2.4.2), they were allowed to settle for a minimum of 10 min before I commenced the boat pass experiments. During this time the dinghy, operated by one of my crew members, was allowed to drift 1 km from the research vessel and dugong herd, where it was anchored until the experiment began.

A single experiment consisted of driving the dinghy from its anchored position, along a straight line to a point 1 km past the outer limit of the dugong herd (i.e., the dinghy was driven 2 km in total, Figure 7.1). The route of the pass was determined by the position of the two boats, the dugongs and other environmental factors such as glare and water depth. I aimed to maximise vision from the blimp-cam. To minimise the risk of hitting

dugongs, the dinghy operator was directed to pass the research boat at a distance that would keep the dinghy 50 m from the outer limit of the dugong herd. Observers on the roof of the research vessel alerted me if dugongs moved into the path of the dinghy during the experiment. I then used the blimp-cam to determine a safer path and either redirected the dinghy or terminated the experiment.

The speed of the experimental boat passes was approximately 7 knots. The following two variables were altered during the experiments to provide four possible treatments (Figure 7.1) as outlined below.

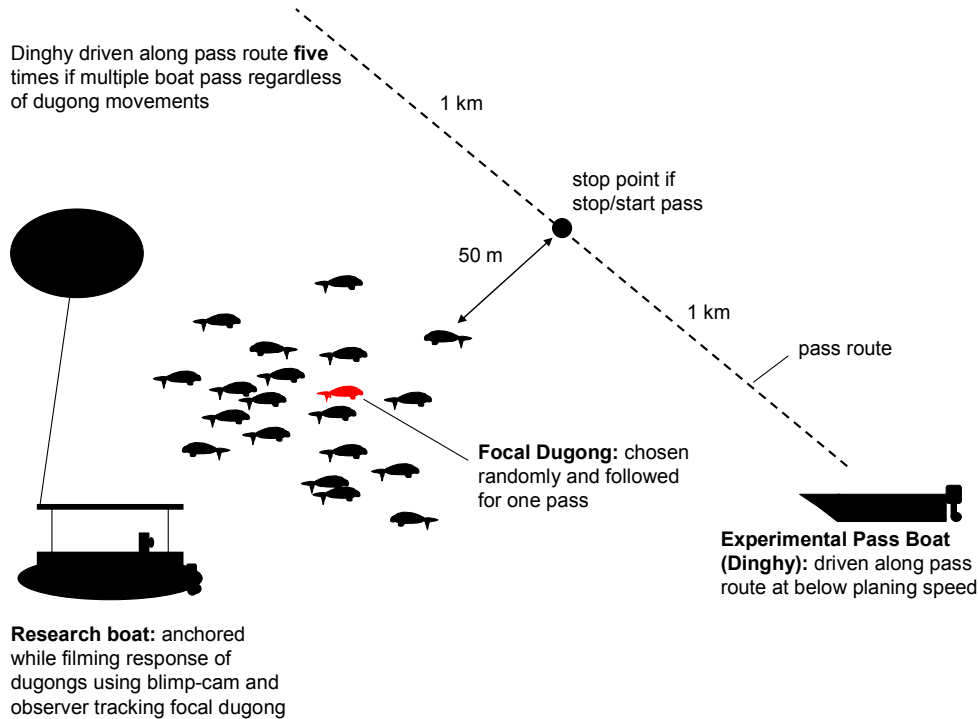
**(1) Number of repetitions**

- a. Single pass – The experiment was begun by switching the engine on. The dinghy was then driven along a straight line past the dugongs until it was 1 km from outer edge of herd, and the experiment was ended by switching the engine off.
- b. Multiple passes – As above, however the dinghy was driven back and forth along the same path until it had passed the dugongs *five* times. The experiment ended when the engine was switched off at the end of the fifth pass.

**(2) Continuity**

- a. Continuous pass – The boat was driven straight past the dugongs without changing speed. The engine was turned on at the beginning and off at the end of the experiment.
- b. Stop/start pass – When the dinghy reached its closest approach to the dugongs, the engine was switched off and on again immediately. The pass was then continued at the same speed and along the same route. The engine was also switched on at the beginning and off at the end of the experiment.

Over 19 days, four experiments (one of each treatment) were conducted each day with a minimum of half an hour between each experiment.



**Figure 7.1** Design of boat pass experiments. The two variables altered were pass number (single pass or multiple passes), and continuity (continuous pass at constant speed, or engine switched off and on when closest to dugongs).

During each individual pass, a focal dugong was randomly selected from the herd and followed. Visibility was the main factor influencing my selection with the aim of picking a focal animal that would remain visible throughout the pass. I avoided dugongs in or near patches of glare or the distance boundary of visibility of the blimp-cam. If the focal dugong was lost during the pass, a new individual was chosen and the pass continued. No obvious mother-calf pairs were chosen to minimise variability because of possible differences in the behaviour exhibited by these individuals. Where possible, each new individual was selected from a position in the herd different from the position where the previous follow had ended to minimise the risk of resampling individual dugongs. Herd sizes were usually large so the chance of resampling during a multiple boat pass was very small.

To aid in keeping the field of view constant when using the blimp-cam, a clear template was placed over the monitor with a square frame, 14 x 14 mm, in the centre. The zoom of the camera was continually adjusted so that the focal dugong filled the width of this

frame as described in Section 3.2.2. However, in this instance even though the size of the frame was chosen to allow the behaviour of the focal individual to be determined, many neighbouring dugongs could also be observed, which allowed assessment of the herd response.

### ***7.2.1.2 Estimating dugong locations***

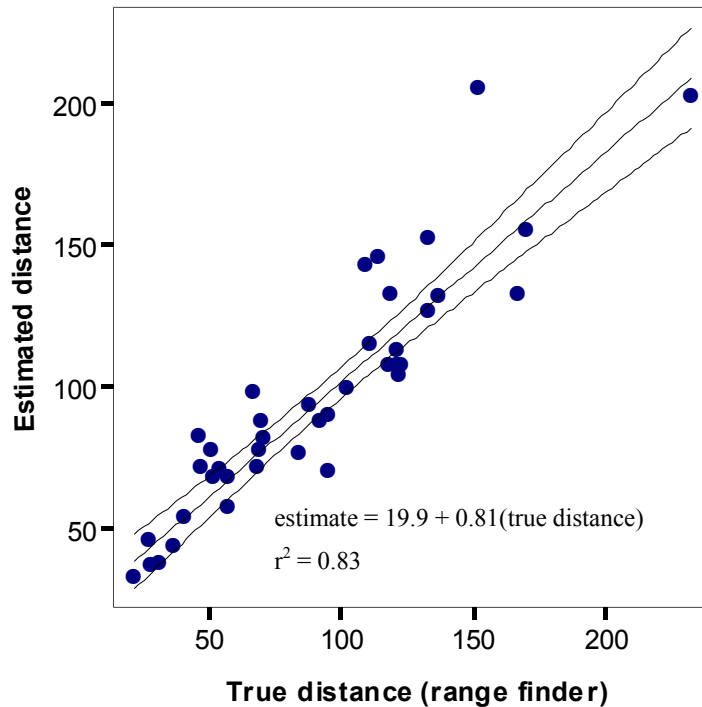
The movements of the focal individuals in relation to the dinghy were determined by obtaining a location of the dugong each time it surfaced. While following the dugong using the blimp-cam, I was able to tell an observer on the roof of the research boat when the individual was about to surface, along with information to distinguish it from other dugongs, such as an approximate location, the direction the dugong was facing and its proximity to other surfacing dugongs. The observer then visually estimated the approximate distance and bearing (using a compass) of the focal dugong from the research boat.

### ***7.2.1.3 Measuring distances***

#### ***7.2.1.3.1 Training and error in estimates***

In order to maximise the reliability of these distance estimates, the observer was trained prior to beginning the boat pass experiments by using a laser range finder on dugongs (when close enough), and other objects. After such training, the observer's accuracy was tested by asking her to estimate a range of distances which were checked using a laser range finder. The differences between the two were calculated to obtain an average error. Because of time constraints this test was conducted only once before any experiments had been carried out. Forty distance estimates were recorded by the observer and checked using a laser range finder. There was a high correlation between the true distance and the estimated distance ( $r^2 = 0.83$ , Figure 7.2). The average error was 15 m within a range of 1 to 51 m. Unfortunately I did not test the capacity of another observer used during the experiments, so this estimate of error is generic rather than observer-specific.

During the experiments, the observer was occasionally able to use the range finder on the focal individual, although dugongs did not remain at the surface long enough to use this method consistently. Additional aids to improve the observer's accuracy of estimating distances during the experiments included using the range finder on the dinghy as it was passing and on any other dugongs that were surfacing near the focal animal.



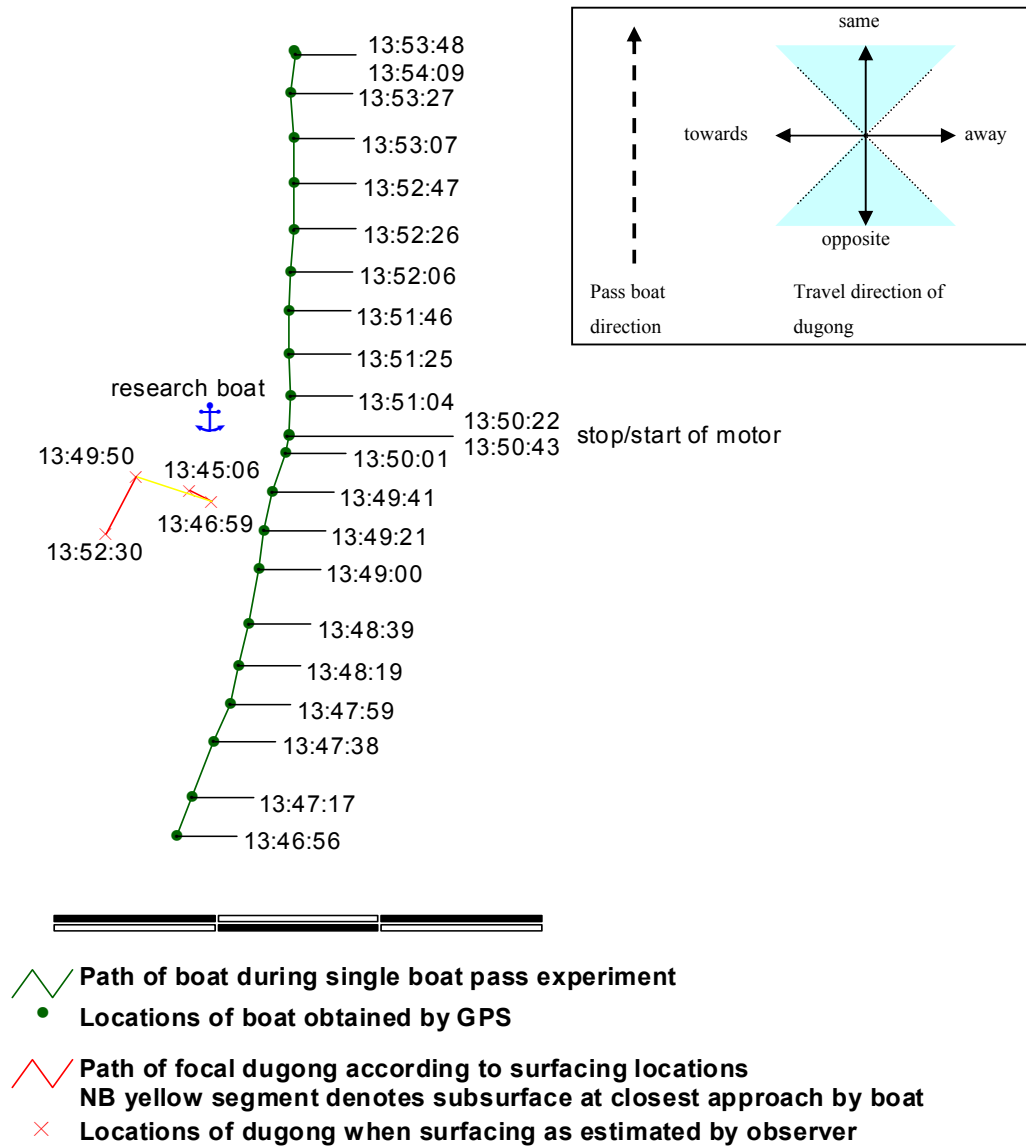
**Figure 7.2** Correlation between the true distance of dugongs or objects obtained using a laser range finder, and the distance estimated by a trained observer. The regression line is presented with 95% confidence limits.

#### 7.2.1.3.2 Plotting locations of boats and dugongs

The GPS location of the research boat (obtained with a Garmin GPS II Plus) was recorded at the beginning of each experiment. The dinghy's route was tracked using a second GPS, which logged the speed, direction, and location of the dinghy every 20 sec. All GPS locations were plotted on a map of Moreton Banks using ArcView GIS 3.3. I used the Distance/Azimuth Tools (v 1.4a) extension (freeware from [www.jennessent.com](http://www.jennessent.com), 2003) to calculate the GPS locations of each focal dugong according to its distance and bearing from the research boat. Figure 7.3 is an example



map showing the dugong and dinghy's tracks and the real time of each location point. The distance of the surfacing dugong from the dinghy could then be calculated.



**Figure 7.3** Example of dugong and dinghy tracks during a single, stop/start boat pass experiment. Insert showing classifications for travel direction of dugong relative to travel direction of dinghy.

7.2.1.3.3 Considering GPS and distance estimate error

I assumed that the total error of the estimates of the distances between the dugong and the dinghy consisted of: (1) 2 x GPS unit error  $\leq 15$  m (according to specifications of GPS unit as outlined in the manual), and (2) error of estimating the distance from the

research vessel to the focal dugong, which averaged 15 m. Some errors were likely to cancel each other out. Thus the maximum error was assumed to be 45 m. It was not feasible to incorporate this error into the results, however my distance estimates should be considered with this error in mind.

#### ***7.2.1.4 Distance of closest approach***

By using the plotted tracks of the focal dugong and the dinghy for each boat pass, I determined the shortest possible distance between the dinghy and the dugong during each subsurface. The subsurface interval during which the distance between the dugong and the dinghy was the shortest (closest approach) for each boat pass, is presented in the results (e.g., Figure 7.3). Although the dinghy was driven past the dugong herd at a distance of 50 m, the known closest approach varied considerably for two reasons:

- (1) the focal dugong could be anywhere within the herd at the beginning of the pass and could therefore be greater than 50 m from the path of the dinghy, and
- (2) the focal dugong moved during the pass and could therefore be greater or less than 50 m from the path of the dinghy.

#### ***7.2.1.5 Subsurface characteristics of focal dugong***

##### *7.2.1.5.1 Characteristics*

Four characteristics of the focal dugong's subsurface behaviour during the time of closest approach by the dinghy were recorded:

- (1) Subsurface time – the time between two respiration surfacings (obtained from video footage),
- (2) Travel distance – the straight line distance travelled between the two respiration surfacing points (obtained using GIS; Figure 7.3),
- (3) Travel direction relative to dinghy – the travel direction of the focal dugong, classified into five categories according to the projected path of the dinghy, whereby the dugong was either heading (within 90 degrees) in the 'same' or 'opposite' direction, or 'towards' or 'away' from the boat, or, if two

successive surfaces were in the same spot, the direction was classified as ‘none’ (obtained using GIS; Figure 7.3), and

- (4) Behaviour – the behaviour(s) exhibited by the dugong, classified into broad behaviour categories (see Section 3.2.2). Only travelling and feeding behaviours were considered in the analysis as the sample sizes for the other behaviours were very small (socialising, resting and rolling comprising only 9 min of a total 3 h 25 min of observations).

#### *7.2.1.5.2 Analysis of Behaviour*

A chi-squared homogeneity test was conducted to determine whether the presence of a boat and its minimum distance from the focal dugong during the boat pass experiments affected the behaviour of the focal dugong during the single subsurface interval sampled. One-tailed Fisher’s exact tests were used to test whether dugongs were more likely to be feeding (and not travelling) when there was no boat than when a boat was present, and when the boat was passing beyond 50 m rather than within 50 m.

To test the response of the focal dugong according to its travel direction, the distance of the dinghy was classed as either < 50 m, 50 – 200 m, or > 200 m. Bearing categories were grouped as ‘same/away’ and ‘towards/opposite/none’. The former grouping was considered to be indicative of a response to the boat, and the latter grouping of no response, as mass movements of dugongs in response to boats were usually away from the boat. I used a Pearson’s chi squared analysis to determine whether there was an effect of distance on the likelihood of dugongs responding to the boat.

#### ***7.2.1.6 Dugong behaviour throughout focal follows***

##### *7.2.1.6.1 Protocol*

The protocol for conducting focal follows on individual dugongs where no boat was present was similar to that used for boat pass experiments (outlined above) and is described in detail in Section 3.2.2.

#### 7.2.1.6.2 *Sampling period*

For the purposes of comparing the behaviour of dugongs during undisturbed focal follows, (defined as no boat within 500 m), and during controlled boat passes, a 4.5 min sample was taken of all follows. This was the minimum time taken to conduct one boat pass. For all boat passes, the middle 4.5 min of the follow was used to include the time during which the dinghy was closest to the dugong. Any passes where the same individual was not followed for the full 4.5 min were omitted from the analysis. For all undisturbed focal follows (all > 5 min), the first 4.5 min of the observation were used in the analysis described below.

#### 7.2.1.6.3 *Herd position*

I scanned all dugongs visible at the beginning of each pass to determine the position of the focal dugong within the herd. The individual's position was classified as either:

- (1) Within main herd – within largest group visible where all individuals were within approximately three body lengths of one another
- (2) Within subgroup – within a group smaller than the main herd, which was separated from the main herd by more than 3 body lengths and within which all individuals were within three body lengths of one another
- (3) Scattered – not within three body lengths of any other dugong

#### 7.2.1.6.4 *Analysis*

Six two-way ANOVAs were conducted to compare the effects of various factors on: (1) the proportion of time each focal individual spent travelling and (2) the proportion of time each focal individual spent feeding. The between-subjects factor was either: (1) boat presence, (2) pass number, or (3) pass continuity. The within-subjects factor was herd position (either in the main herd, subgroup or scattered as described above) in each analysis. When examining the effects of the number of boat passes conducted, only the results from the first, fourth and fifth passes were used as these were most likely to show a significant result if dugongs responded to the first time they heard the boat, or became sensitised to boat noise throughout the experiments. The percentage of time spent feeding was square root transformed in order to meet the assumption of normality

of variance in all three ANOVAs testing this response. As discussed in Section 4.2.1.4, with a large number of tests there is a high probability of Type I error. Again I have reported actual P values and interpreted significant results with caution, rather than adjusting P values.

## **7.2.2 Duration of herd responses to boats**

### ***7.2.2.1 Protocol***

As outlined above, although focal individuals were followed during boat pass experiments, the zoom of the camera was kept wide so as to view as many other dugongs as possible, while still allowing identification of behaviours of the focal individual. Herds were usually too large to view all dugongs at once, so the response of the herd to the passing boat was assessed based on the subset of the herd that I videoed. During opportunistic passes, I stopped focal follows and panned the camera to record the response of the herd.

### ***7.2.2.2 Criteria for assessing herd response***

The herd response to both experimental and opportunistic boat passes was assessed only if: (1) most dugongs were feeding with obvious plumes before the boat passed, which made it possible to eliminate the effects of varying activity states between passes (Williams *et al.*, 2002), and (2) the herd consisted of more than 10 individuals. When dugongs conducted behaviours other than feeding with plumes or the behaviours within the herd were diverse, responses were less obvious and difficult to time.

### ***7.2.2.3 Measuring length of response***

Dugongs were considered to be responding to a passing boat if most of the herd interrupted their feeding to move, and then resumed feeding. The length of the response was defined as the time between the onset and cessation of travelling, where:

- onset = the instant when I visually estimated that over 50% of the herd stopped feeding and started travelling, and

- cessation = the instant when I visually estimated that over 50% of the herd had stopped travelling and resumed feeding.

This protocol was checked by three observers experienced in dugong aerial surveys and who thus had experience in viewing dugongs from this aerial perspective. They agreed that the onset and cessation of movement could be unambiguously timed by a person experienced in observing dugongs using blimp-cam.

If the dugongs were not visible at either the onset or cessation of the response (e.g., the camera was panning around or the dugongs moved too far away), the response time was recorded according to the time when the dugongs were first or last seen travelling. All herd movements occurring while boats were present were assumed to be a response to the boat rather than to individual interactions within the herd. If two herd movements occurred during an experimental boat pass (i.e., over 50% of the herd travelled, went back to feeding, travelled once again, and finally resumed feeding), both movements were assumed to be in response to the boat and the estimated times of each response were combined to obtain the total duration of time responding to that particular pass.

I measured the response times for all boat passes twice, with a time interval of four weeks to reduce bias from memory of the first evaluation. Thus the error value for these measurements is the difference between the times recorded during the first and second evaluations, and is presented with my response duration estimates.

#### **7.2.2.4 Analysis**

To determine if there were any differences between the response times estimated in the repeat evaluations above, the times were compared using a paired t test. The overall average duration of responses was calculated using the averages of the two evaluations for each pass.

The response times obtained during opportunistic boat passes were classified according to whether the boat approach distance was less than or greater than 50 m. These two subsets of data had unequal variances even when transformed. They were compared using a one-tailed Mann-Whitney test where the null hypothesis was that the duration of response was not greater when boats passed within 50 m than if the boats did not come

within 50 m. Opportunistic passes were also categorised as fast (above planing speed) or slow (below planing speed). I used a t test to determine whether there was a difference in response time according to boat speed.

### **7.2.3 Duration of individual responses to boats**

To further investigate the duration of time spent responding to boats, I measured the response of focal individuals during boat pass experiments. Only those passes used in the above analysis where herd responses were observed were used to record individual response times. The length of the response in this case was defined as the time between the onset and cessation of any travelling behaviour conducted by the focal individual that coincided with the herd response. Time spent surfacing (defined in Appendix 3) was not included if the surfacing behaviour represented a switch between feeding and travelling behaviours, but was included if the individual was travelling before and after surfacing.

#### ***7.2.3.1 Analysis***

I conducted a paired t test to determine whether there was a difference in the time spent responding to an experimental boat pass by the focal individual in comparison with the whole herd.

### **7.2.4 Limitations**

Analyses of data from boat pass experiments was limited by the sample size of passes for each combination of variables. There were too few data to conduct more sophisticated tests than those outlined above. I have interpreted my results with this in mind.

All results are provided as means  $\pm$  standard errors.

## 7.3 Results

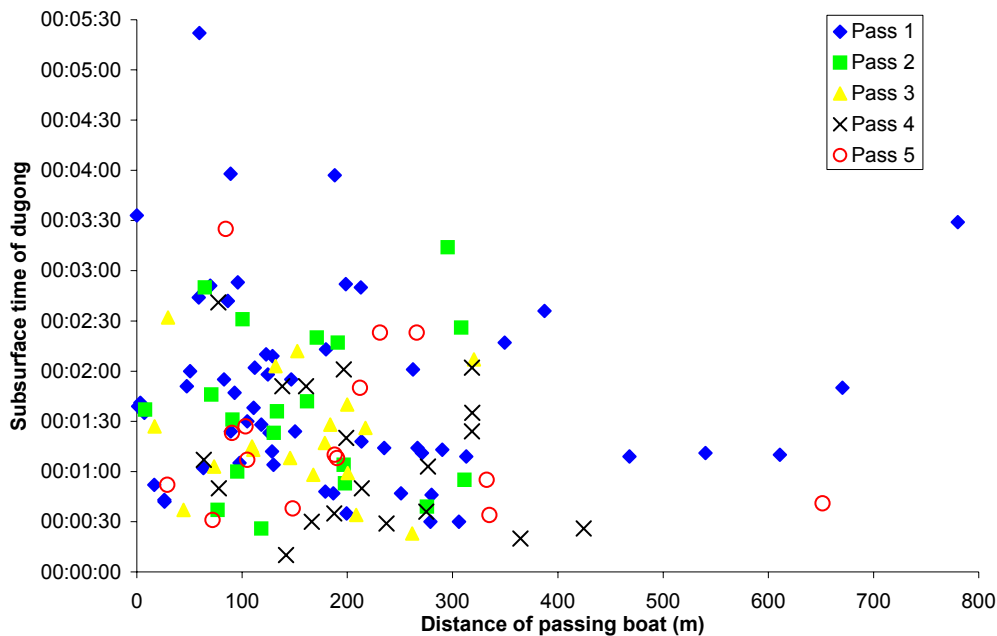
The results of the opportunistic observations are described in Chapter 6.

### 7.3.1 Controlled boat pass experiments

#### 7.3.1.1 Subsurface characteristics of focal dugong

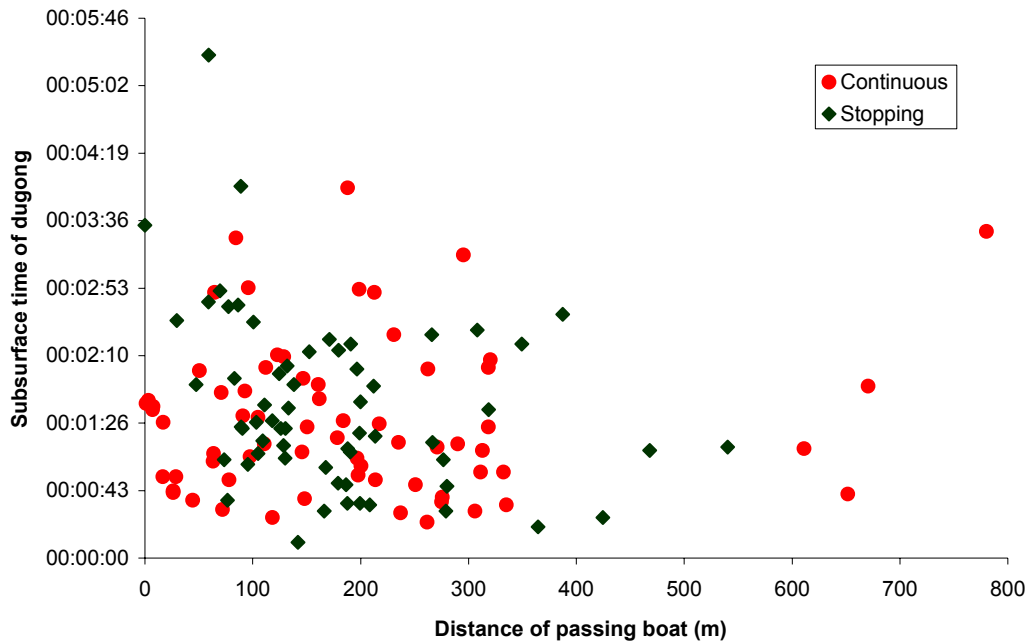
##### 7.3.1.1.1 Subsurface time

The subsurface times of focal dugongs during the control boat's known closest point of approach were extremely variable, ranging from 10 to 322 s. There was no relationship between the distance of the dinghy and the dugong's subsurface time (Figures 7.4 and 7.5). Nor were the subsurface times affected by the number of times the dinghy had passed, and the continuity of the pass.



**Figure 7.4** The subsurface time (length of time between two successive respiration surfaces) for the focal dugong at the time of closest approach by the dinghy during each boat pass, with all single boat passes classified as 'pass 1', and a different symbol representing each successive pass for multiple boat passes.





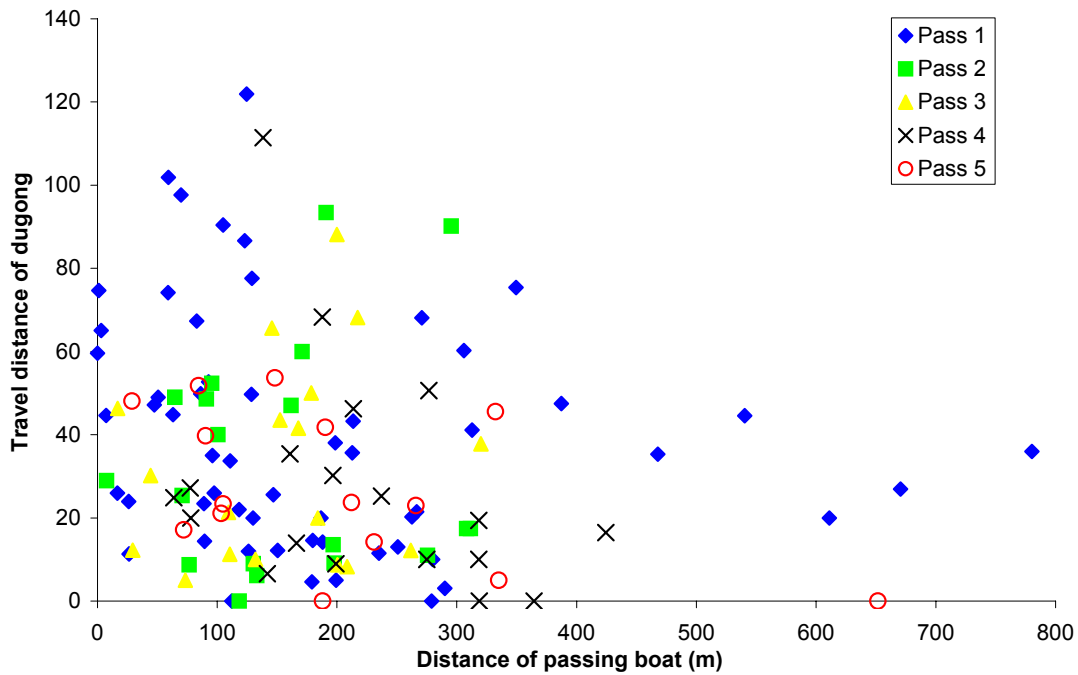
**Figure 7.5** The subsurface time (length of time between two successive respiration surfaces) for the focal dugong at the time of closest approach by the dinghy during each boat pass, classified into either continuous passes or passes with one complete stop at the halfway point.

#### 7.3.1.1.2 Travel distance

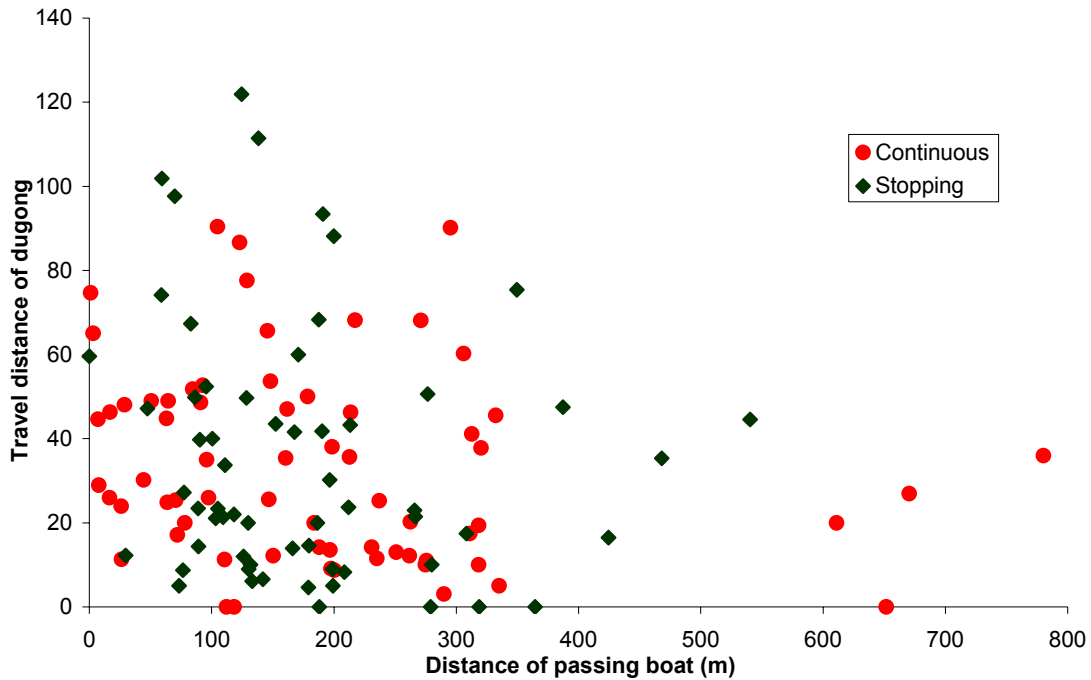
The distance travelled by focal dugongs during the subsurface interval at the time of the closest approach by the dinghy ranged from 0 to 122 m. This distance was not affected by the distance of the dinghy, pass number or pass continuity (Figures 7.6 and 7.7).

#### 7.3.1.1.3 Travel direction relative to distance of dinghy

The distance of the experimental boat did not affect the travel direction of the dugongs. There was no significant difference in the likelihood of dugongs responding by swimming in the same direction or away from the boat compared according to the three distance categories (Table 7.1;  $\chi^2 = 2.96$ ,  $df = 2$ ,  $P = 0.23$ ).



**Figure 7.6** The travel distance of the focal dugong between two successive respiration surfaces at the time of closest approach by the dinghy during each boat pass, with all single boat passes classified as ‘pass 1’, and a different symbol representing each successive pass for multiple boat passes.



**Figure 7.7** The travel distance of the focal dugong between two successive respiration surfaces at the time of closest approach by the dinghy during each boat pass, classified into either continuous passes or passes with one complete stop at the halfway point.

**Table 7.1** Travel direction of dugong relative to passing dinghy compared with the distance of the dinghy. Observed frequencies with expected frequencies in brackets.

	<b>No Response:</b> Towards/Opposite/None	<b>Response:</b> Same/Away
Boat < 50 m	5 (4.9)	8 (8.1)
Boat 50 - 200 m	23 (27.4)	50 (45.6)
Boat > 200 m	20 (15.8)	22 (26.3)

#### 7.3.1.1.4 Behaviour according to presence and distance of boat

The focal dugongs spent most of their time feeding and travelling. The behaviour of the focal dugong during the subsurface interval that corresponds with the closest approach by the dinghy for each pass, and the first full subsurface interval of each focal follow with no boat present, was recorded as either feeding only, travelling only, or travelling and feeding (Table 7.2). The behaviour of the focal dugong was affected by boat presence / distance ( $\chi^2 = 13.37$ ,  $df = 6$ ,  $P = 0.04$ ).

**Table 7.2** Number of focal dugongs exhibiting feeding and travelling behaviour during the single subsurface interval at the experimental dinghy's closest approach distance, compared with the behaviour of dugongs during the first full subsurface interval during focal follows when no boats were present. Observed frequencies with expected frequencies in brackets.

	Feeding Only	Travelling Only	Travelling and Feeding
Boat < 50 m	0 (2.14)	6 (3.42)	1 (1.44)
Boat 50 – 200 m	7 (8.55)	13 (13.68)	8 (5.77)
Boat > 200 m	8 (3.66)	2 (5.86)	2 (2.47)
No boat	25 (25.65)	43 (41.04)	16 (17.31)

Although the proportion of dugongs classified as feeding only was not significantly affected by the presence of a boat (Table 7.3; Fisher's exact one-tailed test,  $P = 0.37$ ), it was significantly lower when boats passed within 50 m rather than beyond 50 m (Table 7.4; Fisher's exact one-tailed test,  $P = 0.03$ ). Thus dugongs were less likely to remain feeding when boats passed within 50 m than if the boats passed further away.

**Table 7.3** Number of dugongs recording feeding only or exhibiting some travelling during the subsurface interval at the boat's closest approach during boat pass experiments compared with undisturbed dugongs.

	Feeding Only	Some Travelling
Boat Passing	15	32
No Boat	25	59

**Table 7.4** Number of dugongs recording feeding only or exhibiting some travelling during one subsurface interval at the boat's closest approach during boat pass experiments when boats were less than or greater than 50 m from the focal dugong.

	Feeding Only	Some Travelling
Boat < 50 m	0	7
Boat > 50 m	15	25

### 7.3.1.2 Dugong behaviour throughout focal follows

#### 7.3.1.2.1 Possible bias

The main problem when attempting to use focal follows to determine the effects of boats was that dugongs travelling away from the passing boat may have been lost from view, biasing sampling towards dugongs that were not disturbed, thereby reducing the likelihood of observing an effect of the boat. All focal follows (with no boat passing and during boat pass experiments) that lasted less than 4.5 mins were classified according to whether or not the dugong was lost because it moved too far away. Undisturbed focal follows (no boat) were cut short as a result of dugongs travelling beyond my field of view in 26% (N = 97) of cases, while during boat pass experiments only 19% (N = 75) were lost for this reason. Therefore, I have assumed that these results were not biased towards dugongs that responded to the passing boat.

#### 7.3.1.2.2 Combined effects of passes and herd position

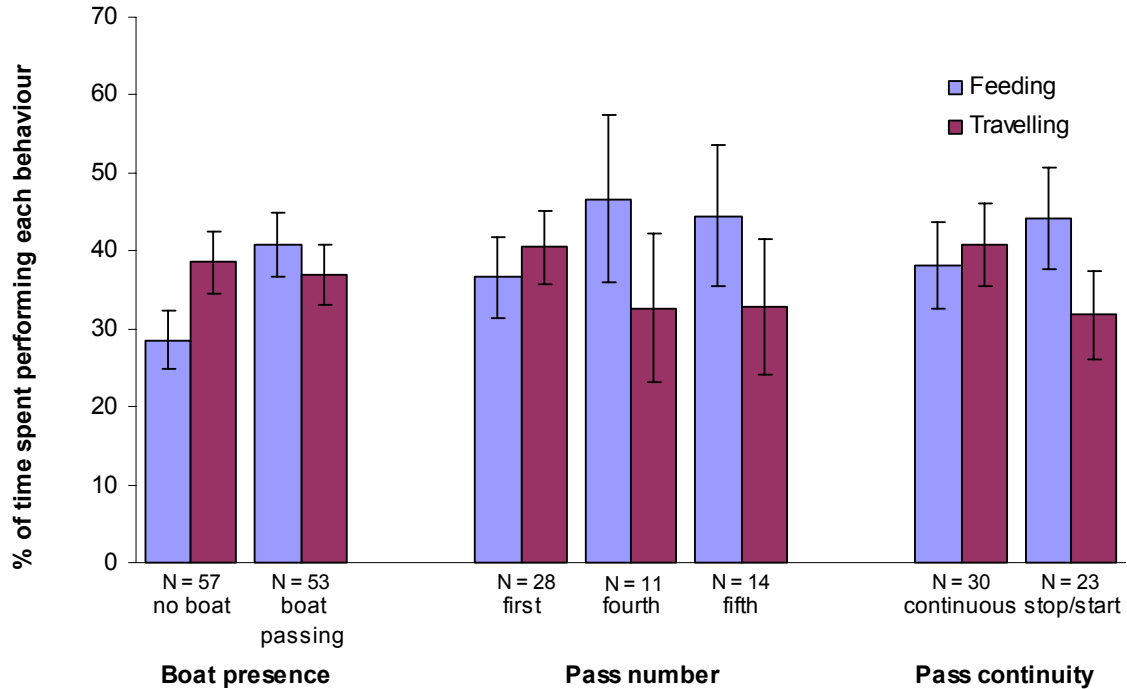
The interactions between herd position and boat presence, pass number and pass continuity were not significant (Table 7.5). All six ANOVAs showed a significant effect of the position of the focal animal within the herd on feeding and travelling behaviour (Table 7.5). This effect is discussed in Chapter 4.

Boat presence did not significantly affect feeding behaviour. Dugongs actually spent a higher proportion of time feeding during the 4.5 min focal follows when the control boat was passing, than during normal follows when no boat was present (Figure 7.8), however this difference was not significant (Table 7.5). The proportion of time spent travelling was also unaffected by boat presence (Table 7.5; Figure 7.8).

There was no significant effect of pass number on the proportion of time spent feeding or travelling when considering the first, fourth and fifth passes (Table 7.5; Figure 7.8). Similarly the continuity of the boat pass (continuous, or with a stop and start halfway) had no effect on dugong feeding or travelling behaviour (Table 7.5; Figure 7.8).

**Table 7.5** Results of six ANOVAs testing the effect of experimental boat passes on the feeding and travelling behaviour of focal dugongs. Three between-subjects factors were tested: (1) boat presence - whether or not the experimental boat is passing, (2) pass number - one, four or five, and (3) pass continuity - continuous or stop/start. The common within-subjects factor is herd position (within main herd, sub-group or scattered).  $P < 0.05$  bolded.

Dependent Variable	Source of Variance	df	Mean Squares	F	P
Proportion of time feeding	Boat Presence	1	6.74	0.80	0.37
	Herd Position	2	107.26	12.68	<b>0.00</b>
	Boat Presence * Herd Position	2	3.85	0.46	0.64
	Error	104	8.46		
	Pass Number	3	2.57	0.30	0.83
	Herd Position	2	89.87	10.47	<b>0.00</b>
	Pass Number * Herd Position	6	6.65	0.78	0.59
	Error	98	8.58		
	Pass Continuity	2	3.10	0.37	0.69
	Herd Position	2	102.86	12.21	<b>0.00</b>
	Pass Continuity * Herd Position	4	6.53	0.78	0.54
	Error	101	8.43		
Proportion of time travelling	Boat Presence	1	80.47	0.10	0.75
	Herd Position	2	3164.07	3.92	<b>0.02</b>
	Boat Presence * Herd Position	2	85.74	0.11	0.90
	Error	104	808.15		
	Pass Number	3	194.55	0.24	0.87
	Herd Position	2	3435.11	4.24	<b>0.02</b>
	Pass Number * Herd Position	6	592.12	0.73	0.63
	Error	98	810.28		
	Pass Continuity	2	715.56	0.88	0.42
	Herd Position	2	3445.43	4.26	<b>0.02</b>
	Pass Continuity * Herd Position	4	200.29	0.25	0.91
	Error	101	809.77		



**Figure 7.8** Percentage of time during a 4.5 min sample spent feeding and travelling by the focal dugong according to boat presence, the number of successive passes made by the experimental boat, and the continuity of passes. Bars depict SE.

### 7.3.2 Duration of herd responses to boats

Dugong herds exhibited mass movements in which the majority (> 50%) of the herd interrupted their feeding, and travelled (cruising, Appendix 3) in a coordinated group, and then resumed feeding. A total of 26 experimental boat passes, and 16 opportunistic boat passes satisfied the criteria for assessing herd response. The average times spent responding to boats are shown in Table 7.6. The duration of each response according to my first and second measurements one month apart (see Section 7.2.2.3 for details) were not significantly different ( $t = -0.74$ ,  $df = 41$ ,  $P = 0.46$ ).

**Table 7.6** The average duration of herd responses (in seconds) to boats on the first and second estimation occasions, and the overall average according to the mean of the two estimates for each boat pass. The average error according to the two estimates for each pass are given for the onset and offset of each response.

	Evaluation			Time Error	
	1 <sup>st</sup>	2 <sup>nd</sup>	Overall Average	Onset	Cessation
Duration of response (s)	121	123	<b>122</b>	5	9

Of the 16 opportunistic boat passes for which the duration of the herd response was timed, ten approached within 50 m of the herd (Table 7.7). The approach distances of the remaining six boats ranged from <100 m to >500 m. The mean duration of responses to opportunistic boat passes within 50 m ( $117 \pm 15$  s) was not significantly different from the response time when boats passed at distances great than 50 m ( $161 \pm 34$  s; Mann-Whitney  $U_{0.05(1),6,10} = 26$ ,  $P = 0.71$ ). The water depth near the herd was < 2 m for all but one opportunistic boat pass. Five of the 16 boats were travelling above planing speed. Dugongs spent more time responding to boats that were travelling below planing speed (mean =  $169 \pm 29$  s) than to those travelling above planing speed (mean =  $90 \pm 21$  s), although this difference was not significant ( $t = 1.70$ ,  $df = 14$ ,  $P = 0.11$ ).

**Table 7.7** The duration of the response by feeding dugong herds and details of each opportunistic boat pass in response to which dugongs exhibited mass movements that could be timed.

Case	Duration of Response (s)	Distance of Boat (m)	Water Depth (m)	Propulsion Type	Speed <sup>a</sup>
1	0:59	> 500	1.8	outboard	fast
2	2:46	> 500	1.1	outboard	fast
3	6:12	< 50	1.0	outboard	slow
4	1:52	> 500	1.3	outboard	slow
5	3:00	< 50	1.9	outboard	slow
6	1:47	100-500	1.6	outboard	slow
7	1:50	> 500	2.0	inboard	fast
8	0:45	< 50	4.0	outboard	fast
9	3:15	< 50	1.0	outboard & sail	slow
10	1:29	< 50	1.6	outboard	slow
11	2:32	50-100	1.8	inboard	slow
12	1:13	< 50	1.9	outboard	fast
13	1:07	< 50	1.9	outboard	slow
14	1:09	< 50	1.5	outboard	slow
15	4:38	< 50	1.6	sail	slow
16	4:03	<50	2.1	outboard	slow

<sup>a</sup> 'Fast' refers to boats that are planing, 'slow' indicates boats that were not planing

### 7.3.3 Duration of individual responses to boats

Successful focal follows (follows that lasted for > 4.5 min) were achieved in 20 of the 26 experimental boat passes for which the herd response could be timed. The average time spent responding by the focal individual was 92 s. This time was not significantly different from the average herd response time during boat pass experiments (paired  $t = 0.51$ ,  $df = 19$ ,  $P = 0.62$ ).

## **7.4 Discussion**

### **7.4.1 Summary of responses**

In general, the behaviour measured for individual dugongs during experimental boat passes was not affected by the boat passing unless the boat was within 50 m. Dugongs were significantly less likely to continue feeding during the subsurface interval that corresponded with the closest approach by the boat when the approach distance was less than 50 m than if the boat passed beyond 50 m from the individual dugongs. Subsurface times, travel distances and travel directions of focal dugongs during this subsurface interval were not correlated with the distance of the boat. The proportion of time spent feeding and travelling by focal dugongs during a 4.5 min time sample did not differ during experimental boat passes when compared with undisturbed dugongs. Neither multiple passes nor passes where the engine noise was altered by stopping and starting the boat were more likely to elicit a response than single or continuous passes respectively.

Herd responses to boats passing opportunistically and during experiments could only be measured when feeding was interrupted and most of the herd moved and then resumed feeding. On average dugong herds spent 122 s responding to boats before they resumed feeding. The herd response times were reflected in the response times measured for the focal individual within the feeding herd, which average 92 s. The duration of herd responses to opportunistic boat passes was not affected by the distance of the boat from the herd (< or > 50 m), although most of the mass movements observed occurred in response to boats within 50 m. Response times were also unaffected by the speed of the boat. However, it should be noted that the small sample size of timed herd responses may have limited the power to detect differences in response durations according to both the distance and speed of boats.

### **7.4.2 Response in relation to boat distance**

The fact that most of herd responses were recorded when boats were opportunistically passing within 50 m, corresponds with the reduction in feeding behaviour observed



when the experimental boat passed within 50 m. Similarly, the response of Florida manatees to boats is typically initiated when the boat is at a distance of 25 – 50 m (Nowacek *et al.*, 2001c). This delayed response by dugongs supports the hypothesis that the susceptibility of dugongs to boat strikes is dependent on boat speed, as this short response distance leaves them little time to evade high-speed boats. The implications of, and possible reasons for, this delayed response are discussed in Section 6.4.

Despite the obvious effects of distance described above, there was no correlation between the distance of individuals to the experimental boat and the subsurface interval, travel distance and travel direction relative to the pass boat. Although the combination of herd position and boat presence did not affect the proportion of time spent feeding or travelling by individuals, it is possible that herding behaviour negated the influence of boat distance on the observed response of individuals. The mass herd responses to boats passing suggest that the likelihood of an individual responding to the boat depends not on the distance of the individual to the boat but the distance of the whole herd. The combined effects of variations in herd composition and variations in individual responses to boats may have also influenced the probability of a herd response, an effect similar to the presence of calves in the response of humpback whale pods to boats (Baur, 1993). Florida manatees displayed individual variation in response to boats, which, as suggested by (Nowacek *et al.*, 2001c), may be ascribed to age, exposure to boats, reproductive state or activity. Although individuals could not be identified during my study, herd composition certainly varied as the number of individuals present differed on different days during the experiment.

I saw dugong herds making four mass movements that appeared to be a response to independent boats passing more than 500 m away. During aerial surveys, Preen (1992) also observed dugongs responding to boats at a distance of over 1 km. I can only cautiously assume that the dugongs were responding to the boats, as mass movements also occurred in response to individual interactions within the herd (*pers. obs.*). Thus more observations of the behaviour of dugongs while boats are passing are needed to confirm that they are disturbed at these distances. In a preliminary study of Antillean manatee (*Trichechus manatus manatus*) responses to experimental boat approaches using digital acoustic data logger tags (DTAGs), as discussed in Section 6.1, increased activity indicated that a manatee detected a boat at approximately 800 m away

(Nowacek *et al.*, 2001d). Similarly, more research is needed to confirm these initial observations of manatees.

Considering that it is likely that both dugongs and manatees can sometimes detect boats in the order of hundreds of metres away, the question that remains is, what factors determine detection distance and the response of the animals? Many factors affect the noise level received by dugongs, including the engine type, boat speed, and environmental factors such as water depth (Richardson *et al.*, 1995; McCauley *et al.*, 1996). In this study, three of the four boats which apparently elicited a response from more than 500 m away were outboards and one an inboard. One was travelling below and three above planing speed, and dugongs were in < 2 m of water on all four occasions. More observations are clearly needed to produce conclusive results or identify general trends.

Without knowing the sound level being received by the dugongs, it is impossible to know whether they respond to all boats detected, or whether some boats are detected but elicit no response. As discussed above, herd composition and individual variation may have influenced the probability of dugongs responding to boats at long distances. Studies using DTAGs (Nowacek *et al.*, 2001d) may provide insight into the detection abilities and responses of dugongs at large distances. Dugongs may respond to all boats, but only exhibit observable responses once boats are within a certain distance. This is the case with manatees, which may increase activity levels in response to boats hundreds of metres away, but observable responses are more likely when boats are within 50 m (Nowacek *et al.*, 2001c; Nowacek *et al.*, 2001d). In my study, dugong herds may have moved in response to boats more than 500 m away, but flight responses appeared to occur at the last moment before dugongs were about to get run over (Section 6.4).

### **7.4.3 Response in relation to water depth**

Preen's (1992) uncontrolled and anecdotal observations during aerial surveys indicated that dugongs in deeper water show little response to boats compared with dugongs in < 2 m of water. Preen's (1992) behavioural observations and water depth estimates would have been limited by the height of the plane, however he could have observed similar

mass movements to those described here. Although I observed herd responses to boats in water  $> 2$  m only on three occasions, the shortest of all response times (45 sec) was recorded for a herd in water 4 m deep. Thus boats may disturb dugongs less in deep water than shallow water. The response of Florida manatees is also affected by water depth, with changes in swim speed occurring more frequently when boats passed manatees in shallow ( $< 2$  m) water than in deep water (Nowacek *et al.*, 2004a).

Water depth affects the response of dugongs to boats by affecting the real and perceived threat of boat strike. Dugongs are on average 2 m in circumference (James Sheppard, *unpublished data*), and thus approximately 0.64 m deep. During this study the dugongs were in average depths of 1.7 – 2.5 m (Section 3.3.1.2). If run over by a boat with large draft (e.g., 1.5 m) at these depths dugongs are likely to be crushed between the boat and the sea floor. Although a dugong may be able to evade a boat with shallower draft by diving deep, the distance between the dugong and the boat is not enough to reduce the perceived risk of being hit and thus the dugong flees if possible. The shallow water in which dugongs were observed during this study made it difficult to determine whether they would always dive before fleeing. There was no obvious tendency for dugongs to flee along the bottom, probably because the fast travel they exhibit while fleeing involves considerable pumping of the tail and needs to be conducted some distance above the substrate. Thus in shallow water there was not enough room for dugongs to make an obvious dive towards the substrate while fleeing.

Deep water can be a refuge for marine mammals and vertical avoidance of boats by diving is a strategy employed by bottlenose dolphins (Nowacek *et al.*, 2001b; Lusseau, 2003a), humpback whales (Baker & Herman, 1989), belugas and narwhals (Finley *et al.*, 1990). The effect of water depth on the response to boats can be likened to the effect of refuge distance on the response of terrestrial animals to predators (Frid & Dill, 2002). In order to limit the costs of fleeing from predators, which include abandoning a feeding site, lost feeding time, and energy expenditure, terrestrial animals tolerate closer approaches by predators the closer they are to a refuge site (Ydenberg & Dill, 1986). In deeper water, dugongs can dive deep to seek refuge from boats, or indeed need only to remain feeding. If dugongs in deeper water perceive that remaining at the bottom is safe, they would be expected to spend less time responding to boats than dugongs in shallow water. This assumption suggests that those in deep water only incur energy

costs of longer interbreath intervals (Hastie *et al.*, 2003), and overall, suffer a lower energy cost from boat disturbance than those in shallow water. Further experiments to test the response of dugongs to boats in water depths > 2 m are needed in light of these possible differences in the effects of boat traffic on dugong behaviour.

#### **7.4.4 Biological significance of responses observed in Moreton Bay**

When assessing the biological significance of disturbance, a common aim is to determine the effect of disturbance on population size. This requires an assessment of the effects on demographic parameters such as survival and reproductive success (Gill *et al.*, 1996; Gill *et al.*, 2001). Considering the decisions made by animals in response to disturbance in the context of those made in response to predation (Gill *et al.*, 1996; Frid & Dill, 2002; Cooper *et al.*, 2003), animals face a trade-off between disturbance rates, and the amount of a given resource that is available in a particular habitat patch (Gill *et al.*, 1996). The decision to move when disturbance reaches a particular level will incorporate a number of other factors similar to those which govern the level of predation risk accepted by an animal, including: the quality and level of investment in the current site, the distance and quality of other sites, and the relative level of disturbance or competition at other sites (Gill *et al.*, 2001).

Although there was no observed effect of experimental boat passes on the feeding behaviour of dugongs, mass herd responses did occur. Dugongs responding to boats presumably incur a cost through energy expenditure and lost feeding, socialising or resting time. According to the low levels of boat traffic observed during this study, however, dugongs on the Moreton Banks would not spend much time moving in response to boats. Response times were only estimated for dugongs that were feeding, however as dugongs at this location spend 41% of their time feeding (Section 3.3.3), there is a high probability that feeding will be interrupted. As dugongs are more likely to be disturbed by boats passing within 50 m, the minimum rate of disturbance during this study was 0.2 boats per hour, while the maximum rate may be considered 1.5 boats per hour according to the number of boats that passed within 1 km (Section 6.3). Using the average time spent responding to opportunistic boat passes (122 s), and assuming boat disturbance occurs only during the day (i.e., 12 hours per day), dugongs may be disturbed for between 4 min 53 s and 36 min 36 s per day. Assuming that all boat passes

occurred while dugongs were feeding, and that all individuals were disturbed during each pass, this represents 0.8 to 6% of the time spent feeding throughout the diel cycle. However, it should be noted that my fieldwork was conducted over winter, and boat traffic increases significantly over the summer, particularly during the holiday period between Christmas and mid-January (Brenda Healey, *pers. comm.*). Boat traffic in summer needs to be quantified so that the potential impact of this increase on dugongs can be evaluated.

Dugongs suffer an energetic cost when continually disturbed while feeding if they sacrifice other behaviours such as resting in order to maintain their required energy intake. The energetic cost includes the energy expenditure while moving in response to the noise. There may also be an added cost of moving to a different patch on the seagrass beds. Dugongs may spend time searching for food patches and once disturbed may feed on less desirable patches until favoured patches are located. If this is the case then feeding efficiency would be reduced as less desirable feeding patches may have lower nutritional value. This effect may be particularly significant considering the 'cultivation' grazing strategy used by dugongs in Moreton Bay (Preen, 1995; as discussed in Section 5.1). Dugongs appear to move across the banks systematically over a period of months, cropping the seagrass in a manner that promotes growth of a favoured pioneer species with high nutritional value in the new shoots produced. The pattern of seagrass patch use may be interrupted by dugongs continually moving in response to boats, and in areas of particularly high boat use dugongs may not be able to graze intensely enough to affect the species composition of the seagrass. Thus the amount of favoured seagrass available would be reduced.

Despite the potential effects of having to move to different seagrass patches, the current low level of boat traffic on the Moreton Banks is unlikely to cause a reduction in dugong survivorship through disturbance alone. However, it is important to consider additional costs of stress and interruptions to social behaviours such as courtship and mating (Baker & Herman, 1989). No mating behaviour was observed during this study, but Preen (1989) describes several instances where a group of dugongs were following, fighting over, and mounting a single animal, and he presumed these to be mating herds. He also acknowledges that these groups disbanded a number of times in response to his boat or kayak. However he notes that one group reformed and continued fighting 20

min after being disturbed. Disruption of this behaviour may limit mating success if the mating herds do not always reform. Knowledge of the mating strategy of dugongs in Moreton Bay is limited to Preen's (1989) observations, and thus it is difficult to assess the potential impact of disturbance. However, the low levels of boat traffic on the Moreton Banks during my study suggest that there is a low probability of mating herds being disturbed, and there is probably little impact of boat disturbance on mating success.

#### **7.4.5 Boat disturbance in other areas**

The trade-off between resource use and disturbance needs to be considered when applying the results obtained in this study to dugongs in other areas. On the Moreton Banks, dugongs used an area of approximately 16 km<sup>2</sup> during my study and were able to move in response to boats while still remaining on the seagrass beds. Therefore they could immediately resume feeding, rather than having to return to their original site. On smaller seagrass beds, movement in response to boats may result in dugongs moving off the seagrass patch. Thus a greater interruption to feeding would be incurred than on large seagrass beds like the Moreton Banks. This is particularly true if there are no nearby patches to which dugongs can move. The only choice then is to move large distances to other suitable habitat, or remain and incur the cost of disturbance and risk of boat strike.

Individual dugongs can move hundreds of kilometres within a few days (Marsh & Rathbun, 1990; Preen, 2001). Indirect evidence of large scale movements of dugongs emerges from time series analysis of aerial survey data from throughout their range in Australia (Marsh *et al.*, 1996; Marsh & Lawler, 2001b; Marsh *et al.*, 2003b; Gales *et al.*, 2004). However, there is heterogeneity in responses to reductions in habitat quality, some dugongs moving long distances and some remaining in the area (Preen & Marsh, 1995). Similar variation likely occurs in response to the risk of disturbance. Those animals that remain in an area have the benefit of decreased competition for forage, which may outweigh the cost incurred through the risk of disturbance (Ydenberg & Dill, 1986).

If high levels of boat disturbance were to lead to large scale movements of dugongs, this may have an affect on population parameters if dugongs are then forced to compete for decreasingly available feeding grounds. However, a lack of movement may indicate a more serious problem. If boat disturbance, or other causes of habitat degradation, occur throughout much of the dugong's range, then these animals will be forced to tolerate the costs of disturbance. Effectively the availability of food will be limited by the time dugongs can spend foraging. Food availability is known to influence dugong population dynamics as dugongs delay breeding when food is limited (Marsh, 1999; Kwan, 2002). A large-scale reduction in food availability through disturbance could therefore reduce dugong numbers by reducing fecundity. This effect is particularly important when combined with other impacts which reduce adult survivorship such as boat strikes.

Management initiatives such as the series of Dugong Protection Areas (DPAs) along the Queensland coast, and the rezoning of the Great Barrier Reef Marine Park to increase conservation areas, will only work if they contain high quality habitat and are areas of high use by dugongs (Marsh, 2000). Thus the effect of boat disturbance on habitat quality is one that should be closely monitored, particularly where high boat traffic occurs in small and/or isolated dugong habitats or DPAs.

## **7.5 Conclusions**

Dugongs on the Moreton Banks showed limited behavioural responses to boat traffic. Boats passing at a variety of distances and speeds caused relatively short interruptions to dugong feeding herds. Relatively low levels of boat traffic in this area mean that a maximum of 0.8 to 6% of feeding time may be interrupted by boats. However, if the number of registered boats in Queensland continues to increase rapidly, as it has done over the past seven years (Maritime Safety Queensland, 2004), this rate of disturbance is likely to increase. Interrupting feeding at rates higher than the maximum of 6% of the daily time budget estimated during my study, may affect dugongs at the population level, by limiting food intake and triggering reduced fecundity. I found that dugongs were more likely to respond to boats that passed within 50 m of a herd, however small sample sizes limited my ability to determine the effects of distance and speed on the

duration of herd responses. Thus further investigation of the effects of these factors on disturbance rates is needed.

## 7.6 Chapter summary

- Disturbance from boats has been documented for many species of cetaceans, but has never been quantified for dugongs. As their distribution is dictated by the presence of seagrass, dugongs occur in shallow coastal areas where boat traffic tends to be highest. Thus there is potential for boats to alienate dugongs from their important habitat areas.
- Controlled boat pass experiments were conducted to test whether the behaviour of dugongs was affected by: (1) boat presence, (2) number of boat passes, (3) continuity of boat passes (i.e., whether pass included a stop and restart), and (4) boat distance.
- Boat presence, number and continuity of passes did not affect the proportion of time spent feeding or travelling during a 4.5 min focal follow of individual dugongs.
- Number, continuity and distances of boat passes did not affect the subsurface time, travel distance or travel direction of focal individuals during the subsurface interval that corresponded with the boats closest approach time.
- The focal dugongs were less likely to continue feeding during the subsurface interval corresponding with the boats closest approach time if the boat passed within 50 m, than if the boat passed at a greater distance.
- Disturbance from boats on the Moreton Banks is currently unlikely to affect dugong populations through interrupting feeding. According to current boat traffic levels, boats may interrupt dugongs for only 0.8 – 6% of the total time budget for feeding. However, if increasing boat numbers further increase the



interruptions to dugongs' daily time budget, the effect of disturbance may affect fecundity levels within this population.



# **Chapter 8**

## **Acoustic alarms fail to move dugongs: the behavioural response of dugongs to pingers in Moreton Bay, Queensland**

**This chapter provides the first quantitative assessment of the response of dugongs to pingers. I assess the possibility of pingers causing disturbance to dugongs in a series of controlled experiments where the response of dugong herds to a pinger array was assessed. These experiments do not attempt to test the potential effectiveness of pingers in reducing dugong entanglements in gill nets. However, I review the efficacy of this bycatch mitigation strategy according to my behavioural observations and studies on the responses of target species occurring along the Queensland coast.**



## **Chapter 8. Acoustic alarms fail to move dugongs: the behavioural response of dugongs to pingers in Moreton Bay, Queensland**

### **8.1 Introduction**

Globally, interactions with fisheries represent the largest single threat to the survival of marine mammals worldwide, particularly inshore marine mammals (IWC, 1994; Reeves *et al.*, 1996; Northridge & Hofman, 1999; Lewison *et al.*, 2004). Fisheries can impact marine mammals in two ways: (1) directly through operational interactions, where animals are killed as bycatch, and (2) indirectly through ecological interactions, where stocks of prey species are depleted or the habitat of both marine mammals and prey species is disturbed or destroyed (Beverton, 1985; Marsh *et al.*, 2003a). DeMaster *et al.* (2001), predict a decline in the extant populations and species richness of marine mammals as a result of competition with fisheries by the end of the 21<sup>st</sup> century. Operational impacts are a concern for almost all species of marine mammals (Northridge & Hofman, 1999; Read & Wade, 2000) and are the focus of this study. The incidental catch of marine mammals in fishing nets occurs throughout the world, and the number of deaths caused by fishing nets far exceeds the number of marine mammals deliberately caught or killed (Reeves *et al.*, 1996). Most importantly for this study, it appears that there is no universal cause for the capture of inshore marine mammals in gillnets, and there is no universal solution (IWC, 1994).

Acoustic alarms, or pingers, are sound emitting electrical devices attached to fishing nets. They are designed to reduce the number of marine mammals incidentally entangled and killed in fishing nets (Reeves *et al.*, 1996). For some marine mammal species, pingers may be an appropriate mitigation tool to be employed in combination with, and perhaps more appropriately, secondary to, other measures such as area closures (Pichler *et al.*, 2003). However, there is concern that they may also have deleterious effects. The widespread use of pingers introduces another source of anthropogenic noise in the world's oceans, which could disturb or displace marine mammals (Dawson *et al.*, 1998).

Pingers were initially designed to reduce cetacean bycatch by either producing sounds which are aversive to non-target species, or which alert marine mammals and prompt them to investigate their surroundings (Dawson, 1994; Dawson *et al.*, 1998).

Experiments to date on the behavioural response of some cetacean species indicate that pingers promote an aversive rather than investigatory response in most species (IWC, 2000; Cox *et al.*, 2001; Culik *et al.*, 2001; Carlstrom *et al.*, 2002; Monteiro-Neto *et al.*, 2004). Although pingers that displace animals over large distances may be effective in reducing bycatch rates, the area of habitat eliminated may have a damaging effect on marine mammal populations equal to that of incidental deaths in nets (Culik *et al.*, 2001).

The success of pingers in producing an aversive response varies among species. Pingers displace (Laake *et al.*, 1998; Culik *et al.*, 2001), and reduce the bycatch of harbour porpoises (*Phocoena phocoena*) (Kraus *et al.*, 1997; Gearin *et al.*, 2000). Bottlenose dolphins (*Tursiops truncatus*) however, approach nets at the same distance with or without pingers (Cox *et al.*, 2003). Bottlenose dolphins have a tendency to investigate novel stimuli and may even approach pingers aggressively, whereas harbour porpoises are less likely to tolerate a new sound in their environment (Reeves *et al.*, 2001; Cox *et al.*, 2003). These results demonstrate the importance of considering the unique habits, hearing abilities and responses of each species of concern, to sound and novel stimuli (Dawson *et al.*, 1998; IWC, 2000; Kastelein *et al.*, 2000). These variations in response may also present a challenge if employing pingers as a solution in a fishery which has a multi-species marine mammal bycatch problem.

There are limited information on the extent of the marine mammal bycatch problem in Queensland. Although reporting of cetacean and dugong catches is mandatory under the *Nature Conservation (Whales and Dolphins) Plan 1997*, entanglements are known to occur without fishers notifying authorities, and are only reliably reported when observers are on board vessels (Haines & Limpus, 2002b; Limpus *et al.*, 2003b). The dolphins in those incidents that are reported are rarely identified to species. However all three inshore cetacean species, Irrawaddy dolphins (*Orcaella brevirostris*), Indo-Pacific hump-backed dolphins (*Sousa chinensis*) and bottlenose dolphins (*Tursiops sp.*), are known to have been killed in set mesh nets (GBRMPA, 2000). Dugongs and cetaceans

are also killed in shark control nets. These nets are deployed to reduce sharks numbers at popular bathing beaches and, prior to 1992, were found at ten locations along the eastern Queensland coast (Gribble *et al.*, 1998; Marsh *et al.*, 2001). High levels of bycatch, including dugongs and many cetacean species, led to changes in the shark control program, and most nets were replaced with drumlines (Gribble *et al.*, 1998).

As seagrass specialists, dugongs are at high risk of entanglement in set mesh nets as these animals rely on protected, inshore marine environments which often overlap with gill net fisheries. This overlap is intensified in bays where tidal fluctuations are high, and both fishers and dugongs use intertidal areas during high tide (Marsh *et al.*, 1999b). The incidental capture of dugongs in gill nets is not only a problem in Queensland. It occurs throughout most of the species' range, and is a known threat to populations in all but four of the 37 countries and territories in which dugongs are found (Marsh *et al.*, 2002). Thus bycatch mitigation measures that can be applied in both developed and developing countries are needed to reduce dugong entanglements and help secure dugong populations on a global scale.

A series of Dugong Protection Areas, where gillnetting practices were either banned or modified was established to reduce the number of dugongs killed in set nets in Queensland (Marsh, 2000). Additional protection has been provided by marine park zoning (Marsh & Lawler, 2001b) which substantially increased from 1<sup>st</sup> July 2004 (GBRMPA, n.d.). Queensland's Department of Primary Industries (DPI) is investigating the potential for pingers to be used to deter cetaceans and dugongs from commercial fishing nets outside of protected areas. Pingers have also been routinely deployed since 1994 on nets at two of the three remaining locations where shark nets occur: the Gold Coast and Sunshine Coast, with the exception being Cairns (Lien *et al.*, 1998, Baden Lane, *pers. comm.*). Despite these initiatives, between 1998 and 2003 there were 16 dugong deaths attributed to net entanglement in the Queensland marine wildlife stranding and mortality database. In addition, four dugongs died in shark control nets equipped with 10 kHz pingers at Magnetic Island near Townsville, and on the Sunshine Coast (Limpus *et al.*, 2000; Haines & Limpus, 2001; Haines & Limpus, 2002a; Limpus *et al.*, 2003a).

As yet no studies have established whether pingers are an effective deterrent to dugongs, or determined the behavioural responses of dugongs to pingers. The hearing ability of dugongs is poorly documented. Only one electrophysiological audiogram has been obtained for a single dugong. This test showed neural responses to a frequency range of 4 to 32 kHz and that it is unlikely that dugongs echolocate (Darlene Ketten, *pers. comm.*). The Florida manatee has a hearing range of 0.4 to 46 kHz, with best hearing at 6 and 20 kHz based on a behavioural audiogram (Gerstein & Gerstein, 1999). The evolutionary pressures of a more hazardous marine environment, as well as preliminary gross anatomical observations, suggest that dugongs may have better hearing sensitivity than Florida manatees, which evolved in freshwater (Ketten, 1992, Darlene Ketten, *pers. comm.*).

Directly testing the effectiveness of pingers in a small fishery where bycatch rates are low can be impossible (Dawson *et al.*, 1998). In Queensland's relatively small fishery, dugong bycatch rates were less than three recorded catches per year over the past five years. Dawson *et al.* (1998) calculates that where the probability of catching an animal per set of nets is 1%, experiments to determine the effectiveness of pingers would require 2,700 each of control sets of net and sets equipped with pingers, to observe a 50% reduction in catch rates with 80% power (at  $P = 0.10$ ). The sink gillnet fishery in New England caught about 2,000 harbour porpoises per year in the early 1990s (Kraus, 1999). To obtain a statistically significant reduction in the bycatch of harbour porpoises required 421 sets of net with active pingers and 423 control sets (Kraus *et al.*, 1997). The cost of this project was in the order of \$US500,000 in 1994 (Dawson *et al.*, 1998). Clearly the probability of a set of nets catching dugongs in Queensland is currently less than 1%. With only 752 netting licence holders in the Queensland fishing industry (Fenton & Marshall, 2001) and an estimated growth value of production of the inshore set net fishery of \$AU39 million in 2003 (Lew Williams, *unpublished data*), such a large experiment is neither logistically possible nor economically feasible or sensible.

The alternative is to observe the behaviour of animals around pinger arrays which simulate pingers on a fishing net (Reeves *et al.*, 1996; Stone *et al.*, 1997; Cox *et al.*, 2001; Culik *et al.*, 2001). Simulated experiments conducted in highly used habitat areas, maximise the opportunity to observe the animals without risk of entanglement. This study used simulated experiments to directly observe the behavioural response of large



dugong herds to a pinger array in Moreton Bay. The objective of this study was to ascertain whether pingers could alienate dugongs from their critical inshore habitats rather than to determine the effectiveness of pingers in reducing the number of animals drowned in nets.

## 8.2 Methods

Experiments were conducted from 6 to 11 August 2002. Behavioural observations were conducted using the blimp-cam (Chapter 2) and all data were extracted from the video footage at the end of the field season. An array of two “BASA dolphin” pingers was used in each experiment. These pingers have a nominal frequency of 10 kHz, and a sound pressure level (SPL) at 1 m of 133 dB re 1  $\mu$ Pa (Baldwin, 2002). The BASA pingers were manufactured in Queensland and designed to be more robust than the Dukane pingers commonly used in the USA. In Queensland, nets are generally set in shallow water where the pingers are exposed to high UV light levels which were found to destroy the casing of the Dukane pingers. Further modifications continue to be made to the pingers being trialled within the Queensland fishery (Baden Lane, *pers. comm.*).

Preliminary investigations of the propagation of pinger sound in the clear, shallow water and sandy substrate of the study area were conducted by Baldwin (2002). These were conducted under the same weather conditions as my experiments (*pers. obs.*). Baldwin (2002) predicted the zone of audibility, that is, the area within which pinger sound is at least 20 dB above ambient noise levels (Richardson *et al.*, 1995), based on recordings of pinger sounds at increasing distances *in situ*. The 10 kHz BASA pingers should be audible (assuming a hearing range that includes this frequency) to distances of greater than 100 m on the Moreton Banks (Baldwin, 2002). The size of the focal arena during my experiments (described in subsequent sections) was based on this audible range.

### 8.2.1 Pinger array

As the pingers could not be switched off without removing the batteries, either two active or two silent pingers were in the water at any one time. At one end of the array, the two pingers (one active, one silent) were mounted above an anchored floating tube,

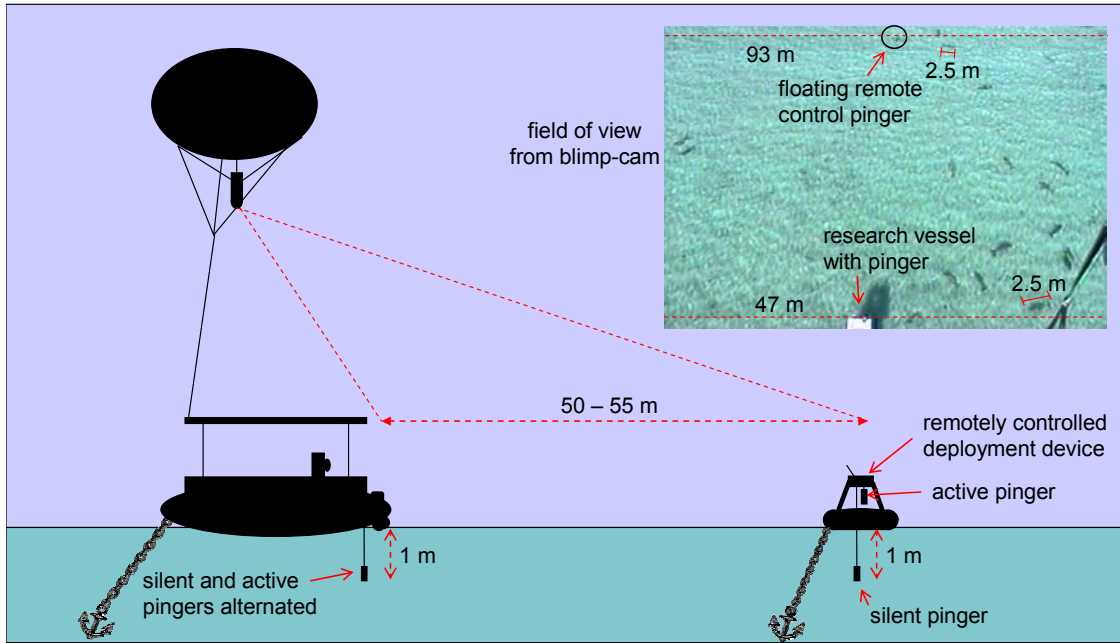
and were lowered into or removed from the water using a remote joystick controller. At the other end, either the active or silent pinger was hung from the bow of the research vessel (Figure 8.1). Each pinger was lowered to a depth of 1 m, which placed it approximately mid water column as the water depth ranged from 1.5 to 3 m. The floating tube was deployed by slowly motoring the research vessel to one edge of the dugong herd, switching off the motor, placing the anchored tube into the water, and allowing the research vessel to drift towards the opposite edge of the herd. The research vessel was anchored when the distance between the vessel and floating tube (and thus the two pingers in the array) was 50 to 55 m according to a laser range finder (Bushnell TPEB800).

### **8.2.2 Focal arena**

The camera on the blimp-cam was directed so that the focal arena was bounded at the top and bottom by the two pingers (i.e., the floating tube and the front of the research vessel, Figure 8.1). The focal arena was effectively wider at the top of the camera image than at the bottom as the blimp-cam was tilted to view both pingers. As the camera angle was unknown, the width of view at the top and bottom of the image was estimated during each experiment according to an average dugong length of 2.5 m. While replaying the video footage I calibrated the width of view by taking advantage of any moment throughout each experiment when a dugong was horizontally in line with the top or bottom of the focal arena. The width of view was taken as the average width estimated according to the four different dugongs at the top and the bottom of the field of view.

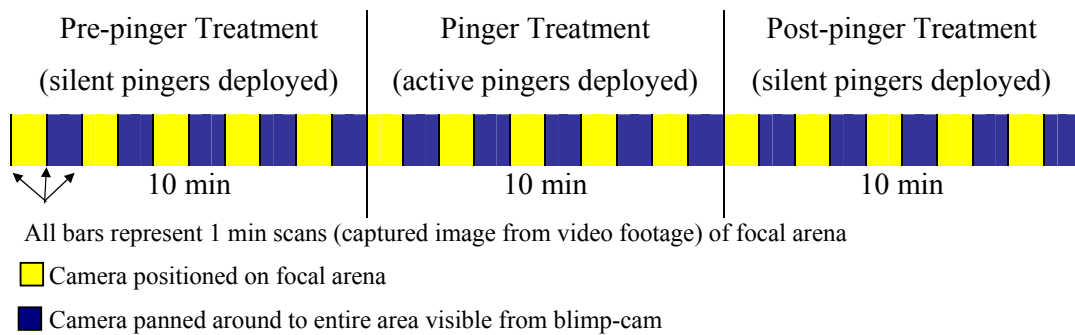
### **8.2.3 Experiment protocol**

Experiments commenced at least 10 min after the research vessel was anchored to allow dugongs potentially disturbed by the research vessel to settle. Each experiment was divided into three treatments: (1) pre-pinger – 10 min with both silent pingers deployed, (2) pinger – 10 min with both active pingers deployed, and (3) post-pinger – 10 min with both silent pingers deployed. Binoculars were used to check that the pingers on the floating tube had deployed as planned.



**Figure 8.1** The array of two pingers, one deployed from the research vessel, the other remotely deployed from a floating tube. Both the research vessel and tube were anchored at a set distance from one another. Silent pingers were exchanged with active pingers during the experiment, manually on the research vessel and using a remote control to the floating tube. The focal arena was bounded by the two pingers and the width of view at the top of bottom was estimated using dugong lengths as a reference when dugongs were aligned with these boundaries.

During each 10 min treatment period, I alternated the field of view of the blimp-cam as follows: (1) odd minutes – the camera was positioned on the focal arena, and (2) even minutes – the camera was panned around to film all dugongs visible from the blimp-cam outside of the focal arena. A still image of the focal arena was captured from the video footage at 1 min intervals providing an instantaneous scan sample (Altmann, 1974) of the dugongs within the arena (Figure 8.2).



**Figure 8.2** Experiment protocol showing deployment of silent and active pingers in 10 min treatment periods and the filming protocol.

### 8.2.4 Number of dugongs within the focal arena

During each experiment, I counted the total number of individual dugongs within the focal arena for each 1 min scan sample. These counts were analysed to produce estimates of differences in the mean count of dugongs in each treatment and estimates of differences in the slope of the line describing the rate of change in dugong numbers in each treatment. The data were characterised by repeated measures over time for each experiment (E), forming a random blocking structure for the analysis. A Poisson error distribution was assumed as the data were counts with some zeros. Exploratory analysis found no evidence for correlation structure among the observations within each experiment over time. The data were analysed using a generalised linear mixed-model with a log link.

The Poisson model was:

$$Y \sim (\text{Treatment}^f * \text{Time}^f) + (\text{Experiment}^r + (\text{E} * \text{Time})^r) + \text{error}$$

In this model, Treatment is a fixed categorical effect representing the three periods of sampling defined by the presence of the pinger (pre-pinger on, pinger on, post-pinger on). Time is a fixed continuous effect representing the linear trend over the 10 sampling times within each Treatment, and was centred, i.e., coded as -4.5 to 4.5, so that the Treatment effect represented the log of the mean count of dugongs in each period. Experiment and E\*Time represent random variation ‘among experiments’ in the mean count and the slope of the linear trend, respectively. The effects of this random variation are not presented here as the fixed effects of Time and Treatment were the factors relevant to this study.

### 8.2.5 Orientation of dugongs within the focal arena

The orientation of each dugong relative to the pinger array at each 1 min scan was calculated using the “Optimas 6.5” imaging program (Figure 8.3). Dugongs on the left hand side of the image were considered to be facing towards the array if their orientation was between 0 and 180° relative to the imaginary line between the two

pingers, and those on the right of the image were facing towards the array if their orientation was between 180 and 360°.

To test the effects of treatment on the orientation of the dugongs, only experiments where dugongs were present in the focal arena during at least two scans in all three treatments were analysed. The average proportion of dugongs facing towards the pinger array was calculated for each treatment in each experiment using scans where dugongs were present. I conducted a Shapiro-Wilk test to ensure that this proportional data was normally distributed. This proportion was then the dependent variable in a one-way ANOVA to compare the rate of dugongs facing towards the pinger array according to treatment (pre-pinger, pinger and post-pinger).



**Figure 8.3** An example of an instantaneous scan sample obtained by capturing a still image of the focal arena from the video. The focal arena is bounded by the boat seen mid-bottom of the image, and the remote floating pinger circled mid-top of the image. All dugongs within the arena are marked in red with the circle indicating the head of the animal. Dugongs were classed as facing towards or away from the array according to their orientation relative to the line between the boat pinger and floating pinger. In this example all dugongs are oriented towards the pingers.

### 8.2.6 Passing between pingers

During each minute that the focal arena was in view, I used the one-zero method (Altmann, 1974) to record whether any dugongs passed between the two pingers. This resulted in five one-minute surveys being conducted for each treatment. A one (if any dugongs passed between the pingers) or zero (no dugongs passed through) was recorded for each survey.

Experiment was a random factor affecting the results and the small number of experiments conducted made it difficult to incorporate this factor in the analysis. To ensure that no one particular experiment biased my results I explored the data by constructing a 2 x 3 table for each experiment so that I could compare the results for each. The effect of treatment on whether a dugong passed between the two pingers was determined by creating a 2 x 3 table with cells representing the total number of ones or zeros in each treatment across all experiments. Only experiments where dugongs were within the focal arena during at least part of each treatment were used. I used two-sided Pearson's chi-squared analysis to determine whether treatment affected the likelihood of dugongs passing between the pingers.

### 8.2.7 Feeding plumes

I also used the one-zero method to record whether feeding plumes could be seen from dugongs estimated to be within 100m of either pinger when panning the entire area visible from the blimp-cam. Again, experiment was a random factor, investigated through exploratory analysis as described above. The presence or absence of feeding plumes was tested using Pearson's chi-squared analysis as described above.

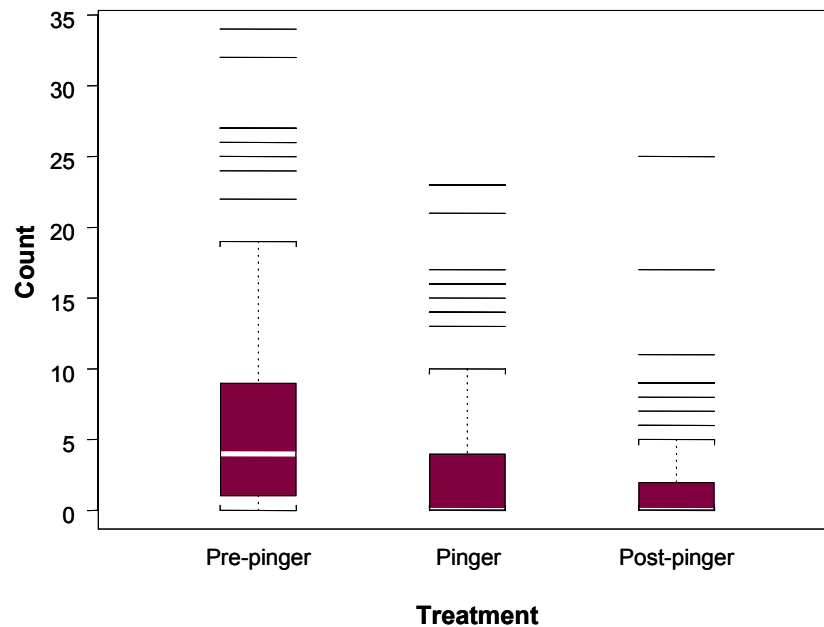
## 8.3 Results

Ten experiments were conducted, and there were dugongs within the focal arena throughout at least part of nine experiments. The focal arena, according to calculations based on dugong lengths, had a width at the bottom of the frame ranging from 43 to 53 m, and at the top of the frame ranging from 65 to 105 m. The length of the frame was 50

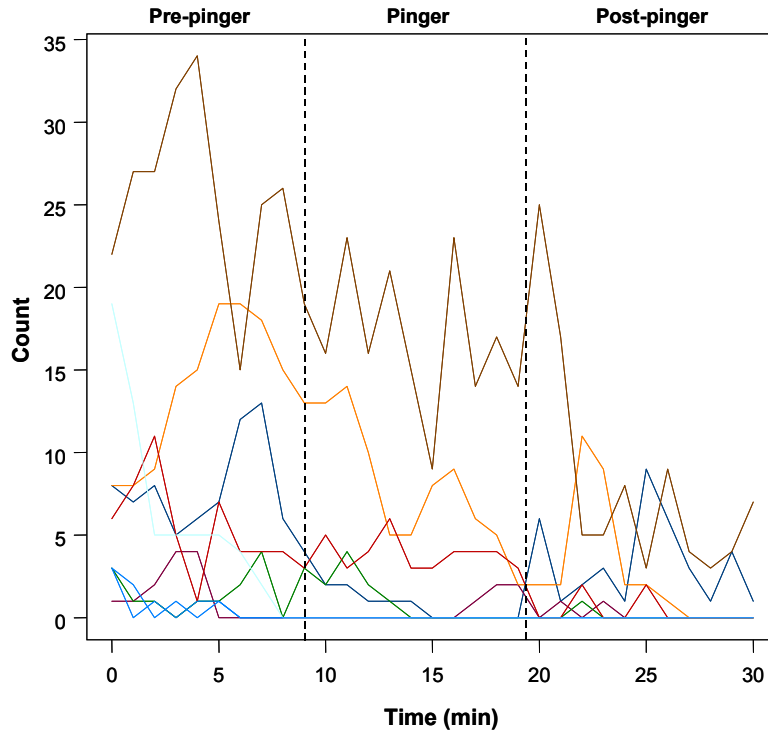
– 55 m. Given the sound propagation range of over 100 m of the BASA 10 kHz pingers on the Moreton Banks (Baldwin, 2002), the pingers should have been audible throughout this focal arena.

### 8.3.1 Number of dugongs within the focal arena

The mean number of individual dugongs present in the focal arena differed significantly among treatment periods ( $F_{2, 265} = 85.8$ ,  $P < 0.01$ ; Figure 8.4). The mean number of dugongs present in the pre-pinger period was 2.7 (95% CI = 1, 7.3), decreasing to 1.3 individuals (0.5, 3.6) in the pinger period, and decreasing further to 0.6 individuals (0.2, 1.6) in the post-pinger period. The rate of change in the number of individual dugongs over time within treatment periods differed significantly among treatment periods ( $F_{2, 265} = 4.3$ ,  $P = 0.014$ ; Figure 8.5). The number of dugongs decreased at a rate of 11.9% (4, 20) during the pre-pinger period. The rate of decrease was not significantly greater in the pinger period than in the pre-pinger period (the rate of decrease was 2.3% (-8.2, 4.1) greater). The rate of decrease was, however, significantly greater in the post-pinger period than in the pre-pinger period (12.3% (3.96, 21.3) greater).



**Figure 8.4** Distribution of the number of individual dugongs observed in each treatment period. Boxes represent the interquartile range of values (i.e., 50% of values), the white line represents the median, and vertical dotted lines extend from the boxes to the highest and lowest values (excluding outliers which are each represented by a horizontal line).



**Figure 8.5** Number of dugongs observed over time in each of the before, during and after treatment periods. Coloured lines represent replicate experiments, dashed lines separate treatment periods.

### 8.3.2 Orientation of dugongs within the focal arena

I recorded dugongs within the focal arena during at least two scans in each treatment of six experiments. The proportions of dugongs facing towards the pingers in each experiment were normally distributed within each of the three treatments (Table 8.1). There was no significant difference in the mean proportion of dugongs oriented towards the pinger array among the pre-pinger ( $0.61 \pm 0.04$  SE), pinger ( $0.66 \pm 0.04$  SE) and post-pinger ( $0.58 \pm 0.11$ ) treatments (One-way ANOVA:  $F_{2,15} = 0.30$ ,  $P = 0.74$ ).

**Table 8.1** Shapiro-Wilk tests to determine whether the proportions of dugongs facing towards the pinger were normally distributed within each treatment.

Treatment	W	df	P
Pre-pinger	0.88	6	0.28
Pinger	0.96	6	0.86
Post-pinger	0.98	6	0.94



### 8.3.3 Passing between pingers

Dugongs were observed passing between the two pingers during all treatment periods, i.e., when each of the silent pingers and active pingers were deployed (Table 8.2).

Results were similar across all experiments according to exploratory analysis (Appendix 5). Pearson's chi-squared analysis showed that treatment period did not affect the likelihood of dugongs passing between the two pingers ( $\chi^2 = 1.82$ ,  $df = 2$ ,  $P = 0.40$ ).

**Table 8.2** Observed and expected counts of one minute surveys where dugongs did or did not pass between the two pingers during each treatment across all experiments. Five one minute surveys were conducted per treatment for each of six experiments, with one data point missing from a 'pinger' treatment.

Treatment		Number of surveys where dugongs did or did not pass between two pingers		
		yes (1)	no (0)	Total
Pre-pinger	Observed	14	16	30
	Expected	11.8	18.2	
Pinger	Observed	12	17	29
	Expected	11.4	17.6	
Post-pinger	Observed	9	21	30
	Expected	11.8	18.2	
Total	Observed	35	54	89

### 8.3.4 Feeding plumes

The likelihood of dugong feeding plumes occurring within 100 m of the pinger array appeared comparable across experiments (Appendix 5) and was unaffected by pinger noise ( $\chi^2 = 1.45$ ,  $df = 2$ ,  $P = 0.48$ ; Table 8.3).

**Table 8.3** Observed and expected counts of one minute surveys where feeding plumes were visible within 100 m of the pinger array or not, during each treatment across all experiments.

Treatment	Count	Plumes visible		Total
		yes (1)	no (0)	
Pre-pinger	Observed	34	18	52
	Expected	35.2	16.8	
Pinger	Observed	26	15	41
	Expected	27.7	13.3	
Post-pinger	Observed	30	10	40
	Expected	27.1	12.9	
Total	Observed	90	43	133

## 8.4 Discussion

### 8.4.1 Dugongs' response to pingers: potential displacement?

Deploying an array of two active BASA dolphin pingers (10 kHz fundamental frequency) did not elicit a clear or direct response from dugong herds. The number of dugongs in the focal arena between the pinger array declined throughout the experiment. However, this decline could not be attributed to pinger noise as the rate of decline was not significantly greater once the active pingers were deployed in comparison with the silent pre-pinger period. When the silent pingers were redeployed for the post-pinger period, the rate of decline was significantly greater than in the pre-pinger silent period. This suggests that the movement of dugongs away from the focal arena resulted from the general movement of dugongs while they were feeding or travelling, rather than a response to the active pingers. This finding could be strengthened using further experiments where silent pingers were deployed throughout a 30 min experiment, as well as by observing the area with no pingers deployed. The natural rate of movement of dugongs over this 30 min time frame could then be compared to the rates of movement observed during the pinger experiments to ensure that deployment of both silent and active pingers did not cause the movements I observed.

Dugongs should have been able to hear the pingers within the focal arena. The frequencies of vocalisations are considered indicative of the best hearing sensitivity of an animal (Wartzok & Ketten, 1999). On this basis, the hearing range of dugongs should include the 3 – 18 kHz bandwidth (Anderson & Barclay, 1995), and therefore dugongs should have been able to hear the 10 kHz fundamental frequency of the pingers. This is further supported by the audiogram conducted on one dugong which suggested a minimum hearing range of 4 – 32 kHz (Darlene Ketten, *pers. comm.*)

I observed feeding plumes within 100 m (i.e., within the predicted zone of audibility) of the pingers throughout the experiments, and the presence or absence of plumes was not affected by whether pingers were active or silent. This, together with the lack of significant movement away from the observation arena while pingers were active,

suggests that dugongs would not be alienated from their feeding grounds by 10 kHz BASA pingers. Several cetacean species show stronger responses to pingers than I observed from dugongs. Tucuxi (*Sotalia fluviatilis*) are less likely to be within 500 m<sup>2</sup> quadrats either side of a pinger array when the pingers are active than when silent (Monteiro-Neto *et al.*, 2004). Pingers displace harbour porpoises from an area with a minimum radius of 125 – 130 m (Laake *et al.*, 1998; Culik *et al.*, 2001). Hector's dolphins (*Cephalorhynchus hectori*) increase their median distance of 299 m from a silent pinger, to 372 m from an active pinger (Stone *et al.*, 1997). Bottlenose dolphins occur more frequently within a 100 m zone around a net deployed with silent pingers than active pingers, although the closest distance of dolphins to the net is not affected by pingers (Cox *et al.*, 2003).

In the studies cited above, the animals avoided the ensonified zone but remained in the surrounding area. In an experiment to test the effectiveness of pingers in Sweden, both active and silent pingers were deployed on nets (Carlstrom *et al.*, 2002). None of the nets caught porpoises, suggesting that the animals were displaced from the area altogether. Assuming that the Dukane NetMark 1000 pingers (10 kHz) used were audible to a distance of 300 m, the pingers effectively produced a longitudinal barrier parallel to the coast over 16% of the coastline fished. This kind of barrier along a coastline can prevent inshore marine mammals from entering areas such as bays that have limited access (Carlstrom *et al.*, 2002). Considering that I observed dugongs swimming between active pingers set up to 55 m apart, it does not appear that the pingers used in this experiment would form an acoustic barrier to dugongs and prevent them from entering important habitat areas.

#### **8.4.2 Implications for the effectiveness of pingers for dugongs**

There are three hypotheses on how pingers are effective in reducing marine mammal bycatch that are relevant to dugongs: (1) by startling the animals and causing them to flee, (2) by producing a sound that is “annoying” to the animals and causes them to avoid the area, or (3) by alerting the animals to investigate their surroundings and thus detect the nets (Kraus, 1999). The observations presented here indicate that the first two of these hypotheses are not applicable to dugongs. Dugongs were regularly seen passing between the two pingers, which were situated closer together (50 – 55 m) than they

would be in practice, as fishers place pingers at 100 m intervals along a net (Dennis Ballum, *pers. comm.*). Therefore, dugongs did not even avoid the area where the SPL of the two pingers combined would be greatest, and indeed, where the net would be situated.

The third hypothesis is difficult to prove or reject based on simulated experiments where no actual net is deployed. Nonetheless, dugongs did not appear to investigate the noise emitted by the pingers, or the boat and floating tube to which the pingers were attached, as there was no change in the orientation of dugongs when active pingers were deployed. The development of pingers has concentrated on odontocetes, which may activate their sonar in response to pingers (Dawson, 1991). Dugongs are not thought capable of producing or detecting ultrasonic sound and occur in turbid waters throughout much of their range in Australia. In early accounts, hunters believed that dugongs' sight was well developed, although not as acute as their hearing (Prater, 1928). Anderson (1981b) believes that dugongs' sight is equivalent to a mask-equipped diver. Thus even if stimulated by pingers to investigate their surroundings visually, high turbidity would prevent them from seeing a net at the distance required to avoid entanglement.

If dugongs learned that pingers represent danger they could act as a stimulus to avoid the surrounding area. Marsh *et al.* (in press) considered the potential for dugongs to learn to avoid shark nets and rejected this hypothesis for three reasons, (1) it is unlikely dugongs would learn through the experience of others as stable social groups are limited to mother-calf pairs (further supported by my study, Chapter 4), (2) the rate of successful releases of dugongs from nets is low, and (3) there is no bias towards young animals caught in nets as would be expected if dugongs learnt from their own experience. It is even less likely that dugongs would learn to avoid mesh nets with pingers set by commercial fishers, because as opposed to the shark nets set for bather protection, the position of mesh nets continually changes.

### **8.4.3 Prospects for widespread use of pingers in Queensland**

My results suggest that 10 kHz pingers are not a suitable bycatch mitigation measure for dugongs. Several different pingers have been trialled in Queensland, including the

“Lien” pinger with a fundamental frequency of 4 kHz, the BASA pinger (both 4 and 10 kHz), and the Airmar pinger with a fundamental frequency of 10 kHz. However too few interactions between dugongs and nets have been observed to determine the success of these devices (Dennis Ballum, *pers. comm.*).

Queensland fishers are eager to find a solution to mitigate bycatch of marine mammals (Gary Ward, *pers. comm.*). Currently pingers are used voluntarily in places where fishers consider it likely that an interaction between marine mammals and nets could occur (Dennis Ballum, *pers. comm.*). During an impending review of the netting practices in Queensland and the production of a draft management plan by 2005, the use of pingers will no doubt be debated (Mark Doohan, *pers. comm.*). Given the results presented here, and the lack of quantitative results from trials with pingers on nets, there is currently no evidence to support widespread use of pingers as a strategy to reduce dugong bycatch in fishing nets.

My results suggest that dugongs are unlikely to be displaced and alienated from their feeding areas by 10 kHz pingers. However, a lack of adverse impacts is not reason enough to support the use of these devices. The costs incurred by fishers, both directly and through the time spent maintaining pingers must also be considered. If pingers were made mandatory, managers may have difficulty checking compliance, monitoring would need to occur at sea if pingers are activated and attached to nets once fishers are out on the water. Battery life would need to be long in pingers as there is no way of ensuring compliance if batteries fail once pingers are deployed (Dawson *et al.*, 1998). In addition, logistical difficulties, such as the ability of fishers to maintain a constant supply of high quality batteries, may limit their success in remote areas (Gary Ward, *pers. comm.*). These constraints along with the initial and ongoing costs of pingers would also prevent them from being successfully implemented in fisheries of developing countries.

It is clear that pingers elicit varying responses from different species of marine mammals. Dugongs show no response to 10 kHz pingers, whereas harbour porpoises show an aversion to them (Laake *et al.*, 1998; Culik *et al.*, 2001). Some bottlenose dolphins have responded to pingers by approaching them aggressively (Reeves *et al.*, 2001; Dennis Ballum, *pers. comm.*). There is also a concern that as bottlenose dolphins

feed on fish either caught in or surrounding nets, pingers may produce a ‘dinner-bell’ affect, attracting the dolphins to the nets rather than repelling them (Reeves *et al.*, 2001; Cox *et al.*, 2003). In Queensland, several species of marine mammals are killed in gill nets and shark nets, including dugongs, bottlenose dolphins, Irrawaddy dolphins and Indo-Pacific hump-backed dolphins (GBRMPA, 2000). It is unlikely that a ‘one pinger fits all’ scenario will occur where one particular sound will deter all species from nets.

Clearly there is a large amount of research still needed if pingers are to reduce the marine mammals caught in set mesh nets in Queensland. This report is the first on the behavioural response of any species currently killed in nets. Similar experiments need to be conducted to determine the response of dugongs to other pingers, such as the 4 kHz pingers that are also used by the DPI, as well as to determine the responses of dugongs in a variety of habitats. The behavioural responses of Indo-Pacific humpbacked dolphins to pingers are currently being investigated (Fiona McKnight, *pers. comm.*). However given current knowledge of the possible ‘attraction’ of bottlenose dolphins to pingers, further studies of the behaviour of this species around pingers will be particularly important before the widespread use of pingers be recommended. As advised by Pichler *et al.* (2003) it is important that pingers are not seen as an easy fix to the bycatch problem, particularly before their effectiveness and potential adverse effects have been properly documented. Other conservation measures, such as area closures and operational changes, currently offer more reliable solutions.

### 8.5 Chapter summary

- The use of pingers as a method of reducing dugong mortalities in fishing nets has been trialled in north Queensland. There is concern that the noise from pingers has the potential to alienate dugongs from the important habitat areas where gill nets are deployed.
- Experiments were conducted to test the behavioural responses of dugongs to 10 kHz BASA pingers in Moreton Bay. In each experiment, two pingers were deployed close to a dugong herd for a total period of 30 min. There were three treatment periods of 10 min each where pingers were inactive (pre-pinger

treatment), active (pinger treatment) and then inactive again (post-pinger treatment).

- The pingers did not cause a startle response from the dugongs, or cause dugongs to move away from the focal arena. Although the number of dugongs within a focal arena decreased throughout each experiment, the rate of decline did not significantly differ during the pinger treatment in comparison to the pre-pinger and post-pinger treatment.
- Dugongs were observed passing between the pingers where the noise level would presumably be the highest, both when pingers were active and inactive.
- Dugongs within the area ensounded by the pingers were observed feeding (with plumes visible) throughout the pinger experiments.
- Pingers did not appear to elicit an investigative response as the orientation of dugongs was not affected by whether the pingers were active or inactive.
- According to the results obtained during these experiments, dugongs are not likely to be disturbed by pinger noise or excluded from key habitat areas. My results also suggest that the pingers tested are likely to be ineffective in reducing the rate of dugong mortalities in fishing nets.





# **Chapter 9**

## **Application of this research to dugong conservation and management**

**In this final chapter I discuss my results in relation to their contribution to improving the conservation and management of dugongs. In particular I use the knowledge gained during this study to provide a risk assessment framework for managers to determine the potential impacts of human activities in important dugong habitats. I also outline directions for future research on dugong behaviour and human impacts on dugong populations.**



## **Chapter 9. Application of this research to dugong conservation and management**

### **9.1 Major results of this project**

Assessing the potential impacts of human activities on a marine mammal requires a good understanding of the biology of the species of interest. Information on ‘normal’ behaviour provides a baseline from which we can assess human impacts. Coupled with direct observations of the response of animals to human activities, this information allows us to predict whether human activities will affect the population. Prior to this study, baseline information on dugong behaviour was limited as dugongs are difficult to observe. In addition, there have been no previous experimental assessments on how human activities affect the behaviour of dugongs. My research has contributed to filling these gaps in our knowledge of dugong behavioural ecology, and human impacts on dugong populations. I summarise how I have achieved the specific objectives of my research below.

#### **9.1.1 Objective 1. Develop a technique to conduct continuous observations of individual dugongs and to observe herd behaviour**

I successfully developed the blimp-cam as a tool for observing dugong behaviour. This development enabled me to obtain information on dugongs that was previously unobtainable. The main advantages of the blimp-cam are: (1) it afforded a continuous view of dugongs even when they were feeding on the bottom at depths of up to 4 m in the clear water of Moreton Bay, (2) it enabled me to track individual dugongs that lacked characteristic markings while they were within large herds, (3) it enabled me to see dugongs up to 200 m from my research vessel allowing me to anchor my vessel and eliminate noise disturbance, and (4) it provided an aerial view of dugongs herds so that herd behaviour, size and structure could be assessed.

### **9.1.2 Objective 2. Describe the normal daily behaviour and movements of dugongs on the Moreton Banks, including development of an ethogram and time budget**

I have provided the first ethogram and time budget for dugongs. As anticipated, dugongs spent most of their time (41%) feeding, at least in daylight hours and shallow water. Approximately one third of the daily time budget comprised travelling; relatively little time was spent socialising and resting. Dugongs clearly used different areas of the seagrass banks according to water depths at high and low tide. However tides, together with the range of water temperature and Beaufort sea state recorded during this study, had a limited affect on time budget of individuals. The time budget of mothers with calves was not significantly different from that of single individuals, however, calves spent significantly less time feeding and more time travelling than their mothers.

Calves had a higher respiration rate than their mothers. Consequently, mothers spent a higher proportion of time exhibiting surfacing behaviour than single individuals, presumably ascending and descending slowly to stay near the surface while their calves respired multiple times. Respiration rates were also affected by the behaviour of individuals. Submergence intervals were longer when dugongs were feeding or conducting multiple behaviours during a submergence interval, than if they were travelling or conducting any other single behavioural category.

In Moreton Bay, calves suckle by positioning themselves with their muzzle at the base of their mother's pectoral fin and their dorsum uppermost. This differs from previous descriptions of dugongs in Shark Bay which suckle with the ventrum uppermost. Calves are often positioned above their mother's back while resting and travelling, and often ascend to the surface or descend by briefly crossing over their mother's back. Mothers and their calves were the only animals observed conducting social behaviour indicative of affiliative behaviour.

### **9.1.3 Objective 3. Investigate the function of large herds on the Moreton Banks through observations of the behaviour and positions of individual dugongs**

Large herds of dugongs were found on the Moreton Banks throughout both field seasons of my study. I found that feeding rates increased as: (1) the number of dugongs

visible increased, (2) nearest neighbour distance decreased, and (3) when focal dugongs were within the main herd rather than in a subgroup. These results suggest that by feeding in large herds, dugongs in Moreton Bay can forage more efficiently than if they are in small groups or solitary. The function of the herds did not appear to be primarily predatory defence as calves, which are presumably most vulnerable to shark attack, were less likely to have other dugongs surrounding them than single individuals. In addition, dugongs did not seek large herds for resting, which is when I would expect them to be most vulnerable to shark attack. These herds did not have an apparent social function. Social behaviour was relatively uncommon and was not related to herd size. My data are supported by Preen's (1995) theory that the large herds of dugongs in Moreton Bay are primarily feeding aggregations, which allow the dugongs to cultivate the seagrass by promoting growth of their favoured pioneer species and increasing the nutritional quality of the seagrass.

#### **9.1.4 Objective 4. Determine what factors affect the risk of boat strikes to dugongs by observing their behaviour while boats are passing opportunistically**

Of the 25 instances where I filmed boats passing opportunistically within 50 m of dugongs herds, four passed directly over the top of dugongs in shallow water (< 4 m). All four boats were travelling above planing speed within the Moreton Banks Dugong and Turtle Go Slow Zone where boats are required to remain below planing speed. It was clear from the blimp-cam footage that speed is the main factor determining the risk of boat strikes to dugongs. I hypothesise that there are four stages in the response of a dugong to an approaching boat:

- (1) unaware – the dugong cannot detect the boat and thus no response is observed,
- (2) detection – the dugong detects the boat but does not perceive the boat as a threat,
- (3) response – the dugong perceives the boat as a potential threat and exhibits an obvious behavioural response, though the energetic cost of fleeing is still perceived to be higher than the risk of boat strike due to the uncertainty of the boat's direction and thus the appropriate flee direction,
- (4) flee – the flee response is evoked because the risk of strike is perceived as greater than the cost of fleeing.

Boat speed is the main factor affecting the risk of boat strike because the time available for a dugong to flee is equal to the time the boat takes to travel the distance from the flee threshold to the dugong. It should also be noted that as speed increases, so too does the impact of the collision, all else being equal, and thus the risk of death or serious injury to the dugong.

#### **9.1.5 Objective 5. Assess whether disturbance from boats significantly affects the time available for normal behaviours, or has the potential to cause displacement from key habitats**

During my experimental trials, an aluminium dingy with a 20 HP engine was driven past the edge of a dugong herd within the regulated speed limit (below planing). Either one or five consecutive passes were conducted to determine whether repeated passes caused a higher level of disturbance. Each pass was either continuous or included a stop and restart when the vessel reached the dugong herd. No significant relationships were found between the distance of the boat from the focal animal and the duration, distance or direction of its subsurface behaviour. The percentage of time spent feeding and travelling by individual dugongs over a 4.5 min interval was also unaffected by the boat's passing, the number of passes made, the continuity of pass, or the focal individual's position in the herd relative to these three factors. Thus any response to the boat was delayed and short. The behaviour exhibited by focal dugongs during the subsurface interval corresponding with the time of the boat's closest approach was affected by the distance of the boat's approach. Individuals were less likely to remain feeding when the boat passed within 50 m than if it passed at greater than 50 m.

Feeding herds exhibited obvious mass movements in response to some boats, however, the average duration of these movements was only 122 s. This time was not affected by the distance or speed of the boat. According to the current levels of boat traffic at my study site, the Moreton Banks, boats currently disturb dugongs for 0.8 – 6% of the day. I consider that this level of disturbance presents little risk of affecting dugong populations at this site. However, it should be noted that my observations were conducted over winter. Higher levels of boat traffic, and thus disturbance, may occur during other times of the year such as the summer holiday period, that during my field seasons. Boat traffic is likely to increase if numbers of registered boats in Queensland

continue to increase at current rates. Thus the proportion of time dugongs are disturbed by boats may also increase.

### **9.1.6 Objective 6. Determine whether pingers have the potential to alienate dugongs from their important habitat areas**

Direct observations of dugong behaviour in response to 10 kHz pingers suggests there is little risk of dugongs being alienated from key habitat areas by this sound source.

Compared with silent pingers, active pingers did not affect the rate of dugongs moving from an ensonified area. Dugongs fed within the ensonified area throughout the pinger experiments and passed between two pingers at the same rate irrespective of whether they were active or inactive. Although the potential effectiveness of pingers on nets was not specifically tested in this study, my observations suggest that 10 kHz pingers may not prevent dugongs from being entangled in fishing nets. The pingers did not cause dugongs to flee from, or avoid the ensonified area, or the space between the pingers where a net would be situated. Conversely, my results suggest that it is unlikely that pingers would work by stimulating dugongs to investigate their surroundings and see the net, as the orientation of dugongs did not change when active pingers were deployed.

### **9.1.7 Applicability to other dugong populations**

My study has greatly improved the knowledge of the behaviour of dugongs on the Moreton Banks and provides an assessment of the response of dugongs on the Moreton Banks to boats and pingers. I have used the responses of dugongs in this area to predict the likelihood of these two human activities affecting other dugong populations.

However, in order to determine the applicability of these predictions, the specific environmental factors affecting dugong movements and behaviour at other important habitat areas need to be tested. It would be time consuming and expensive to conduct empirical tests at every site. Therefore, in this chapter I present a risk assessment framework that can be used by managers when assessing current or potential human activities in important dugong habitat areas. I then provide recommendations for managers according to the results I have obtained during this study. I also outline future research that would improve baseline knowledge of dugong behaviour.

## 9.2 Boat strikes: a risk assessment

Boat strikes appear to be a more immediate threat to dugong populations than disturbance from boats or pingers. Nonetheless, as discussed in Chapter 1, the impact of boat strike mortalities on the population status of dugongs would be difficult to monitor. Population estimates are confounded by movements. Consequently, trends will not be detected for many years, and the population may decline to a critically low level during this time (Marsh *et al.*, in press). Marsh *et al.* (in press) advocate monitoring human impacts on dugong populations by using Wade's (1998) Potential Biological Removal (PBR) method. The PBR is the maximum rate of anthropogenic mortalities that can occur while still maintaining an optimal sustainable population (Section 1.3.3). According to Marsh *et al.*'s (in press) most conservative estimate of the PBR for dugongs on the urban coast of Queensland from Cairns south, managers should be aiming to reduce human-related dugong mortalities to zero. I also used the PBR method to determine that the current level of boat strikes in Moreton Bay is not sustainable (Appendix 4). Although the number of mortalities from boat strikes is currently small in comparison to those from indigenous hunting (Marsh *et al.*, 2003b), managers should be aiming to reduce all human caused mortalities. It should also be noted that according to the Australian Law Reform Commission, traditional hunting should take priority over both commercial and recreational non-traditional activities (Australian Law Reform Commission, 1986). Thus the issue of boat strikes is of immediate concern and managers need to determine methods to prevent this cause of mortality, particularly as boating activity increases in Queensland.

In order to reduce dugong mortalities, managers need to consider the factors that affect this risk relative to each area in which dugongs are found. This would allow managers to focus efforts to reduce boat strikes in high risk areas, as well as assess the risk presented by future developments. The risk posed by any adverse event is the product of two components: (1) the probability of the event occurring, and (2) the consequences if the event occurs (Whyte & Burton, 1980). The level, type and speed of the boat traffic, the number of dugongs, and the habitat characteristics in an area are all factors that affect the probability and consequences of boat strikes.



I have developed a risk assessment framework based on the main factors that affect the probability and consequences of boat strikes occurring (Table 9.1). To show how this framework should be implemented I have provided examples using two areas in each of three locations where dugongs occur. The risk of boat strikes is assessed for each area by scoring each factor with high, medium and low values. These values are based on the knowledge available from my research and studies by Preen (2001), Groom (2003), and Groom *et al.* (2004). The overall score given for the probability and consequence of boat strikes in each area is based on the number of high, medium and low scores for the various factors. However, in implementing this risk assessment framework, each factor would need to be ranked according to its level of influence on the probability and consequence of a boat strike in order to provide an accurate assessment of risk. Thus the examples provided here highlight the information needed to accurately assess the risk of boat strikes, rather than providing a conclusive risk assessment. In the following I discuss each location and provide recommendations to reduce the risk of boat strikes within these sites.

**Table 9.1** The risk of boat strikes in six locations along the urban coast of Queensland, based on the probability and consequence of a boat strike occurring. Probabilities and consequences are scored according to the likelihood of a range of scenarios. These likelihoods are scored using information known about boat traffic and dugong presence in each location. Where this information is unknown, scores are estimated, as indicated by ‘?’.

		Moreton Bay		Cleveland Bay <sup>3</sup>		Hinchinbrook Area <sup>3,4</sup>	
		Southern Bay Islands <sup>1</sup>	Moreton Banks <sup>2</sup>	Townsville Port	Eastern Area	Missionary Bay	Hinchinbrook Channel
Probability	average number of boats transiting	high	med	high	med?	med	med
	average number of dugongs	low	high	low	high	high	low
	likelihood that if present, dugongs will be in the boat's path (i.e., size/width of area)	high	low	low	med?	med	low?
	the likelihood of dugongs being in shallow water (i.e., < 2 m)	high	med	low	med	med	med?
	median draft of boats (i.e., likelihood of being > 1 m)	high	low	high	low?	low	low?
	median speed of boats (i.e., likelihood of being > planing speed)	high	med	high	high?	med	high?
	median mass of boats (i.e., likelihood of boats being > 6 m)	high	low	high	low?	low	low?
	likelihood that a boat will have a propeller with no guard	high	high	high	high	high	high
	<b>Probability of a boat strike</b>	<b>high</b>	<b>med</b>	<b>med</b>	<b>med</b>	<b>med</b>	<b>med</b>
	<b>Consequences of a boat strike (severity of injury on impact)</b>	<b>high</b>	<b>med</b>	<b>high</b>	<b>med</b>	<b>med</b>	<b>med</b>
<b>RISK</b>	<b>HIGH</b>	<b>MED</b>	<b>MED-HIGH</b>	<b>MED</b>	<b>MED</b>	<b>MED</b>	

Sources of information:<sup>1</sup> (Groom *et al.*, 2004), <sup>2</sup> this study, <sup>3</sup> (Preen, 2001), <sup>4</sup> (Groom, 2003)  
 med = medium

## 9.2.1 Moreton Bay Marine Park

### 9.2.1.1 *Current boat strike record*

Moreton Bay (Figure 9.1a) has the highest recorded incidence of dugong mortalities from boat strikes on the east coast of Queensland from Cairns to the southern Queensland border, with at least 13 mortalities since 1996 (Limpus *et al.*, 2003a; Miles Yeates, *pers. comm.*). Most carcasses with boat strike injuries in Moreton Bay (11 individuals including a mother and calf since 2001; (Limpus *et al.*, 2003a; Miles Yeates, *pers. comm.*) have been recovered from the Southern Bay Islands area (Figure 9.1c). The only report of a boat strike from the Moreton Banks area occurred prior to the implementation of the Go Slow Zone. A carcass with propeller wounds was found outside the bay at the northern end of North Stradbroke Island. According to Yeates and Limpus (2002), records of tagged turtle carcasses found in the same location show that they are usually from the Amity Banks (inside the bay adjacent to Stradbroke Island) or Moreton Banks, and probably carried by currents through the South Passage. It should be noted that dugong carcasses could conceivably be carried to open ocean in this manner and never retrieved. Thus mortality rates of dugongs on the Moreton Banks may be under-estimated.

### 9.2.1.2 *The Southern Bay Islands area*

#### 9.2.1.2.1 *Probability of boat strikes*

In contrast to my study site, the Moreton Banks (Figure 9.1b), the Southern Bay Islands area has not previously been considered an important dugong habitat area. In addressing the issue of boat strikes around the Southern Bay Islands, the Queensland Parks and Wildlife Service (QPWS) contracted researchers to determine the distribution of dugongs at this site (Groom *et al.*, 2004). They found that the area supports relatively few dugongs (Figure 9.1c), with only 9 sightings of 10 dugongs over a 25 day period (Groom *et al.*, 2004). However, as shown in Table 9.1, there is a high probability of boat strike in this area because of the nature of the boat traffic and the characteristics of the habitat in which dugongs and boats occur.

A relatively high level of boat traffic occurs in the Southern Bay Islands area as a result of its proximity to Brisbane, the capital city of Queensland (Figure 9.1a), which has a population of 1.7 million people (Australian Bureau of Statistics, 2003). Approximately 3,000 people inhabit the larger of the islands and use private boats or water taxis to regularly traverse to the mainland (Yeates & Limpus, 2002). However, under the land use and planning strategy for the area there is provision for the population of the islands to increase to over 22,600 people (Redland Shire Council, 2002). The area is classified as a Conservation Zone according to the *Marine Parks (Moreton Bay) Zoning Plan 1997* (Appendix 1), and the new zoning plan proposed by the Queensland Environmental Protection Agency (Figure 9.1a). Boating and fishing are allowed, with the only restriction being that jet skis must remain within navigation channels. Water taxis pass through the areas used by dugongs approximately 60 times per day (Figure 9.1c), along with barges and large recreational boats (Yeates & Limpus, 2002; Groom *et al.*, 2004). To accommodate the projected increase in demand for transport between the islands and the mainland, the planning strategy includes provision for increased ferry services (Redland Shire Council, 2002). There are currently no speed limits in the Southern Bay Islands area and the water taxis and recreational boats regularly travel at speeds in excess of 20 knots (Rachel Groom, *pers. comm.*).

The waters within Southern Bay Islands area are relatively shallow (< 3 m). The water taxis that regularly pass through the area are likely to have a large draft (1 – 1.2 m), and thus there is little opportunity for dugongs to escape from boats by diving under them. This boat traffic is concentrated into narrow boating channels that in some areas are less than 100 m wide. During low tide, the habitat available to dugongs is restricted to these boating channels (Groom *et al.*, 2004) and thus the likelihood that dugongs will be in the path of an approaching boat is relatively high. In addition, Groom (2004) observed boat keel marks on the surrounding seagrass beds, which also contained dugong feeding trails.

#### 9.2.1.2.2 Consequences of boat strike

The large boats, including water taxis and barges, that regularly pass through the Southern Bay Islands area at high speed, have relatively large draft and no propeller guards. With this combination of factors, collisions between boats and dugongs are

likely to be fatal to the animals. Evidence supports this assumption as the propeller cuts on most dugong carcasses found in this area are consistent with those made by large vessels rather than from outboard motors (Yeates & Limpus, 2002). A mother and calf were sighted within the boating channel 20 m from the path of a water taxi during the period of Groom *et al.*'s (2004) study. A mother and calf, possibly the same animals, were subsequently found fatally injured by large propeller wounds (Groom *et al.*, 2004). In addition, the severity of collisions in this area are amplified by large draft of the boats and shallow water. Dugongs compressed between a boat's hull and the sea floor can be killed as a result of fractured ribs and ruptured organs (Yeates & Limpus, 2002).

### **9.2.1.3 Recommendations**

Despite the Southern Bay Islands area being inhabited by relatively few dugongs, the high risk of boat strikes in this area has resulted in the relatively large number of mortalities currently occurring (Groom *et al.*, 2004). Groom *et al.* (2004) advocate the implementation of a go slow zone with speed limits of 4 – 5 knots in the areas where dugongs were sighted during their survey (Figure 9.1c). They also recommend that compulsory vessel lanes be introduced in the area so that boats are not permitted to traverse shallow seagrass beds where dugong feeding trails were sighted. Other recommendations include compulsory propeller guards on water taxis, and that QPWS, along with the Queensland Department of Transport, investigate the efficacy of using hovercraft as water taxis. These two latter measures may reduce the impact of boat strikes on dugongs, and thus may reduce mortality rates (Groom *et al.*, 2004).

### **9.2.1.4 The Moreton Banks**

#### *9.2.1.4.1 Probability of boat strike*

A moderate level of boat traffic occurs on the Moreton Banks, which are located on the eastern side of Moreton Bay, adjacent to Moreton Island (Figure 9.1a; Chapter 2). There are few residents on Moreton Island, which is 98% national park and currently supports a sparse population of holiday houses, and a tourist resort. According to the boating activity recorded during my study (winter), boats pass within 1 km of dugong herds on the Moreton Banks approximately 1.5 times per hr, and within 50 m of herds

approximately 0.2 times per hour (Section 6.3). The speed restrictions associated with the Go Slow Zone on the Moreton Banks (Figure 9.1b; Chapter 2; Appendix 1), limit the number of boats travelling above planing speed. However, I observed a 64% non-compliance rate of boats within the Go Slow Zone (Section 6.3).

In contrast to the Southern Bay Islands area, the Moreton Banks support large herds of dugongs (Chapter 3). During high tide dugongs occur at average depths of 1.7 m (Section 3.3.1.2), however, the likelihood of a dugongs being in a boat's path is low because of the size of the Moreton Banks, which allow dugongs and boats to be distributed over a relatively large area.

The probability of boat strikes is increased during low tide when dugongs occupy the edges of the seagrass banks, which places them outside the Go Slow Zone (Figure 9.1b). In addition, during low tide, the banks are too shallow for boats to traverse, and boaters usually travel around the edges of the banks (*pers. obs.*), where dugongs are located. However, the deeper water occupied during low tide (average 2.5 m; Section 3.3.1.2) may moderate the risk of boat strikes while dugongs are feeding as they are unlikely to be crushed between a boat and the substrate.

The draft of boats on the Moreton Banks is generally shallow as the area is mainly used by small recreational boats (< 6 m; *pers. obs.*). I observed dugongs being run over by boats during low tide (Section 6.3), and some appeared to remain between the boat motor and the substrate, but did not appear to be injured. Thus despite the shallow water depths at this site, the fact that most boats are relatively small may reduce the risk of lethal collisions.

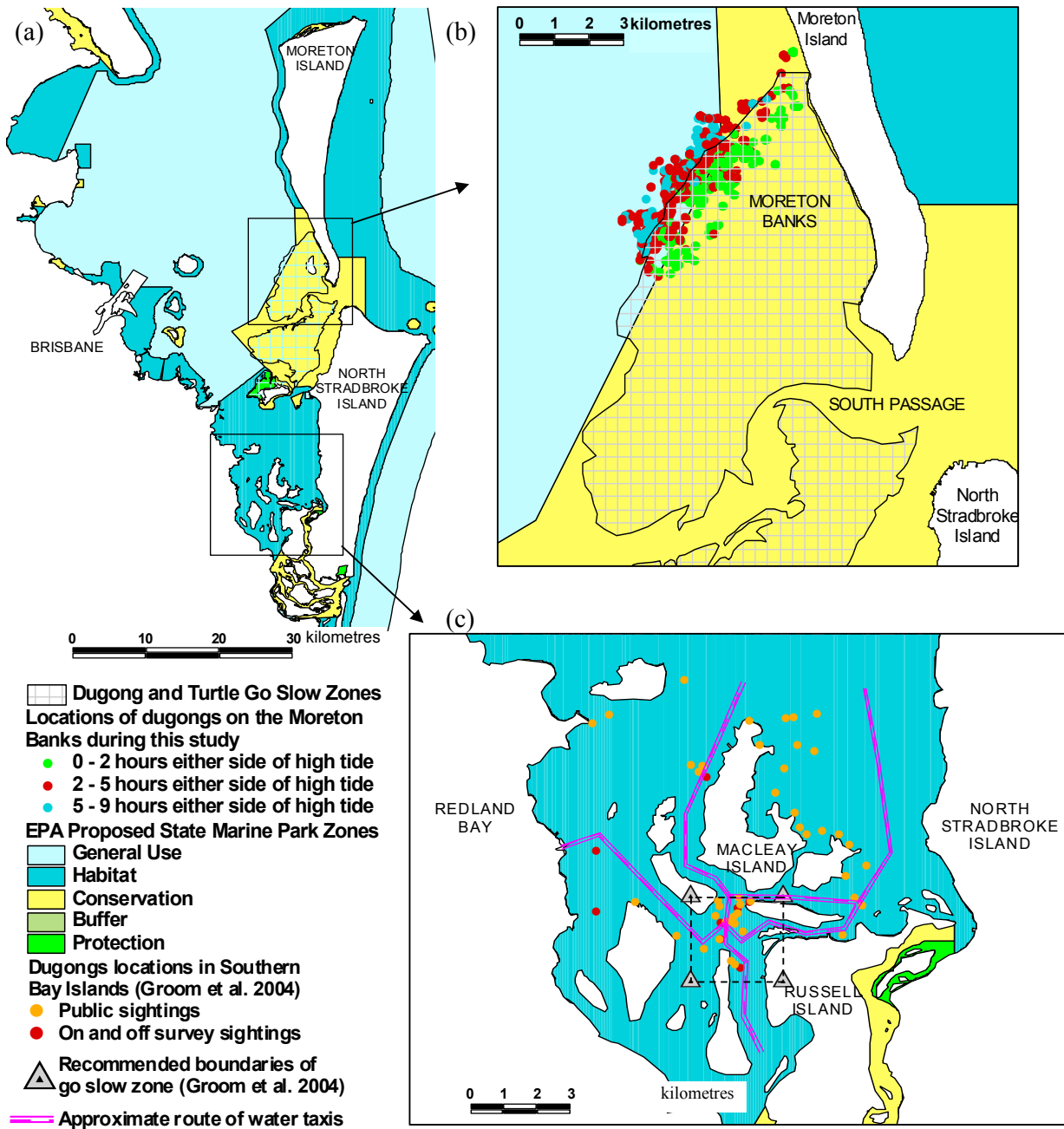
#### *9.2.1.4.2 Consequences of boat strike*

Though dugongs on the Moreton Banks are likely to be in shallow water, the small size of boats and speed restrictions should reduce the severity of injuries to a dugong in a collision with a boat on the Moreton Banks in comparison with the Southern Bay Islands area. The consequence of a collision with a boat not complying with speed restrictions, or with boats outside the Go Slow Zone would be more severe. Dugongs on the banks are susceptible to propeller cuts as most boats I observed had outboard motors

(Section 6.3), which are unlikely to have been equipped with propeller guards as they are not a requirement.

#### ***9.2.1.5 Recommendations***

In summary, dugongs on the Moreton Banks appear to be at relatively moderate risk of boat strike as a result of the speed restriction in the area. The risk of boat strikes could be reduced further by extending the Go Slow Zone to include the low tide habitat of dugongs. The implementation of a blanket speed restriction in this area seems appropriate considering there is relatively little boat traffic traversing the Moreton Banks. I found that the herds move steadily across the Moreton Banks as they gradually deplete the seagrass beds, and return to similar areas at similar times of the year (Section 3.3.1.1). In this situation, transit lanes that cut across these banks would be inappropriate, as dugong herds would spend an extended portion of time within the lanes at some times of the year depending on their use of the banks relative to the location of the vessel lanes.



**Figure 9.1** (a) Map of Moreton Bay indicating the location of (b) the Moreton Banks and (c) the Southern Bay Islands area. Current and proposed zoning plans, and the locations of dugongs are shown to illustrate the relative risk of boat strikes in each of these areas.



## 9.2.2 Cleveland Bay

### 9.2.2.1 *Current boat strike record*

No boat strikes of dugongs have been reported or recorded on record for Cleveland Bay. (Limpus *et al.*, 2000; Haines & Limpus, 2001; Haines & Limpus, 2002a; Limpus *et al.*, 2003a; Kristy Currie, *pers. comm.*).

### 9.2.2.2 *Townsville Port*

#### 9.2.2.2.1 *Probability of boat strike*

Cleveland Bay borders Townsville, a major city with an expanding population. The most recent figures show that Townsville's population increased at a rate of 1.9% per year during 1996 to 2001, and the projected population figures show an increase from 146,000 people in 2001, to 171,000 in 2011 (Hornby, 2003). The port is under the control of the Townsville Port Authority and thus is not part of the Great Barrier Reef Marine Park (GBRMP). In the 2002/03 financial year, a total of 803 heavy vessels (> 200 tonne) passed through the port (Townsville Port Authority, 2003). Adjacent to the port is a 243 berth marina and thus a large amount of recreational boat traffic also passes through this area. In addition, ferries travelling at up to 30 knots traverse between the Townsville Port and Magnetic Island 15 times per day.

This high level of boat traffic poses a risk of boat strike to dugongs as Preen's (2001) tracking data showed that dugongs occasionally travel across the port zone. However, the probability of a boat strike is much lower than in the Southern Bay Islands area for two reasons: (1) vessels in the Townsville Port travel across a wide expanse of water, which reduces the likelihood of a dugong being in the path of a vessel, and (2) dugongs do not appear to occur consistently within the port zone (Preen, 2001). In contrast, the mother-calf pair observed within the boating channel in the Southern Bay Islands area had been observed repeatedly in that area by the public (Rachel Groom, *pers. comm.*). Nonetheless, if a dugong is in the path of a boat, its opportunity to escape is reduced by the large draft (up to 13.1 m) and width (up to 37 m) of many of the vessels (Townsville Port Authority, 2003), and the high speeds of ferries and ships.

#### *9.2.2.2.2 Consequences of boat strike*

The size of the ferries and ships in the Townsville Port means that collisions are likely to be fatal to dugongs. Propeller wounds are also likely from ferries as these vessels are not equipped with propeller guards. However, the deep water throughout most of the port controlled waters reduces the likelihood of dugongs being crushed between the vessels and the sea floor.

#### *9.2.2.3 Recommendations*

The Townsville Port is not heavily used by dugongs, and thus the probability of dugongs being hit is low. However, if struck by one of the ferries or ships passing through this area, dugongs are likely to be killed, which increases the overall risk of boat strike. Preen (2001) found that dugongs passed through this area when moving from one site to another. Another important consideration is the potential changes in dugong movements and distribution patterns. Following a cyclone in late 1971, particularly high capture rates of dugongs occurred in shark nets set for bather protection along Townsville beaches (one within the Townsville Port) and at Picnic Bay, Magnetic Island (Heinsohn & Spain, 1974). Heinsohn and Spain (1974) suggest that this was a result of dugongs moving to find food after much the seagrass beds were destroyed. In this situation, large numbers of dugongs would be moving across the boating lanes of the Townsville Port, greatly increasing the risk of boat strike. Dugongs appear to travel along the sea floor when moving long distances (James Sheppard, *unpublished data*) and this may serve to minimise the potential for dugongs to be struck by boats within the Townsville Port. Further research on movements of dugongs through this area is needed to provide a more accurate risk assessment.

#### *9.2.2.4 Eastern Area of Cleveland Bay*

##### *9.2.2.4.1 Probability of boat strike*

Preen (2001) found that the highest number of dugongs in Cleveland Bay occurred in the shallow eastern area as shown in Figure 9.1c. The area is divided into mostly

Conservation Park and some General Use Zones according to the GBRMP zoning plan, and thus boating and fishing are permitted. The area is also classified as a Dugong Protection Area, Zone A, however this classification restricts the use of gill nets rather than boating. Planned future developments in to accommodate the increasing human population in Townsville include a large marina which will double the number of boat berths available in Cleveland Bay (Townsville City Council, n.d.). Thus the number of recreational boats using this eastern area of the bay is likely to increase.

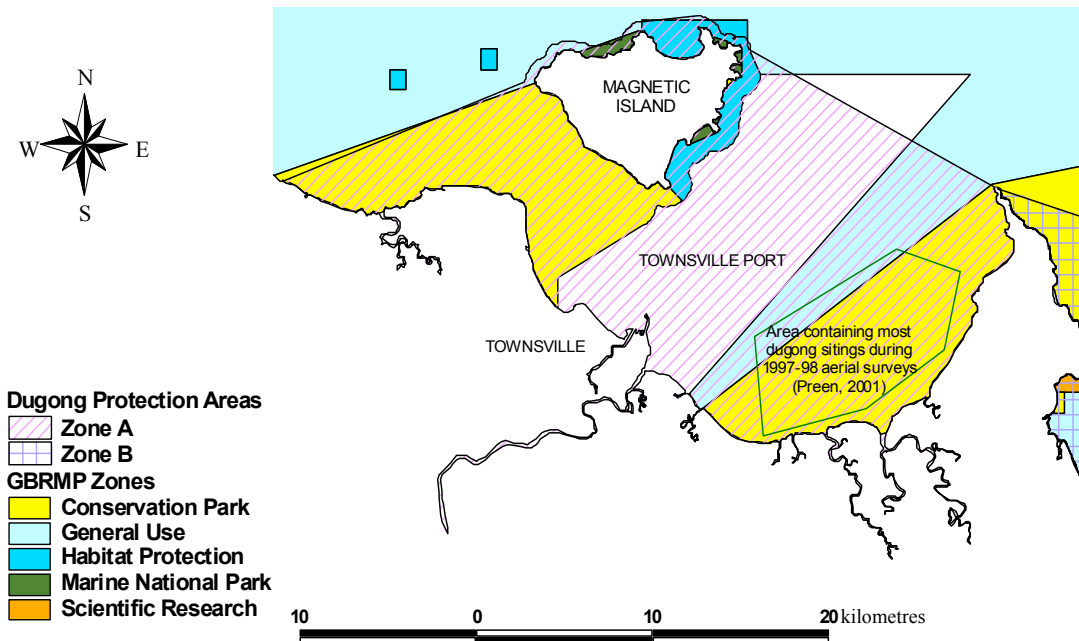
The important feeding areas for dugongs in relation to boat traffic in this eastern area is unknown, and thus it is difficult to assess the likelihood of dugongs being in the path of boats. However, dugongs in eastern Cleveland Bay often occur in waters less than 2 m deep (Preen, 2001; Guido Parra, *pers. comm.*), and thus are unlikely to be able to escape from boats by diving beneath them.

#### *9.2.2.4.2 Consequences of boat strike*

If most boats using the area are recreational fishing boats, then they are likely to be small (i.e., low mass), however the lack of speed restrictions in the area increases the likely force of impact. As propeller guards are not required in this area, dugongs hit by boats are likely to sustain propeller wounds, and the shallow water increases the likelihood of dugongs being crushed against the substrate.

#### *9.2.2.5 Recommendations*

Although dugongs in Cleveland Bay are at lower risk of being struck by ferries than those in the Southern Bay Islands area, there is no protection from boat strikes afforded to dugongs in the eastern bay. Thus dugongs in Cleveland Bay appear to be at higher risk of boat strike than those on the Moreton Banks. I recommend that the habitat use by dugongs and the boating activities in this eastern bay area be further investigated to better estimate the risk of boat strikes and whether zoning changes are needed to reduce this risk.



**Figure 9.2** Map showing the zoning plans in relation to the area used by dugongs in order to estimate the risk of boat strikes to dugongs Cleveland Bay, Southern GBRMP. The Townsville Port is outside of the GBRMP and thus is not zoned.

### 9.2.3 The Hinchinbrook area

#### 9.2.3.1 Current boat strike record

Two dugong mortalities resulted from boat strikes in Missionary Bay, Hinchinbrook in 1996 (Col Limpus, *pers. comm.*). Since that time there have been no incidents reported in the Hinchinbrook area (Limpus *et al.*, 2000; Haines & Limpus, 2001; Haines & Limpus, 2002a; Limpus *et al.*, 2003a; Kristy Currie, *pers. comm.*).

#### 9.2.3.2 Missionary Bay

##### 9.2.3.2.1 Probability of boat strike

The permanent human population of the Hinchinbrook region is relatively static (Environmental Protection Agency, 2003). However, the rapidly growing tourism industry in the area means that this population can double during the peak tourism season from May to October (Environmental Protection Agency, 2003). The most

significant recent development in the area was Port Hinchinbrook, which includes a new boat ramp and marina. Preen (2001) observed an increase in the boating activity in the area as a result of this development during his 1997-98 surveys of Missionary Bay, however subsequent surveys by Groom (2003), showed no further increase in boat traffic.

Although part of the Hinchinbrook area is classified under a state zoning plan rather than the federal GBRMP zoning plan, these plans are congruent, and the zones are classified in the same way. Missionary Bay is divided into Conservation Park and General Use Zones (Figure 9.3), and thus recreational boating activity is not unrestricted. However, the Hinchinbrook Plan of Management (GBRMPA, 2004) and Draft Hinchinbrook Marine Management Plan (QPWS, 2001), recognise Missionary Bay as a “sensitive location” because the area supports a large number of dugongs (Preen, 2001; Figure 9.3).

The Great Barrier Reef Marine Park Authority (GBRMPA) and the Hinchinbrook Local Marine Advisory Committee, introduced Voluntary Vessel Transport Lanes in 2002 and installed navigation markers. Boats can travel at speeds of 25 knots within these lanes and are encouraged to travel at a voluntary speed limit of 10 knots when over seagrass beds or near large sea animals (QPWS, 2001; Figure 9.3). The objective of these transit lanes is to direct boat traffic away from shallow seagrass beds where boat strike risk to dugongs is considered particularly high. There is however, a large expanse of shallow seagrass beds in Missionary Bay that must be traversed in order for vessels (including ferries) to reach popular locations on Hinchinbrook Island (e.g., the Hinchinbrook Resort boardwalk). Thus there is a transit lane that crosses these seagrass beds. There is a moderate risk that dugongs will be in the path of boats as dugongs are known to feed near some of the lane markers (Groom, 2003). Given these circumstances, the efficacy of transit lanes in this area is questionable.

However, an even greater problem with this management strategy is a lack of boater compliance. Only 26% of boats travel within the transit lanes, and 80% of boats traverse the shallow seagrass beds in Missionary Bay at speeds greater than the voluntary non-planing speed (Groom, 2003). In addition, Groom (2003) found that dugongs moved to intertidal waters close to Hinchinbrook Island during high tide, an area which is heavily

used by boaters seeking sheltered waters. Thus boats and dugongs are restricted to a shallow area, further increasing the likelihood that dugongs will be in the path of boats, and the probability of dugongs being struck by boats.

#### *9.2.3.2.2 Consequences of boat strike*

Large boats (> 20 m) are not permitted in Missionary Bay (QPWS, 2001; GBRMPA, 2004). Together with the voluntary speed limits, this regulation should minimise the impact of boat collisions with dugongs. However as discussed above, there is an extremely low rate of compliance with this speed limit, and a large number of speed boats (< 7 m length) using the area (Groom *et al.*, 2004). Few of these boats are likely to have propeller guards as they are not compulsory and thus propeller injuries are likely to occur as a result of boat strikes. Furthermore, most of the bay is less than 2 m deep which increases the likelihood of dugongs being crushed beneath boats.

#### **9.2.3.3 Hinchinbrook Channel**

##### *9.2.3.3.1 Probability of boat strikes*

The increase in boating activity as a result of the Port Hinchinbrook development observed by Preen (2001) was mainly in the Hinchinbrook Channel. The channel is also heavily used by dugongs (Preen, 2001). A voluntary transit lane is marked in the Hinchinbrook Channel where boaters are “encouraged” to travel at a maximum of 25 knots, and again, a voluntary non-planing speed limit applies to surrounding shallow seagrass beds (QPWS, 2001). The Draft Hinchinbrook Marine Management Plan also proposes that no water sports be permitted in the channel (QPWS, 2001). The Hinchinbrook Channel is relatively wide, and thus the likelihood of dugongs being in the path of boats in Hinchinbrook Channel is probably lower than in the boating channels of the Southern Bay Islands (Moreton Bay) The Hinchinbrook Channel is also deeper (up to 10 m), affording dugongs a higher chance of diving beneath boats than in the Southern Bay Islands. However, Preen’s (2001) tracking data shows that dugongs often traverse the transit lane, and there is presumably a similar low level of compliance with the voluntary transit lanes as in Missionary Bay.

#### *9.2.3.3.2 Consequences of boat strike*

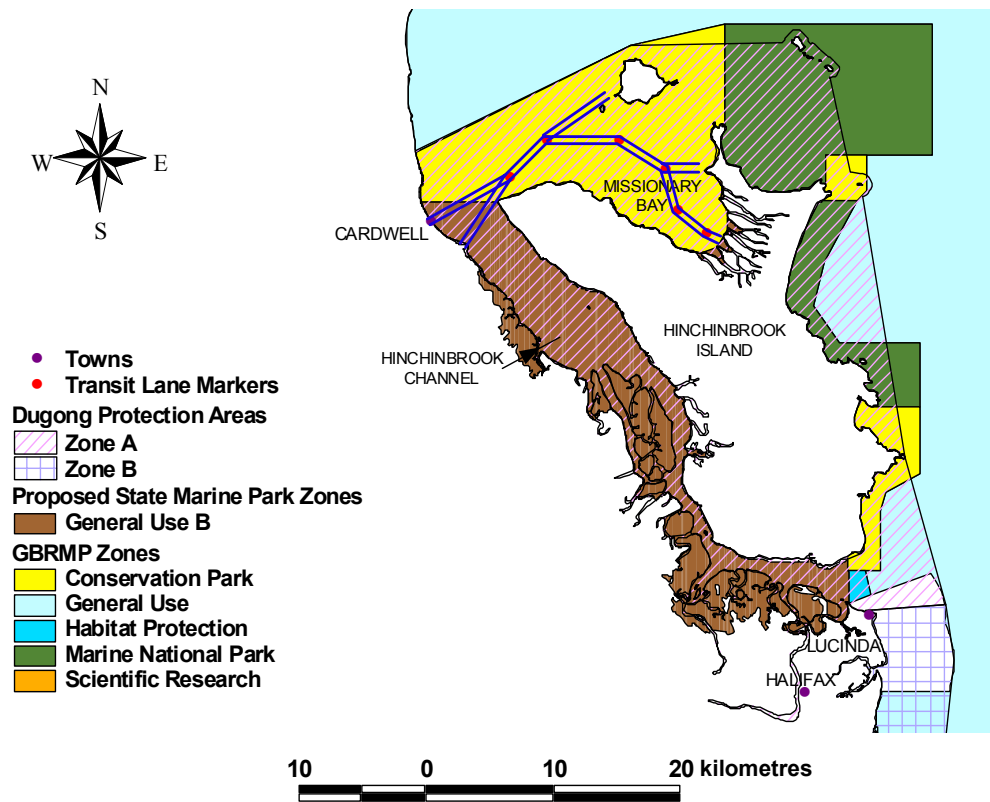
Boat strikes in the Hinchinbrook Channel are less likely to cause dugongs to be crushed beneath boats than in Missionary Bay as the area is deeper. However, there is no restriction on boat size in the channel, thus the force of impact of boats could be high. Boats are not required to have a propeller guard and thus propeller injuries are likely during collisions. The consequences of boat strikes would be highest on the shallow seagrass beds at the edges of the channel. There is no information on whether boaters comply with the voluntary speed limits over these seagrass beds.

#### **9.2.3.4 Recommendations**

Groom (2003) concludes that the current management strategy of encouraging boaters to adhere to voluntary speed limits and transit lanes is ineffective, suggesting that in Missionary Bay, dugongs are still at relatively high risk of boat strike, particularly if further development of maritime facilities in the area increase boat use. The topography of the Hinchinbrook Channel, and the fact that high speed ferries do not traverse this area means that dugongs are likely to be at lower risk of boat strikes in this channel than the boat channels around the Southern Bay Islands, Moreton Bay. The Cardwell foreshore area may pose a high risk of boat strikes to dugongs but further observations of dugongs in relation to the movements of boats along this area are needed. Groom (2003) recommends that measures to reduce boat strike risk in the Hinchinbrook area be enforced rather than voluntary. There appears to be limited value in boat transit lanes which cross shallow seagrass beds where high densities of dugongs occur.

Implementation of regulated go slow zones (less than planing speed) over the entire Missionary Bay area would reduce the risk of boat strikes to dugongs in this area.

Transit lanes in the Hinchinbrook Channel, however, are a method of directing boat traffic away from the shallow seagrass areas and may reduce the risk of boat strikes in the channel.



**Figure 9.3** Map showing both the state and federal (GBRMPA) zoning in the Hinchinbrook area, and voluntary transit lanes designed to reduce the risk of boat strikes.

### 9.3 Further management considerations

#### 9.3.1 Compliance with speed restrictions

Although my research advocates implementation of speed restrictions in important dugong habitat areas, these restrictions need to be adhered to in order for them to be effective. During my study, I filmed 25 boats passing within 50 m of the dugong herds on the Moreton Banks. Of these boats, 64% were travelling above planing speed (Section 6.3). As discussed above, Groom (2003) found that voluntary transit lanes and speed limits in the Hinchinbrook area had an even lower compliance rate (74% and 80% non-compliance respectively). Boater compliance within go slow zones designed to protect Florida manatees was not improved by introducing signs that appeal to boaters' fear of being fined (Sorice *et al.*, 2003), while surveys of boaters showed a lack of knowledge about manatees and confusion about the speed zones (Flamm *et al.*, 2003).



In the absence of studies on boater knowledge and behaviour in Australia, I use my experience on the Moreton Banks to make the following recommendations for increasing compliance with the go slow zones designed to protect dugongs.

1. **Policing:** QPWS Marine Parks could increase patrol pressure to ensure greater compliance with speed restrictions. During patrols, Marine Parks officers can provide information about speed restrictions and the justifications behind them to boaters who are speeding.
2. **Delineation of zones:** Go slow zones should have a clearly delineated and enforceable boundary, which encompasses areas used by dugongs at both high and low tide. This necessity is exemplified on the Moreton Banks where the Go Slow Zone is depicted by the 2 m depth contour, a boundary which is not obvious to a boater. As I have shown above (Section 9.2.1.4) dugongs are usually outside of this area during low tide where the risk of boat strikes remains relatively high. I suggest that an unambiguous boundary of the Go Slow Zone on the Moreton Banks be created and extended to include the entire area used by dugongs. In general, zone boundaries should be depicted by signed markers, similar to channel markers, clearly visible to boaters. The new zone boundaries within the GBRMP can now be installed on GPS units, providing boaters with a simple method of determining what activities are permitted in any location while on the water. This tool could also be used to provide boaters with accurate knowledge of speed restrictions as they as driving their boats.
3. **Signage:** Signs at the boundaries of Go Slow Zones are needed that state the speed limit, demark the boundaries of the zone, and give the consequences of speeding. At present on the Moreton Banks there are only two small signs alerting boaters to the Go Slow Zones, but which do not provide any of the above information. Thus to comply with the speed limits, boaters on the Moreton Banks must have acquired this information prior.
4. **Education:** Several education campaigns are currently being conducted by QPWS and local community groups in Brisbane. These include a series of television commercials with the slogan “go slow for those below”. It is important to carefully design these campaigns and evaluate their effectiveness through boater surveys if they are to result in actual changes in boater behaviour (Flamm *et al.*, 2003). The video footage I obtained using the blimp-cam shows

clear evidence that high-speed boats pose a danger to dugongs, and in my experience promotes a strong response in viewers when they see dugongs run over by boats. This footage may be a powerful tool in promoting awareness of this issue. Education programs should include other safe-boating practices such as manoeuvring boats around dugong herds, and passing dugongs on the shallow-water side to reduce the likelihood of dugongs swimming across the path of boats in an attempt to reach other members of the herd or deep water (refer to Section 6.3).

### 9.3.2 Technical alternatives to reduce boat strikes

Other than implementing speed restrictions, potential measures to reduce the risk of boat strikes of dugongs involve technical alternatives that fall into two categories:

- (1) Alert, alarm or warn the animals away from the boat's path, or
- (2) Enhance the detection of dugongs so that boat operators can change course and avoid them.

There is currently no device proven to successfully alert marine mammals and move them from a boat's path. If an alert / alarm device is proven effective, there may be energetic costs to the animals when disturbing and displacing them in this manner, which could have an impact on marine mammal populations (Chapters 5 and 7). At present, the use of pingers on boats is being investigated to reduce boat strikes of both North Atlantic right whales and Florida manatees. The sound signals used are designed to (1) be within the best hearing range of the target animals, (2) be audible above ambient noise, and (3) provide localisation cues for the animals so that they can determine the direction of the approaching boat (Gerstein, 2002; Gerstein & Blue, 2004; Nowacek *et al.*, 2004b). Nowacek *et al.* (2004b) found that North Atlantic right whales respond to these signals by abandoning their foraging dives, rising to the surface and remaining at or just below the surface for extended periods. This response actually increases the likelihood of boat strike. The response of manatees to Manatee Alerting Devices (MADs), which produce a directional beam of sound from the bow of a boat, has not yet been tested (Gerstein, 2002; Gerstein & Blue, 2004). During my study I did not detect a response from dugongs to 10 kHz pingers designed to reduce entanglements

in gill nets (Chapter 8). Thus it is unlikely that alerting devices such as MADS installed on boats would elicit a faster response from dugongs than boats without these devices.

Other techniques currently being trialled to reduce boat strikes of Florida manatees aim to detect and warn boaters of the presence of manatees. These include passive detection of manatee vocalisations using sonabuys combined with a warning system. Initial trials indicate that tonal vocalisations may be detectable over short ranges (to 10 m), but investigations of the rate of manatee vocalisations are needed to allow an evaluation of this method (Mann *et al.*, 2002). Dugongs vocalise relatively infrequently and their sounds don't appear to propagate very far (less than 50 m) in shallow water (*pers. obs.*). Thus this technique is probably unsuitable for reducing dugong boat strikes, particularly in areas of low dugong abundance.

In the absence of proven alternative technology to reduce the risk of boat strikes to dugongs, speed restrictions remain the most suitable mitigation strategy. However, as boat strikes are an increasing threat to marine mammals, new technology continues to be developed. It is likely that a combination of techniques will be required to mitigate boat strikes of dugongs, according to boat types, operational requirements and environmental factors as highlighted in Section 9.2.

### **9.3.3 Minimising disturbance**

Although the level of boat traffic on the Moreton Banks during winter probably has a minimal impact on the daily time budget of the dugongs at this site (Section 7.4.4), boating activity is likely to be higher during summer and is expected to increase in the future. I suggested in Sections 5.1 and 7.4.4 that the greatest impact of boat disturbance on the Moreton Banks may be the interruption of the dugongs feeding regime which allows them to cultivate the seagrass. These effects need further investigation as discussed in Section 9.4.3.2 below. In addition, there is likely to be interest in the development of dedicated dugong watching tourism at this site as these animals occur in large numbers in relatively clear, shallow water, and can be reliably located. A code of conduct for dugong tourism is currently being developed and experiments designed to test the effectiveness of the code (Birtles *et al.*, 2004). The following recommendations

to minimise the impacts of boating activities, were included in this code of conduct as they apply to both tourism and recreational boats:

1. Boaters should not approach within 50 m of dugongs. My research showed that dugongs are unlikely to remain feeding when boats pass within 50 m.
2. Boats should not be allowed to drift through herds. A boat drifting through a herd inevitably causes the dugongs in its path to move, which can then causes further disruption to the neighbours of those animals (*pers. obs.*). In the absence of further studies, I predict that disturbance is minimal if boats remain on the outer edge of herds.
3. Where boaters must traverse shallow seagrass banks, they should be encouraged to pass on the inshore side of dugongs if possible according to water depth. During this study, dugongs appeared to head towards deep water when threatened by a boat. Thus if boats are required to pass on the shallow-water side this should reduce the likelihood of dugongs fleeing across the front of boats.

#### 9.3.4 Implementation of pingers

Although my research does not suggest that 10 kHz pingers would adversely affect dugong populations by alienating them from their important habitat areas, I also found no evidence that 10 kHz pingers would reduce the risk of dugongs being caught in gill nets. There are no dedicated studies to support the effectiveness of pingers in reducing dugong bycatch. However, as discussed in Chapter 8, research has shown that cetacean species exhibit various responses to pingers, ranging from approach and attack, to avoidance. There is currently no knowledge of how Pacific humpback dolphins (*Sousa chinensis*) and Irrawaddy dolphins (*Orcaella brevirostris*) respond to pingers, and both species occur within the same range as dugongs. I caution against the use of pingers as a bycatch reduction device until further studies have been conducted to assess the behavioural response of all marine mammals occurring within the areas where gill netting is conducted.

## **9.4 Limitations and future research**

This study has overcome one of the main limitations of researching dugongs: the inability to track individual dugongs and observe their behaviour below the surface. There are still, however, many limitations in observing dugong behaviour I did not overcome, which I discuss below. In addition, my investigations of the effects of anthropogenic influences on dugong behaviour were limited by the following constraints: my field studies were conducted at a single site across limited seasons (i.e., two field seasons that occurred mostly in winter), and my experiments were limited to one particular boat and pinger type. Thus my research needs to be replicated in a variety of ways in order to conclusively determine the effects of boats and pingers on dugongs. In particular, my results are applicable to dugongs at the southern limit of their range, where their behaviour is likely influenced by water temperatures. Comparative studies in warmer waters are needed to ascertain the degree to which water temperatures affect dugong behaviour.

In Chapter 1, I outlined the reasons why studying the behaviour of a species is important in assessing the current impacts of human activities on a population, as well as predicting the future impacts of anthropogenic influences. Here I outline future research needs in order to overcome the limitations of my study and to equip managers with an understanding of dugong behaviour that will allow them to assess and predict human impacts.

### **9.4.1 Identifying individual dugongs**

#### ***9.4.1.1 Interpreting behaviour***

The most significant impediment in investigating dugong behaviour is that there is currently no method to recognise individual animals long-term, or to determine the sex of individuals other than mothers with calves without catching them. This constraint made it difficult for me to interpret some behaviours in terms of possible sexual or social connotations, and in most cases my ethogram is limited to a simple description of the behaviours observed. Developing an understanding of social behaviour relies on a

record of the history of interactions between individuals, which then provides a context for the behaviour and a basis for establishing association patterns (Mann, 2000). Knowledge of the long-term relationships between individual dugongs, and most importantly, the sex of these individuals, would enable a more accurate interpretation.

#### ***9.4.1.2 Social structure***

An understanding of social structure and mating systems can also be determined through understanding and documenting the long-term association patterns between known individuals, and knowing the sex of individuals. My research was limited to recording the length of time a focal individual maintained its position next to a nearest neighbour before the nearest neighbour changed. Using this measure of short term associations, there appeared to be little structure within herds. Sex and reproductive status could only be assumed for mothers with calves. Therefore preferences for nearest neighbour type was limited to these two categories. This assessment again showed little evidence of herd structure. There was, however, a tendency for mother-calf pairs to be separated from the herds. A more accurate knowledge of herd composition in terms of the male-female ratio, age and associations between individuals may reveal a structure within these herds that was not evident during my study. Some of this information may be revealed through a current mark-capture study of dugongs on the Moreton Banks (Lanyon *et al.*, 2002), though this study is limited to single adults, as capture of mothers with calves is not permitted in Australia (as noted in Section 3.1). Perhaps the most complete understanding of social structure and mating systems could be obtained from genetically sampling individuals to determine individual identity, sex, kinship, and possibly relative age (Dunshea, 2003), combined with behavioural observations.

#### ***9.4.1.3 Movement patterns and habitat use***

I was unable to ascertain whether the same individuals were present throughout each field season or from one field season to another. At present, knowledge of dugong habitat use and movements between habitats is based on tracking individuals over relatively short periods in the order of weeks to months (Marsh & Rathbun, 1990; Preen, 1992; Preen, 2001; James Sheppard, *unpublished data*). These animals could not be re-identified across years to determine whether the large scale movements over

hundreds of kilometres occur regularly, and whether individuals tend to revisit the same sites. Nor is there data on how levels of relatedness or social relationships determine the movement patterns of individuals. Knowledge of habitat areas may be passed on from mothers to calves or through social groups. This knowledge may affect the ability of dugongs to recolonise an area where the population is depleted through human influences such as boat strikes (Groom *et al.*, 2004), and the choices available to individuals in areas where the habitat is degraded such as in areas of high boat traffic. For instance, a dugong may not move to seemingly appropriate habitat in response to disturbance because it has no knowledge of that habitat, or because it is prevented by social dynamics from intermixing with individuals already in that habitat. That dugong may then exhibit an alternative strategy to cope with sub-optimum environmental conditions, such as reducing fecundity (Kwan, 2002). Thus the mechanisms that determine dugong dispersal and movement patterns effectively determine the area of habitat available to dugongs. With an understanding of these mechanisms, predictions could be made about how populations will respond to changing conditions such as increased boat traffic. The most reliable way to investigate these movement patterns is to identify individual dugongs and study their long term movements patterns.

#### **9.4.2 Long term studies**

As I have described above, social structure and mating systems can only be determined by examining long term associations between individuals, preferably in combination with genetic studies. My observations were limited to two field seasons, the first in winter and early spring, and the second in late autumn and winter. This limitation may have implications for behaviours I observed. Mating behaviour is probably seasonal in Moreton Bay as Preen (1992) noted that most new calves were observed in the summer months. Thus, further studies are needed during summer to determine the mating strategies occurring within this population. The behaviour of mothers with younger calves may differ from those I observed, as small calves are presumably the most vulnerable to attack by sharks. In addition, sharks appear to occur in larger numbers near the Moreton Banks in summer. Thus mothers with calves may spend more time vigilant and less time feeding, or seek herds more during the summer months.

Herd behaviour may also differ during summer when herds can be larger than those I observed (Preen, 1992; Lanyon, 2003). Warm water temperatures in the bay during summer mean that dugongs are less likely to travel outside the bay to access warm waters (Preen, 1992). Summer is also the growing season for the dugongs' preferred seagrass species. *Halophila ovalis* occurs during summer (McMahon, 2003), and thus there is likely to be more seagrass available than during my study. The relative size and density of dugong herds in relation to these effects of season may provide a greater insight into the feeding function of these large herds. Although I was able to show that the dugong herds were steadily moving across the banks throughout my field seasons, I could not determine how often dugongs revisit each area of seagrass. Expanding studies to the summer months would provide a better understanding of how the dugongs are cultivating the seagrass, and how much area on the banks is utilised by these herds.

### **9.4.3 Anthropogenic influences**

#### **9.4.3.1 Boat strikes**

In Chapter 6, I presented a theoretical explanation for my assertion that boat speed is the main factor affecting the risk of boat strikes to dugongs. This theory was based on my observations of dugongs that were run over by boats travelling at high speed. I proposed that dugongs respond to boats when the boats are at a distance where the perceived risk of boat strike is greater than the cost of fleeing, and that this distance is independent of boat speed. Speed restrictions meant I was limited to conducting boat pass experiments at below planing speed, and thus the risk of boat strikes in relation to boat speed could only be assessed from observations of opportunistic boat passes.

To test my theory on response thresholds (Section 6.4), further controlled experiments could be conducted using boats of various sizes and engine type, travelling at various speeds, and in various depths. It is likely to be difficult to obtain ethical approval to conduct controlled experiments to test the dugong's response to boats travelling at high speed. However, in my opinion, such experiments could safely be conducted in areas where dugongs form smaller groups than on the Moreton Banks, as long as all dugongs can be monitored continually throughout a boat pass using the blimp-cam, and there is reliable communication between the research vessel and boat conducting the



experimental passes. In addition, the pass boat should be equipped with a propeller guard.

The most valuable information that could be obtained from such further studies is how the response of dugongs to boats relates to water depth. I presume that dugongs on shallow seagrass beds are the most at risk of being hit by boats as they cannot dive deep to avoid boats. However, the dive response of dugongs to boats was not tested during this study. I noted that dugongs rest at the surface between long feeding bouts in deep water. Further research should investigate both the boat avoidance and surface resting behaviours of dugongs in deep water, and compare the relative risk of boat strikes to dugongs in deep and shallow water.

#### ***9.4.3.2 Boat disturbance***

My assessment of the effects of boat disturbance on dugongs had similar limitations as those described above for boat strikes. Further experiments need to be conducted to determine how different boat types and speeds affect the response of dugongs to boats. Most importantly however, my experiments need to be replicated at sites other than the Moreton Banks. The time spent responding to boats is likely to be dependent on the exposure of dugongs to boat noise. Dugongs on the Moreton Banks may be habituated to boat noise and those in areas with less boat traffic may be more sensitive to disturbance. Such potential differences have important implications for future developments or tourism, as increases in boat traffic may initially illicit stronger behavioural responses than those observed during this study.

The likelihood of dugongs being displaced as a result of increasing boat traffic may also differ according to location. Dugongs on the Moreton Banks were able to move in response to boats, while still remaining on the seagrass beds. Further studies should investigate the response of dugongs on small, isolated seagrass beds. The cost of disturbance may be greater when dugongs have to move off seagrass beds to avoid boat traffic, but have limited options in terms of moving to other seagrass patches (as discussed in Section 7.4.5).

### 9.4.3.3 Pingers

In this study, I tested the response of dugongs to only one type of pinger which produced sound with a fundamental frequency of 10 kHz. The other common frequency used in pingers is 4 kHz, and the response of dugongs to these pingers needs to be tested also. As outlined in Section 8.4, my experiments also need to be replicated with a control period in which the movement rates of dugongs with no pinger noise over the whole time period (30 min) of an experiment needs to be determined. According to my behavioural observations, 10 kHz pingers are unlikely to reduce the risk of incidental deaths of dugongs in gill nets. However, further research on the behaviour of dugongs around pingers attached to gill nets is needed to determine how dugongs respond when a net is present. These studies should be conducted in the varying habitats in which dugongs occur, as the propagation of pinger sounds will vary according to water turbidity, substrate type and depth (Richardson *et al.*, 1995; Baldwin, 2002).

## 9.5 Integration of behavioural studies in conservation

Efforts to conserve dugong populations are inhibited by our lack of knowledge about dugong behavioural ecology. My research has used direct behavioural observations to aid the conservation of dugongs in two ways: (1) by expanding our fundamental knowledge of dugong behaviour to allow better predictions of their responses to environmental change, and (2) by quantifying their response to human influences and determining the biological significance of these responses to provide an assessment of these impacts on dugong populations. By understanding the environmental pressures that have influenced the behavioural strategies employed by a species, it is possible to predict whether these strategies are flexible enough to cope with novel circumstances. I found that dugongs on the Moreton Banks do not appear to be affected by boat disturbance as they are able to avoid boats while still remaining on the large seagrass beds, and exhibit short, delayed responses that have little effect on their daily time budget. However this delayed response is an inappropriate strategy for avoiding boat strikes as it leaves dugongs vulnerable to boats travelling at high speed. Using this information managers can now direct conservation efforts towards reducing the risk of boat strikes to dugong.

One of the main reasons for the lack of emphasis on behavioural studies is the time scale required to obtain meaningful behavioural data. Conservationists and managers generally emphasise the need for studies that have direct application, while behaviouralists advocate fundamental research. However, often it is this fundamental research that can provide new insights that are valuable for conservation (Arcese *et al.*, 1997). This study has provided the first basic time budget and ethogram for dugongs which is the first step in quantifying dugong behaviour. I have also shown that the dugongs on the Moreton Banks exhibit a feeding strategy which almost certainly differs from dugongs in other areas with different environmental pressures. However, the environmental variables governing the feeding strategies and herding behaviour of other populations are unknown. Moreover, there is currently no information on the social structure of dugongs, and mating behaviour has only been documented in two locations, and the strategies appear different in each. Preen (1989) observed mating herds in Moreton Bay, while Anderson (1997) observed presumed males forming leks in Shark Bay. Long term studies of known individuals are needed to provide insight into the social behaviour, movement patterns and habitat use of dugongs, the flexibility of behaviours under varying environmental pressures, and how these pressures affect population parameters. This understanding will aid managers in setting appropriate mortality rate (PBR) targets, as advocated by Marsh *et al.* (in press), by providing a basis for setting appropriate maximum rates of population increase and recovery factors to calculate the PBR. In this respect behavioural studies are an essential tool, which when combined with studies of population trends and demographics, will enhance our ability to protect dugong populations.



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## **Appendix 1. Moreton Bay Marine Park Zoning Plan**

## **Appendix 2. Video footage of individual focal follows and opportunistic boat passes**

This DVD contains two video files:

- (1) Focal Follow Examples, which shows:
  - a) A focal follow of a single individual filmed at the focal length normally used, providing a field of view of approximately three body lengths either side of the dugong.
  - b) A close-up view of the same individual feeding and surfacing.
  - c) A close-up view of a calf suckling while the mother is feeding and surfacing (only short segments of the suckling bout are shown).
- (2) Dugongs and Boats, which shows:
  - a) A boat passing opportunistically under the non-planing speed limit. It drives through the middle of a herd and separates a mother and calf. The calf can be seen backtracking across the path of the boat to rejoin its mother.
  - b) An opportunistic boat pass at above planing speed. The boat ‘runs over’ two individuals which are circled in the video clip. The first dugong run over is circled again at the end of the clip, travelling towards the top of the screen.

*The DVD is available from the author upon request*

### Appendix 3. Ethogram and counts of each behaviour described during observations of dugongs on the Moreton Banks

**Table A3.1** Dugong behaviours observed during focal follows of individual dugongs in Moreton Bay, Queensland. Focal individual (FI) is the animal conducting the behaviour and the other individual (OI) is the recipient.

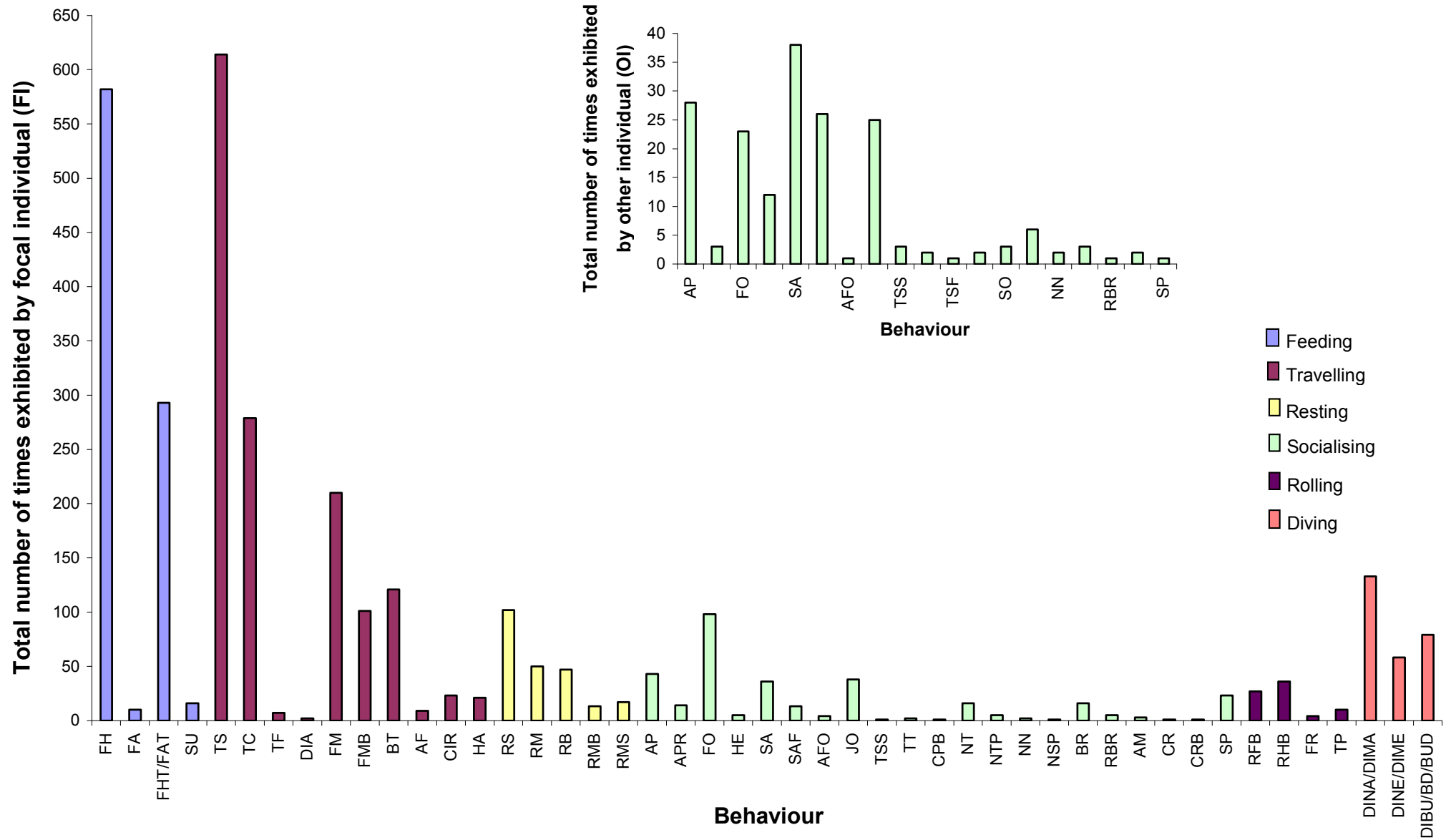
Behavioural Category	Specific Behaviour	Code	Description
Feeding (FE)	Horizontal	FH	Body resting on substrate, slow movement forward, nose turned down, whole body pressed to substrate, with no shadow visible beneath body.
	At angle	FA	As FH but tail raised well above substrate.
	With plumes	FHT/ FAT	As FH/FA but with sediment plumes visible.
	Suckling	SU	Calf has nose at base of mother's pectoral fin, ventrum is angled slightly towards her. May continue while mother is feeding or surfacing.
Travelling (TR)	Slow	TS	Movement forward barely detectable but not along substrate, tail pumping not obvious or very occasional, indefinite direction of movement.
	Cruising	TC	Swimming at continuous speed with obvious movement forward, tail pumps obvious but not rapid, definite direction.
	Fast	TF	Swimming with rapid and obvious pumping of tail, bow wave often seen when animal surfacing.
	Attempted surface	SUA	Rising as if to surface but nostrils do not break the surface.
	Follow mother	FM	Calf travelling behind mother or to side but not further forward than her nose.
	Follow mother on back	FMB	Calf travelling with mother either resting on or slightly above her back.
	Back track	BT	Doubles back either while travelling or directly after surfacing (often when coming within 3 body lengths of OI, or while circling novel stimuli).
	Abrupt Flee	AF	A fast back-track where FI turns and moves off quickly. Usually when turning there is a bow wave or splash at surface, tail may come partly out of water. May be in response to novel stimuli.



<b>Behavioural Category</b>	<b>Specific Behaviour</b>	<b>Code</b>	<b>Description</b>
Travelling (continued)	Circling novel stimuli	CIR	Swimming around novel objects (e.g., boat or blimp shadow) or other animals (e.g., rays), periodically stopping and turning towards them.
	Halt	HA	Stops mid-travel, turns head towards OI (or object), then continues travelling in same direction.
Resting (RE)	At surface	RS	Floating still, no pumping of tail, very close to surface although whole body still submerged.
	Mid water column	RM	As RS but not obviously near surface or on substrate.
	On substrate	RB	As RS but just above or touching substrate with no movement forward and nose not pressed to substrate.
	On mother's back	RMB	Calf remaining on or slightly above mother's back while she is stopped still.
	At mother's side	RMS	Calf resting next to mother's side while she is stopped still.
Socialising (SO)	Approach	AP	Facing towards OI, or changes heading to direct towards OI within 3 body lengths, changes to a follow when OI starts to swim away.
	Rapid approach	APR	As AP but deliberate and fast, makes sudden tail pump to accelerate to OI.
	Follow	FO	Begins when within 3 body lengths of OI or OI starts to swim away. FI remains directly behind OI and obviously adjusting swim direction to do so. OI is swimming away or travelling. Ends when FI turns away from OI, can continue at greater than 3 body lengths.
	Herding	HE	Blocks OI's path and forces OI to swim along side. FI may be in front of OI but all attempts by OI to break away are blocked.
	Swim away	SA	Begins with a change in direction or speed when OI is within 3 body lengths. FI travelling away from OI. Ends when FI disappears, stops swimming, or resumes previous behaviour (if this was travelling then FI slows down, surfaces or changes direction), can continue when FI no longer being pursued.
	Swim away fast	SAF	As SA but is fast or cruising travel.

<b>Behavioural Category</b>	<b>Specific Behaviour</b>	<b>Code</b>	<b>Description</b>
Socialising (continued)	Abrupt flee from other	AFO	As AF but in response to AP by OI.
	Join	JO	Swimming right along side OI with coordinated movements and/or adjusting travel direction to remain next to OI.
	Tail swipe sideways	TSS	Swipe of tail directed sideways towards OI, may include a half roll.
	Tail swipe raised	TSR	Swipe of tail directed upwards towards OI with flexed back.
	Tail swipe with flip	TSF	OI is in front so FI does abrupt flip to swipe with tail.
	Tails touch	TT	Both tails of FI and OI obviously overlap and touch, perhaps accidental.
	Swim over	SO	Crosses over the back of OI, may be while surfacing of submerging.
	Close pass by	CPB	Both FI and OI swim directly towards each other so that will seemingly collide but pass by each other almost touching.
	Nose to tail	NT	Nose touches or almost touches tail stock of OI (as if near genitals).
	Nose to tail push	NTP	As NT but touches with force of movement toward OI.
	Nose to nose	NN	Noses of both FI and OI touching or almost touching.
	Nose to side	NS	Nose touches or comes very close to side of OI.
	Nose to side push	NSP	As NS but touches with force of movement towards OI.
	Body rub	BR	Rubs against OI while swimming past, either ventrum to dorsum, ventrum to ventrum, side to dorsum, dorsum to dorsum, or dorsum to ventrum.
	Receiving body rub	RBR	Continuing formal behaviour (e.g., resting or feeding) while OI is performing body rub.
	Attempted mount	AM	Swims onto OI's back but results in aggression from OI
	Calf retrieval	CR	Mother does an abrupt half turn back towards the calf as the calf is heading in a different direction to her. The calf then turns and follows her.
	Over back retreat	CRB	Calf crosses over mother's back to opposite side from OI when mother involved in interaction with OI.
Spurt	SP	Large visible spray of water occurs when breathing, often occurs after interaction with other.	

<b>Behavioural Category</b>	<b>Specific Behaviour</b>	<b>Code</b>	<b>Description</b>
Rolling (RO)	Full roll on substrate	RFB	Rotating horizontally (at least 180 degrees) touching substrate, may see cloud of sand from impact.
	Half roll on substrate	RHB	As RFB but only rotating 90 degrees.
	Full roll mid-water	RFM	AS RFB but does not touch ocean floor.
	Half roll mid-water	RHM	As RHB but does not touch ocean floor.
	Front rub	FR	Rubs ventrum on sand by swimming rapidly across substrate, may see cloud of sand from impact.
	Tail Push	TP	Forceful push off ground with tail and arching back while rising.
Surfacing (SU)	Surface	SU	Starts ascending to surface by lifting head and/or spreading pectoral fins to steer body upwards, exhales and inhales at surface, descends and returns to former behaviour or begins a subsequent behaviour by pumping tail, ceasing movement, or reaching the sediment to feed
	Almost synchronised surface with OI or mother	SUNA/ SUMA	Is at surface for at least part of the time the OI (within 3 body lengths), or if calf, the mother, is also surfacing to respire.
	Exactly synchronised surface with OI or mother	SUNE/ SUME	As SUNA/SUMA but surfaces and submerges at the exact same time as OI or mother.
	Over back surface during ascent or descent or both	SUBU/ SUBD/ SUBUB	Calf crosses over or goes briefly onto mother's back during surfacing behaviour.



**Figure A3.1** Total counts of every behaviour observed during all focal follows of individual dugongs, and (insert) total counts of behaviours conducted by other individuals during social interactions with the focal individual. For abbreviations see Table A3.1.

## Appendix 4. Potential biological removal for dugongs in Moreton Bay

The sustainable level of human-related mortalities for dugongs in Moreton Bay is calculated here in Table A4.1 using the Potential Biological Removal (PBR) method defined by Wade (1998), and subsequently used for dugongs by Marsh *et al.* (2004). This technique provides the maximum number of animals that can be removed from the population other than by natural causes, while allowing the population to reach an optimum sustainable level (i.e., between carrying capacity and maximum net productivity). The following is the formula to calculate the PBR:

$$\text{PBR} = N_{\min} \times 0.5 R_{\max} \times \text{RF} \text{ (Wade, 1998)}$$

Where:  $N_{\min}$  = the 20<sup>th</sup> percentile of a log-normal distribution based on an absolute estimate of the number of animals  $N$  in the population.

$R_{\max}$  = the maximum rate of increase, for which Marsh *et al.* (2004) use a range of estimates of 0.01 – 0.05 due to uncertainty of estimates of age of first reproduction, fecundity and natural mortality levels.

$\text{RF}$  = a recovery factor of between 0.1 and 1, which if  $< 1$ , allows population growth and uncertainties in estimates of  $N_{\min}$  or  $R_{\max}$ , and for which Marsh *et al.* (2004) use 0.5, which is the default value for stocks of unknown status (Wade, 1998).

**Table A 4.1** Potential Biological Removal (PBR) values for Moreton Bay according to published aerial survey population estimates<sup>a</sup>, using two  $R_{\max}$  estimates.

Reference	Time of Survey	N	SE	$N_{\min}$	$R_{\max}$	RF	PBR
(Lanyon, 2003)	January 1995	1019	166	846	0.01	0.5	2
(Lanyon, 2003)	July 1995	503	64	436	0.01	0.5	1
(Lawler, 2001)	December 2000	344	88	252	0.01	0.5	1
(Lawler, 2001)	November 2001	493	45	446	0.01	0.5	1
(Lanyon, 2003)	January 1995	1019	166	846	0.05	0.5	11
(Lanyon, 2003)	July 1995	503	64	436	0.05	0.5	5
(Lawler, 2001)	December 2000	344	88	252	0.05	0.5	3
(Lawler, 2001)	November 2001	493	45	446	0.05	0.5	6

<sup>a</sup> Variation in population estimates may be due to large-scale movements of dugongs from Moreton Bay to Hervey Bay, though this hypothesis has not been proven (Lawler, 2001).

## Appendix 5. Exploratory analysis of pinger experiments

**Table A5.1** Number of 1 min surveys during each treatment of each experiment where dugongs passed between the two pingers.

Experiment	Treatment	Number of scans where dugongs did or did not pass between two pingers	
		No (0)	Yes (1)
2	Pre-pinger	4	1
	Pinger	2	2
	Post-pinger	4	1
5	Pre-pinger		5
	Pinger		5
	Post-pinger		5
6	Pre-pinger	3	2
	Pinger	4	1
	Post-pinger	5	
10	Pre-pinger	1	4
	Pinger	3	2
	Post-pinger	3	2
11	Pre-pinger	5	
	Pinger	4	1
	Post-pinger	5	
12	Pre-pinger	3	2
	Pinger	4	1
	Post-pinger	4	1

**Table A5.2** Number of 1 min surveys during each treatment of each experiment where dugongs were observed feeding with plumes visible within 100 m of the pinger array.

Experiment	Treatment	Plumes visible	
		No (0)	Yes (1)
1	Pre-pinger		5
	Pinger	2	2
	Post-pinger		5
2	Pre-pinger		5
	Pinger	2	3
	Post-pinger		4
3	Pre-pinger	6	
	Pinger	3	
	Post-pinger		
5	Pre-pinger		6
	Pinger	5	
	Post-pinger	3	2
6	Pre-pinger		5
	Pinger		4
	Post-pinger		5
8	Pre-pinger	1	4
	Pinger		4
	Post-pinger		1
9	Pre-pinger	6	
	Pinger	3	
	Post-pinger	5	
10	Pre-pinger	3	2
	Pinger		5
	Post-pinger	1	4
11	Pre-pinger	1	3
	Pinger		4
	Post-pinger		5
12	Pre-pinger	1	4
	Pinger		4
	Post-pinger	1	4