BACKGROUND

Dugongs were specifically highlighted as one of the World Heritage values of the Great Barrier Reef World Heritage Area (Great Barrier Reef Marine Park Authority 1981). Dugongs are listed as Vulnerable in Queensland (*Nature Conservation Act 1992* (Qld)) and internationally (IUCN 1996). They are susceptible to human disturbance because they have evolved a reproductive strategy that relies on a high level of adult survivorship. Consequently, a small increase in the rate of mortality of adult dugongs can cause a population to decline (Marsh et al. 1984; Marsh 1995). Human causes of dugong mortality include incidental drowning in mesh nets, hunting, habitat degradation and boat strikes.

Aerial surveys indicate that the dugong populations of the Great Barrier Reef Marine Park, south of Cooktown, declined by approximately 50% over the eight years to 1994 (Marsh et al. 1996). This level of decline, for a slow breeding species like the dugong, is of great concern. The surveys suggest that the only important dugong population that did not decline was in the region between Cape Cleveland (near Townsville) and Dunk Island, which includes Hinchinbrook Island (Marsh et al. 1996). The waters of this region are one of the two most important dugong habitats in the Great Barrier Reef region south of Cooktown. The other area is Shoalwater Bay. The importance of these areas was recently recognised when they were declared as category 'A' Dugong Protection Areas and afforded a higher level of protection from mesh netting than any of the other Dugong Protection Areas (Fisheries Amendment Regulation (No. 11) 1997 (Qld); DPI 1998; GBRMPA 1998). Furthermore, the traditional owners of the Port Clinton/Shoalwater Bay area have voluntarily suspended dugong hunting in that area (Smith et al. 1997) and the Great Barrier Reef Ministerial Council has decided not to permit Indigenous hunting in the southern Great Barrier Reef (Dugong Communique, Cairns, 14 June 1997).

The category 'A' Dugong Protection Areas are designed to provide a high level of protection to those areas that still support significant dugong populations. The strategy relies, in part, on the preservation of the habitat in these areas. If the habitat is degraded, the dugongs may be displaced to areas that do not afford appropriate protection from mesh nets.

Developments in the Hinchinbrook Channel have the potential to compromise the quality of dugong habitat in the Hinchinbrook Dugong Protection Area. A major marina-based residential estate is being developed at Oyster Point near the northern end of the Channel. A smaller marina is being developed at Dungeness at the southern end of the Channel, and the boat ramp near the middle of the Channel (Fishers Creek; figure 1) is planned for upgrading. These developments will significantly increase boat traffic in the Hinchinbrook area and have the potential to reduce the quality of the area as dugong habitat.

Boats and Threatened Marine Wildlife

Dugongs and Boat Strike

Boat strike is a documented cause of dugong mortality (Anderson 1981, 1998; Hill et al. 1997; Illidge 1996; Preen 1992; Bob Prince pers comm.), especially in areas of high boat traffic (Preen 1992). The responses of dugongs to boat traffic, however, are not well understood.

Anderson (1981) reports that relatively slow moving vessels (5–8 kn) initiate an evasive response in dugongs at a distance of 150 m. My experience in Missionary Bay and Hinchinbrook Channel suggests that individual dugongs differ greatly in their response to slow vessels. I spent weeks in a small boat stealthily following known tagged dugongs, and some dugongs were very tolerant, while others were very sensitive. These differences may be innate, or they may reflect past experiences.

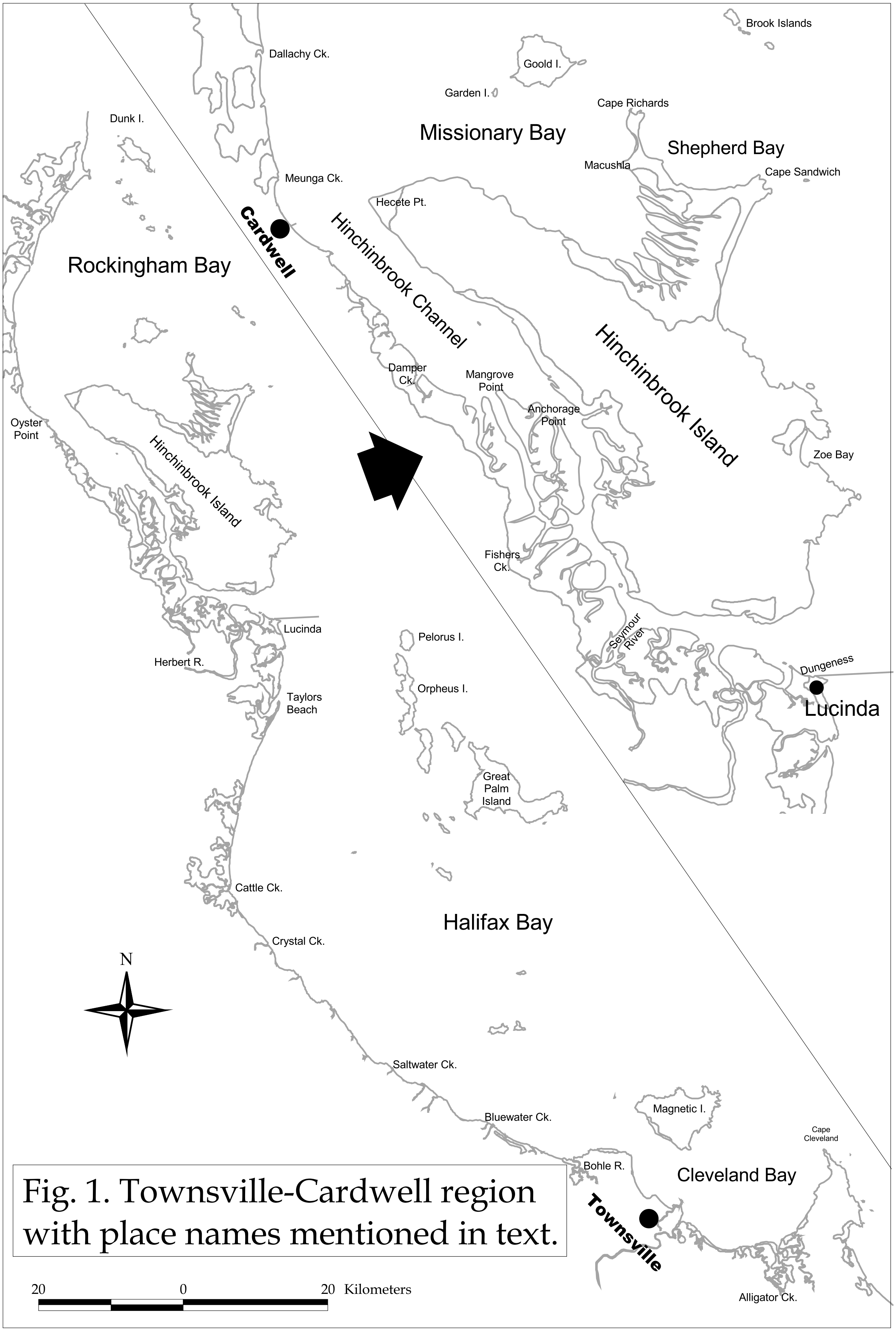

Fig. 1. Townsville-Cardwell region with place names mentioned in text.

20 0 20 Kilometers

The responses of dugongs to high speed boats also varies. In one experiment, Anderson (1981) was unable to detect any anticipatory or evasive action by a group of dugongs that was bisected by a fast (27 kn) speedboat. The boat passed within 1 m of some animals, causing the experiment to be abandoned. In another situation, a herd of dugongs detected and responded to two speedboats travelling at approximately 20 kn, from a distance of 1000 m (Preen 1992).

Some observations suggest that the sensitivity of dugongs to fast boats may be related to water depth, and hence, a perceived level of safety. The dugongs previously referred to that responded to boats 1 km away, were in very shallow water (1.7 m). Their response was to sprint towards deeper water, even though this took them, for a while, towards the boats. However, at another location (about 5 km away), planing speedboats passed through a herd of dugongs on three occasions in 80 minutes, without dispersing the herd. In that case, the dugongs were in 3.4 to 6 m of water (Preen 1992).

Prevailing weather conditions may also affect a dugong's response to fast vessels. I have observed a vessel travelling at approximately 25 kn pass within about 50 m of a tagged dugong that I was watching. It was not until after the vessel had passed the dugong that she reacted. She stopped feeding and swam off apparently for some considerable distance, as I was unable to relocate her transmitter's signal. There was a 15-20 kn wind and the sea surface was choppy. It is possible that the ambient level of underwater noise during such weather may mask the sound of an approaching boat.

Sailing boats are generally less of threat to dugongs because of the slower speeds at which they travel. Although dugongs apparently do not detect approaching sailing boats acoustically, in relatively clear water they can visually detect most sailing boats in time to respond (Anderson 1998). However, high speed sailing craft such as windsurfers and sport catamarans may not be detected in time to take evasive action (Anderson 1998). In areas of turbid water, such as Hinchinbrook Channel, dugongs probably have very limited ability to detect high speed sailing craft.

Manatees and Boat Strike

The dugong's closest relatives are the three extant species of manatee, which are also within the Order Sirenia. The Florida manatee (*Trichechus manatus latirostris*) and the dugong are similar in many aspects of their biology and ecology, although the manatee is less specialised and appears better able to cope in urban environments. The Florida manatee has been studied in more detail than any other Sirenian and much more is known about its biology and causes of mortality, particularly the impacts of boats, than is known about dugongs.

Manatees in shallow water (≤ 2 m) generally move to deeper water in response to an approaching boat, and once they have reached the bottom (at depths of 3 m or more) they appear to be little concerned by a passing boat (Hartman 1979; Weigle et al. 1994). Manatees at the surface that are surprised by an approaching boat are sometimes 'spooked', and cows and calves can be separated during the resulting flight (Hartman 1979). Some manatees habituate to boats, but this increases the risk of collision (Curtin & Tyson 1993).

Initial anatomical studies suggested that manatees would detect a narrow, low frequency range of sounds, but with poor sensitivity and localisation ability (Ketten et al. 1992). Subsequent behavioural testing, however, demonstrated a wide range of hearing, from 0.15 to 46 kHz, which means the manatee can detect infrasonic and ultrasonic pulsed signals (Gerstein et al. 1994). The manatees greatest sensitivity is in the 6–20 kHz range, but below 3 kHz, the manatee still has the greatest sensitivity to low-frequency sound of all the marine mammals that have been tested (Gerstein et al. 1994). Although the high-frequency hearing of manatees may be used to determine the direction of a sound (localisation), the acoustic signatures of a variety of tested outboard engines fall outside or just within the outer margins of their hearing. Consequently, manatees may have difficulty detecting and localising boat noise in time to take evasive action (Gerstein et al. 1994).

A series of experiments running an outboard powered boat through a group of manatees seems to confirm this prediction. A 5.3 m powerboat with a 120 hp outboard engine was used to make multiple runs through a group of manatees. The experiments were coordinated and filmed from an overhead airship (Weigle et al. 1994). The trials found that the manatees began reacting to the approaching boat

at about the same distance irrespective of boat speed. At slow speed (5–6 kn) reactions occurred at a distance of 16–92 m, with an average of 52 m (n = 16). At moderately fast speed (17 kn), reactions commenced at 32–87 m, with an average of 50 m (n = 4), and at high speed (26 kn) the distance ranged from 15–99 m, with an average of 58 m (n = 4; Weigle et al. 1994). Based on the hearing abilities of manatees and the measured sound emitted by the experimental boat, the researchers concluded that the manatees should have been able to hear the boat at distances of up to 100 m (Weigle et al. 1994).

Between 1986 and 1992, watercraft collisions were responsible for 83% of all human-related manatee deaths in Florida, and 38% of all deaths that had identified causes (Ackerman et al. 1995). Detailed analysis of 406 manatees killed by boats revealed that 55% of deaths were caused by impact strikes (no propeller injuries), 39% were caused by propeller cuts, 4% by impact and propeller, and 2% by other factors (Wright et al. 1995). Fatal impact injuries were caused by fast-moving craft, while fatal propeller cuts were most often caused by large (> 7.3 m) direct-drive vessels with large propellers (Wright et al. 1995). Only 2% of propeller strikes occurred to the manatees' head, while 98% occurred on the dorsum, indicating that the manatees were moving in response to the approaching vessel when they were struck (Wright et al. 1995).

The rate of boat sticks of manatees has increased with the increase in boat traffic. For the period from mid-1976 to mid-1993 there is a strong correlation between the number of manatees killed by boats and the number of registered boats in Florida ($r^2 = 0.87$, n = 17 years, p = 0.0001; Ackerman et al. 1995). Although correlation does not prove causation, this agreement is striking. Given the low reproduction rates of manatees, there is now concern that the Florida manatees will not be able to sustain the current rate of boat kills (O'Shea 1995).

Years of experience has 'lead virtually all those involved in manatee conservation to conclude that reducing boat speeds will reduce the likelihood of boat/manatee collisions' (Frohlich 1994). Strategies that have been implemented to reduce boat related deaths of manatees include: establishing speed limits for powerboats; establishing No Entry and No Powerboat zones; and increasing boater education and awareness (Frohlich 1994). Last year (1998) saw a record high number of boat related manatee deaths in Florida (Florida Dept. of Environmental Protection media release, 11/1/99), suggesting that the controls on boat speeds have been less successful than hoped. This may have been because of the essentially political, and at times judicial, process of implementing boat control rules (Frohlich 1994). As a result of this process boat control zones were applied at a micro scale, with an often-complex arrangements of Idle Speed, Slow Speed, Caution Speed and No Entry zones in close proximity to one and other (Boater's guide to manatees: the gentle giants 1982). Such arrangements required very complex regulations that are difficult to sign, understand and enforce (Frohlich 1994). Simpler rules that have been preferred by managers have often been rejected as either too weak or excessively restrictive (Frohlich 1994). Broader recommendations such as state-wide night time speed limits for all waters, day time speed limits for all channels, and mandatory boater safety education with a manatee awareness component have yet to be passed into law, although rules for manatee protection speed-zones have been approved in 11 counties (O'Shea 1995).

In an attempt to reduce the impact of anticipated human population growth, management agencies in Florida also direct coastal development, particularly facilities such as marinas, away from important manatee habitat (Ackerman et al. 1995; Frohlich 1994).

Comparison between the situations with manatees in Florida and dugongs around Hinchinbrook must be made with caution because the level of boat traffic in most parts of Florida far exceeds the level of boat traffic in the Hinchinbrook area. Furthermore, manatees are not dugongs and there may be important behavioural differences that affect their susceptibility to boat traffic. For instance, although dugong calls (5-22 kHz; Anderson & Barclay 1995) occur within a range that is very similar to the peak range of manatees' hearing (6-20 kHz; Gerstein et al. 1994), there is some suggestion that dugongs may have better low-frequency hearing than manatees, as the lower range of their bark calls probably falls outside the hearing range of manatees (Anderson & Barclay 1995). Nevertheless, much of Hinchinbrook Channel resembles the narrow waterways of Florida much more closely than most dugong habitat, so the analogy with Florida may be more legitimate here than in many other areas. The

linear, confined nature of these waterways, with their often-narrow channels bordered by narrow strips of seagrasses, force greater interaction between the manatees/dugongs and boats.

Other Effects of Boat Traffic on Dugongs and Manatees

Boat strike is not the only threat to wildlife posed by boat traffic. Other threats may result from direct disturbance by boats and/or the noise they generate. Such impacts include the displacement of fauna from parts of their habitat or constrictions put on access to areas.

Disturbance by boats has been shown to affect the localised distribution of manatees (Buckingham 1990). Moreover, chronic boat disturbance has displaced manatees from some large areas (Provancha & Provancha 1988). Dugongs too, may eventually be displaced by heavy or persistent boat traffic. During 28 aerial surveys of dugongs in Moreton Bay a total of 10 326 dugong sightings were recorded. Of these, just 15 (0.14%) were in the central-western part of the bay, where the density of boats was 2.6 times that in the eastern side (Preen 1992). This reciprocal pattern of distributions of dugongs and boats in Moreton Bay suggests possible avoidance by dugongs of areas of high boat use. Anecdotal evidence also suggests that dugongs have been displaced from this area of Moreton Bay. Within the last century, Aborigines hunted dugongs in the central-western bay (Alfredson 1984; Petrie 1932), and a dugong oil factory was based there (Lack 1968; Welsby 1905). Today, however, dugongs are virtually absent from this area. In a discussion on dugongs in Moreton Bay in the late 1800s, Welsby (1905, p. 99) stated '*In former days they could be found in summer in Redland Bay, but the traffic of steamers has driven them out of that'*. There are other possible explanations for the loss of dugongs from the western bay. For instance, there may have been a loss of, or change to, the seagrass meadows in this area or the population may not have recovered from the dugong oil industry. In the absence of definitive evidence, however, a precautionary interpretation would be prudent.

Disturbance by boat traffic also has the potential to reduce dugongs' access to particular feeding locations, without necessarily displacing them from an area. In Hinchinbrook Channel most seagrasses are limited by low light penetration to intertidal and near-subtidal depths (Lee Long et al. 1998). Hence, the dugongs' access to some feeding areas will be restricted primarily to periods around high-tide. Evidence from feeding trails and tracking indicates that seagrasses in these locations are often favoured by dugongs. Boat traffic in these areas, around high water, may prevent dugongs from accessing these seagrasses. If these near-intertidal seagrasses are of nutritional importance to the dugongs, then this disturbance may be significant, as restricted food availability can reduce dugong fecundity (Preen & Marsh 1995). Such an impact may further decrease the sustainable level of human-related mortality of this already slow breeding species (Marsh et al. 1984).

Boats and Turtles and Cetaceans

The Hinchinbrook area is habitat for threatened marine species other than dugongs. The area is populated by Green, Loggerhead and Hawksbill turtles, which are listed respectively as Endangered, Endangered and Critically Endangered internationally (IUCN 1996) and Vulnerable, Endangered and Vulnerable in Queensland (*Nature Conservation Act 1992*). Turtles are particularly susceptible to boat strike, partly because of their habit of basking at the surface (Miller in van Tiggelen 1996; Venizelos 1993). In some areas, restrictions such as No Boat zones and 6 kn maximum speed zones have been applied to protect turtles from boats (Dimopoulos 1994).

The Hinchinbrook area, especially Hinchinbrook Channel, is also proving to be an important habitat for Irrawaddy and Humpback dolphins. Both species are listed as Rare under the *Nature Conservation Act 1992*. Approaching boats have been shown to alter the surfacing behaviour and movement patterns of dolphins (Janik 1996; Kruse 1991), and underwater noise generated by boats can alter the basic structure of the songs of humpback whales (Norris 1994). The significance of these effects is not known, but may be cause for concern (Wells & Scott 1997).