FOREWORD

This report is a significant contribution to scientific literature about the movement and migration of dugongs within the Great Barrier Reef. Its results add to information derived from aerial surveys and sighting records gathered over many years. It also provides valuable information on how dugongs use, and move between, different habitats in the Hinchinbrook Region. The report also provides information on use of the Region by species such as dolphins, turtles and manta rays, and on patterns of vessel use.

The Great Barrier Reef Marine Park Authority (GBRMPA) supports many of the Report's recommendations. All of the recommendations will be considered and included where practicable in management plans for the Hinchinbrook Region that are now being prepared. These plans are being developed in an integrated manner by Commonwealth and Queensland Government agencies in consultation with stakeholders such as those represented in the Hinchinbrook Local Management Advisory Committee (LMAC).

Following are the Authority's comments on the Report's recommendations.

Recommendation	**GBRMPA comment**
1. Develop an education and awareness program to: (i) foster an appreciation by boaters of the significance of the Hinchinbrook Dugong Protection Area (DPA), and the threats posed to dugongs by boats; (ii) encourage boaters to travel slowly and cautiously in shallow areas, or areas known to support seagrass or dugongs; to use marked channels where possible; and to comply with boating regulations.	**1. Supported and implemented.** The Authority has published brochures on the Hinchinbrook DPA and updated DPA publications to include voluntary transit lanes for boaters to use in the Hinchinbrook region. The Authority has also produced leaflets and stickers for boaters to encourage them to slow down in DPAs and to raise their awareness of dugong conservation. Dugong information kits have been published and a website dealing with dugong issues has been added to the GBRMPA corporate site. Dugong awareness and DPA signage have been installed at boat ramps. In Hinchinbrook, this signage directs boaters to use voluntary transit lanes. The Authority is currently working with the Hinchinbrook LMAC to prepare a detailed brochure for the Hinchinbrook area specifically on dugong and other conservation issues.
2. Establish five Boating Management Areas (BMAs) within the Hinchinbrook Dugong Protection Area for the regulation of boating activity.	**2. Not supported in the recommended form, however some aspects are supported and are being implemented.** The recommended BMAs are complex, difficult to understand and vessel use of them would be difficult to monitor. The proposed BMA arrangements may also raise significant safety issues. However management agencies have established voluntary vessel transit lanes and promoted their use. The placement of these lanes generally follows the boundaries separating each of the BMAs proposed in this report to minimise risks to dugongs. Where the lanes differ from the boundaries in the report, it is usually for human and boating safety reasons. Similarly, the voluntary speed limits in the transit lanes generally conform to those recommended in the report. The boating management arrangements now implemented in the Region are based upon the results and concepts of this report, and have been developed in consultation with a broad range of stakeholders. The success of the voluntary transit lanes in channeling vessel use will be monitored and altered if required. The Great Barrier Reef Ministerial Council has asked the

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SUMMARY

This report summarises the results of a study of dugongs and boat traffic in the Townsville-Cardwell region, with emphasis on the Hinchinbrook Dugong Protection Area (DPA). The study was commissioned by Commonwealth Environment Minister, Senator Hill and was intended to inform regional planners tasked with developing a boat traffic management plan for the Hinchinbrook area.

In 1994, the Townsville-Cardwell region supported 49% of dugongs occurring between Cooktown and Hervey Bay. It was the only significant region along that whole coast not to show a decline in dugong numbers since aerial surveys commenced in 1987. In an effort to protect remaining dugong 'populations', Dugong Protection Areas were established along the populated coast of Queensland in 1998. Within the Townsville-Cardwell region, the Hinchinbrook area and Cleveland Bay host two of the three largest DPAs that prohibit mesh-netting practices that most threaten dugongs. For the DPAs to live up to their name, all activities that threaten, directly or indirectly, the dugongs or their habitat will have to be carefully managed.

There is concern that in the Hinchinbrook DPA, marina-based developments in the Hinchinbrook Channel will increase boat traffic in the area, potentially threatening dugongs and compromise their habitat.

Boat traffic may adversely affect dugongs by: (i) increasing mortality through boat strike, (ii) alienating dugongs from areas of suitable habitat due to boat strikes, underwater noise or unintentional harassment, and (iii) limiting dugongs' access to nutritionally important near-intertidal seagrasses that may be safely accessed only at high tide.

This study provides the first detailed, year-round picture of dugong distribution, abundance and movement patterns in the region. It used repeated aerial surveys, satellite tracking, historical aerial surveys and other approaches to obtain independent data on habitat use.

The core dugong habitat in the region is centred on Missionary Bay in the Hinchinbrook area and eastern Cleveland Bay in the Townsville area. The tracking of 13 dugongs over 19 months demonstrated, however, that surrounding areas, such as Hinchinbrook Channel, the Lucinda coast and Bowling Green Bay are tightly linked to these core areas. Furthermore, there is considerable movement of dugongs between Missionary Bay and Cleveland Bay. The importance of Hinchinbrook Channel as dugong habitat was further supported by sightings reported by the public, a feeding trail survey, and data from 25 aerial surveys conducted primarily in the 1970s.

The aerial surveys and public sightings also indicate that Hinchinbrook Channel is an important habitat for Irrawaddy dolphins and Humpback dolphins. Both species are listed as Rare under Queensland legislation.

A comparison of sighting rates of dugongs, dolphins, turtles and manta rays during the 26 historical aerial surveys of Hinchinbrook Channel and Halifax Bay with the nine contemporary surveys of these areas indicates a reduction in dugong numbers, especially in Hinchinbrook Channel. The sighting rate of dugongs was significantly higher in the 1970s than during the surveys of 1997–98. Dugongs were seen 4.15 times more frequently in the 1970s. No other species showed a reduction in sighting rate between the 1970s and 1997–98. Several factors may be implicated in this apparent decline, including the known increase in boat traffic.

The areas of greatest dugong abundance in Missionary Bay and Cleveland Bay, as indicated by the recent aerial surveys and tracking, were also areas of low boat traffic. Such an apparent correlation does not prove causation. Nevertheless, there appears to have been a contraction of the area used by dugongs in Cleveland Bay since the 1970s and the areas that are now little used by dugongs are now well used by boats.

The number of boats estimated to be on the water in the Cleveland Bay and Hinchinbrook aerial survey blocks ranged from 4 to 88 and 13 to 63, respectively, on different surveys. The average for each area was 42.

Approximately 56% of boat movements in northern Hinchinbrook Channel were between the Cardwell area and Missionary Bay. Within Missionary Bay, about 26% of movements were between Cardwell and Goold/Garden Island. About 25% were between Cardwell and the Missionary Bay Creeks, about 10% were between Cardwell and Macushla, and about 7% were between Cardwell and Cape Richards.

Powerboats (small to large planing vessels), which are the type of vessel most likely to strike dugongs or turtles, accounted for 76% of boat movements in northern Hinchinbrook Channel and 84% of movements in Missionary Bay. By comparison, sailboats and trawler-like boats accounted for approximately 11% and 6% of movements in the northern channel and 10% and 3% in Missionary Bay.

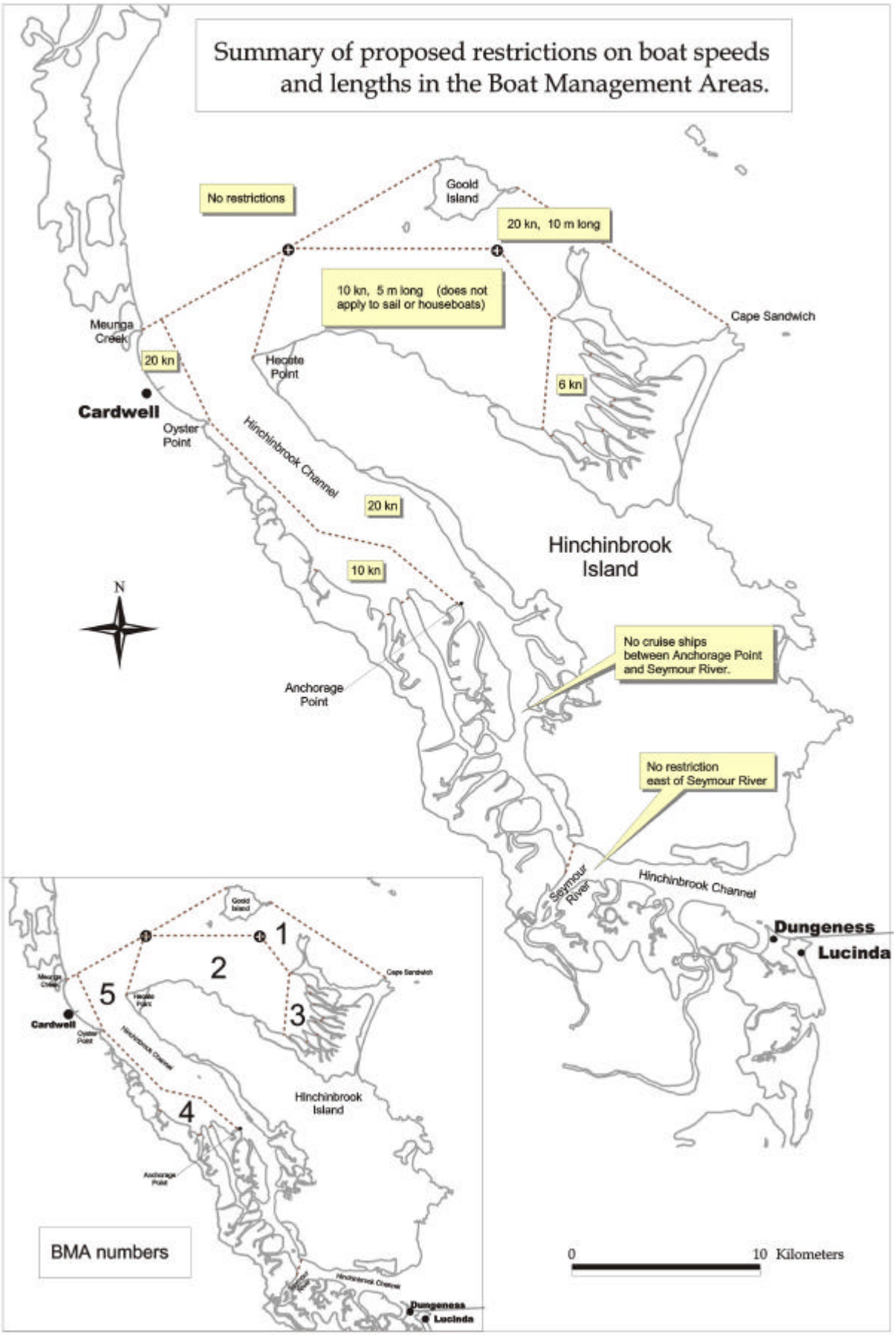
Fast commercial passenger ferries operating between Cardwell and Cape Richards, Macushla and the No. 7 Creek/Thorsborne Trail accounted for 15% of boat movements in Missionary Bay. During weekdays this percentage increased considerably (to 39% during our sample periods).

On the basis of this information, a series of recommendations has been made for the regulation of boat traffic in the Hinchinbrook DPA. The aim of these recommendations is to protect the integrity of the dugong habitat, while allowing continued reasonable boating activity. If these suggestions are implemented, the inevitable increase in boat traffic in the Hinchinbrook DPA could be managed in an ecologically sustainable manner with respect to marine wildlife, and based on current information.

The dugong tracking has demonstrated that the boundaries of both the Hinchinbrook and Cleveland Bay DPAs should be amended to incorporate adjacent, integral areas of dugong habitat. The Hinchinbrook DPA 'A' should be extended to include the Lucinda coast (currently a DPA 'B' zone') and the Cleveland Bay DPA 'A' should be extended to include Bowling Green Bay (currently a DPA 'B' zone).

Summary of Recommendations

1. Develop an education and awareness program to foster an appreciation by boaters of the significance of the Hinchinbrook Dugong Protection Area, the threats posed to dugongs by boats and to encourage cautious driving by boaters.
2. Establish five Boating Management Areas (BMAs) within the Hinchinbrook Dugong Protection Area for the regulation of boating activity. The recommended boundaries of these areas and general restrictions are summarised in the following figure.
3. Install channel markers in the northern end of Hinchinbrook Channel to encourage boaters to use a single corridor.
4. Require boat-based commercial dugong watching to operate under a permit system.
5. Require operators of commercial passenger craft to report suspected boat strikes to the Queensland Environmental Protection Agency and the Great Barrier Reef Marine Park Authority.
6. Review the boat traffic management plan at set intervals.


Summary of proposed restrictions on boat speeds and lengths in the Boat Management Areas.
No restrictions
Goold Island
20 kn, 10 m long
10 kn, 5 m long (does not apply to sail or houseboats)
Cape Sandwich
Meunga Creek
20 kn
Hecate Point
6 kn
Cardwell
Oyster Point
Hinchinbrook Channel
20 kn
Hinchinbrook Island
10 kn
N
No cruise ships between Anchorage Point and Seymour River.
Anchorage Point
No restriction east of Seymour River
Seymour River
Hinchinbrook Channel
Dungeness
Lucinda
1
2
3
4
5
BMA numbers
0
10 Kilometers

ACKNOWLEDGMENTS

Peter Buosi provided gallant assistance in every aspect of the fieldwork and provided helpful comments on a draft of this report. George Heinsohn generously allowed access to the raw data of his earlier aerial surveys and allowed the information to be included in this report. Vito Napoli assisted in the field in the Hinchinbrook area and Ray Aldridge assisted in Cleveland Bay. Ken Parker and Fleur O'Neil provided aerial support in Hinchinbrook and Cleveland Bay, respectively. Helene Marsh provided valuable comments on the report and helped negotiate funding for the project. The considerable assistance provided by all these people is gratefully acknowledged. The project was funded by the Great Barrier Reef Marine Park Authority, Environment Australia and the Cooperative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef.

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

at the surface in Moreton Bay, Queensland, where all dugongs feeding in 2–3 m of water were visible. That proportion was determined from vertical aerial photographs. The availability correction factor makes the untested assumption that the proportion of dugongs at the surface is constant across depths, time and activities. Although this is improbable, this correction factor is likely to be conservative and provides a means of standardising for repeat surveys of the same area. The availability correction factors for turtles were calculated by standardising against the number of turtles seen at the surface in a survey of the northern Great Barrier Reef (blocks 8–13; Marsh & Saalfeld 1989b). The proportion of turtles sighted at the surface on that survey was the lowest of any survey so far reported. The availability correction factor for turtles is likely to be a considerable underestimate because: (i) the correction factor does not fully account for turtles not visible below the surface, (ii) small turtles are very difficult to see at the survey altitude, and (iii) turtle sightings are particularly dependent on sea surface conditions (Marsh & Sinclair 1989a).

Table 4. Correction factors (CF) and their coefficients of variation (CV) used to calculate population estimates.

	Survey number									
	1	3	4	5	6	7	8	9	10	11
Dugong										
Availability CF	4.2498	5.6472	5.5386	3.5508	4.0002	3.5220	3.0912	2.8572	4.2858	4.2582
Availability CV (%)	13.8	11.9	13.0	13.2	14.4	16.3	15.7	16.7	26.0	15.4
Group size CF	1.7143	1.4167	1.8571	1.7193	1.6000	1.4375	1.5349	1.5750	1.4000	1.3478
Group size CV (%)	8.3	10.0	23.0	9.0	13.4	7.5	5.4	9.7	15.6	7.4
Turtle										
Availability CF	3.3449	3.9097	3.4531	2.583	2.6238	3.5747	1.9475	1.5795	1.8619	2.7646
Availability CV (%)	8.4	13.4	10.4	11.6	10.3	8	10.6	13.2	31.5	13.1
Group size CF	1.1905	1.1111	1.0263	1.1212	1.1099	1.1034	1.0875	1.1478	1.0769	1.1
Group size CV (%)	4.8	9.4	2.5	3.6	3.6	3.6	2.9	3.7	6.9	4.3
Boat										
Group size CF	1.2222	1.1	1.1053	1.0625	1.125	1	1	1.0938	nc*	1.2727
Group size CV (%)	10.3	8.6	6.4	5.7	7.4	0	0	4.7		10.6

* Not calculated - too few boats seen on transect.

Standard dugong surveys have two isolated, independent observers on each side of the aircraft, and a mark-recapture analysis of sightings is used to calculate a perception-bias correction factor to adjust the results to allow for the animals visible, but missed by observers (Marsh & Saalfeld 1989a). Because we had a single observer on each side of the aircraft, we could not derive this correction factor. However, perception bias correction factors are typically very small and have little effect on the resulting population estimate (for example, on a recent survey one observer on each side of the aircraft had no prior experience, but the perception correction factors for dugongs for each side were 1.012 and 1.015; Marsh et al. 1998).

The significance of the differences between the abundance of dugongs and turtles amongst surveys were tested using analysis of variance, both with and without the inclusion of environmental covariates. Blocks and surveys were treated as fixed factors and transect as a random factor nested within block. Input data for all analyses were corrected densities per square kilometre, with each transect contributing one density per survey. The densities were transformed ($\log_{10}$ (x+1)) to equalise the error variances.

Two measures of survey conditions were included in the analyses as covariates: sea state and light penetration. The roughness of the sea surface was regularly recorded using the Beaufort scale, and the average value for each transect calculated. Penetration of light into the water was affected by water turbidity and cloud cover. Rough maps of turbidity and heavy cloud cover were drawn during each

survey and these were used to score the light penetration along each transect using the following scale: 1: penetration good; 2: penetration very significantly reduced by turbidity or darkness; 3: no penetration (animals visible only at the surface).

Because the Townsville and Cardwell blocks were not flown on every survey, and because the design of the Hinchinbrook block was changed during the surveys, four separate analyses of dugong and turtle estimates were necessary. These were: (1) a comparison of the seven surveys of Cleveland Bay; (2) a comparison of the three surveys of Hinchinbrook using the initial design; (3) a comparison of the five surveys of Hinchinbrook using the revised design; and (4) a comparison of the four surveys that included both Cleveland Bay and Hinchinbrook (revised transects) (table 2).

The estimates of boat abundance were not statistically compared amongst surveys because the number of boats was expected to vary substantially. As most boats are used for recreation, their number is expected to vary, depending on day of week, forecast weather and actual weather. Surveys were conducted on all days of the week (table 3), except Sunday, when the aircraft was not available.

Historical Aerial Surveys

Between 1974 and 1981, Dr George Heinsohn and colleagues from James Cook University conducted 26 shoreline aerial surveys between Townsville and Hinchinbrook Island. Raw data from the Heinsohn surveys were processed to provide a comparison of sightings in the 1970s with those of the present study.

Most of the Heinsohn surveys (20 of 26) were conducted from 1974 through 1976. The surveys were flown at an altitude of 900' (274 m) dropping to 200' (61 m) when circling animals. The high-wing aircraft (Cessna 182 or 172) was flown at approximately 80 kn (148 km/h) in the Hinchinbrook area and Cleveland Bay, and up to 120 kn (222 km/h) through Halifax Bay. Heinsohn's offshore path through Halifax Bay (through the Palm Islands) was sometimes flown at a height of 1000' (305 m). Two to three observers recorded observations on to data sheets. The search area was not delineated by transect markers, but was estimated to be about 800 m wide (Heinsohn et al. 1976).

Heinsohn's flight path through Cleveland Bay and Missionary Bay (including the area north of Cardwell) stayed close to the coast, so most of those bays were not surveyed (figure 3). Hence, Heinsohn's sightings from these areas cannot be directly compared with those obtained during the current study. However, his sightings from Hinchinbrook Channel and Halifax Bay (including eastern Hinchinbrook) can be compared with the current study. Due to the linear nature of Hinchinbrook Channel, Heinsohn's flight path was similar to the transects flown in the current study, and in Halifax Bay both studies flew the same flight path (figures 2 and 3).
figure 3

Between September 1974 and January 1976, Heinsohn flew 16 consecutive monthly surveys of Hinchinbrook Channel. A subsequent 10 surveys were flown at less regular intervals until December 1982. This amounted to 1960 km of survey flown through Hinchinbrook Channel. Most of these surveys also incorporated the Halifax Bay flight paths. The near-shore (western) Halifax Bay path was surveyed on 25 occasions, although two were truncated. The offshore path was flown 21 times, including two shortened flights. The total distance surveyed through Halifax Bay was 4640 km. Sightings from the coast around Lucinda were not included in the analysis of sightings as this area was covered by transverse transects in the current study. That study surveyed Hinchinbrook Channel nine times between April 1997 and May 1998 (table 3), a total of 927 km surveyed. The near-shore and offshore legs through Halifax Bay were surveyed 10 and seven times, respectively, a total of 1664 km surveyed.

Results of the two sets of surveys have been compared on the basis of sighting rate: individuals seen/km flown. A comparison based on sightings/minute was precluded by inadequate time records. Differences in sighting rates in the 1970s and 1997–98 were tested using Kruskal-Wallis one-way nonparametric analyses of variance. A nonparametric procedure was used, as it was unlikely that the sighting rates were normally distributed.

Sightings by the Public

The amount of time a researcher can spend in the field is insignificant compared with the collective time spent there by local residents. In an attempt to collect some of the sightings made by local people in the Hinchinbrook area, and at the same time provide some educative material, I prepared two marine mammal sighting sheets (appendix 1). These provided illustrations of a dugong and the dolphins that occur in the area, a map for locating sightings, and a brief form to fill in. A separate logbook was prepared for commercial operators, who were likely to encounter marine mammals frequently. In 1997 the sighting sheets were distributed through Department of Environment offices, tackle shops, boat ramps and commercial operators including charter fishing and passenger ferry businesses.

Identification of dolphins is not necessarily easy for inexperienced people and it is likely that mis-identifications occurred. To reduce this risk, observers were asked to assess their confidence of identification (Certain / Pretty sure / Not certain; appendix 1), and I attempted to speak to people who reported dolphin sightings to further assess the likelihood of their identifications.

Feeding Trail Survey

Several lines of evidence suggested that the Cardwell foreshore may be an important grazing area for dugongs. On several occasions I observed herds of dugongs feeding on the intertidal seagrasses in front of Cardwell and I regularly observed feeding trails at two locations in front of Cardwell; several reports were received of dugongs feeding adjacent to the Cardwell jetty; a Cardwell-based commercial net fisher had told me that he did not net on the north side of Cardwell because there were too many dugongs there; the waters off Cardwell were used by some of the satellite tagged dugongs; and Lem Aragones had documented repeated grazing of a patch of seagrass at Cardwell that he studied over more than two years (Aragones 1997).

To test the hypothesis that the Cardwell foreshore is an important grazing area, the nearshore seagrass meadow between Meunga Creek and Oyster Point was surveyed for dugong feeding trails. Under most conditions, high water turbidity in this area makes it impossible to assess the presence of dugong feeding trails. However, a band of seagrass (between approximately 50 m and 100 m wide), along the western edge of the meadow extends into the inter-tidal zone. On low spring tides, this seagrass is exposed and the presence of feeding trails can be appraised.

The abundance of feeding trails was assessed at 20 inter-tidal sites during the spring low tide (0.67 m) on 12 November 1997 and at a further six sites on the next equivalent tide on 12 December (0.29 m). The later sites occurred within a special lease area around Oyster Point and approval had to be obtained from Cardwell Properties Pty Ltd before seagrasses in this area could be surveyed. Due to this delay, these sites had to be surveyed at night. (The next suitable day-time spring tide was not forecast until 26 March 1998). Sites were mostly 200–400 m apart. The sites covered the full stretch of coast from Meunga Creek to Oyster Point, a distance of 6.5 km.

Each site was reached by walking or crawling (depending of the consistency of the intervening mud) the shortest straight-line distance from the sand beach across the band of intertidal mud (50–150 m wide) to near the seaward edge of the exposed area of seagrass. For the six sites surveyed in December, the seaward edge of the seagrass was approached by canoe. The abundance of feeding trails was scored in three quadrats, each approximately 10 m by 10 m, located 5–10 m to the right, left and in front of the observer. (The limited period of the lowest part of the tide precluded the measurement and precise delineation of quadrats). Feeding trails in each quadrat were scored on the following semi-log scale:

0 = no feeding trails
1 = 1 feeding trail
2 = 2–10 feeding trails
3 = 11–100 feeding trails

A GPS location was recorded, along with notes on the freshness and clarity of feeding trails. Photos were taken at some sites.

The age of the feeding trails was estimated by comparing their freshness with feeding trails of known age on the northern side of the Cardwell jetty. I watched the feeding dugongs create these trails on 11 October 1997 and photographed them the next day on the low spring tide. These feeding trails, therefore, were exactly one month old when the main survey of grazing was conducted (sites 1–20). The areas around two sites (19 and 20) sampled in November were resampled in December (sites 26 and 25, respectively), and the differences between periods provided further insights into the recovery of the seagrasses.

Boat Traffic

There are several ways of measuring aspects of boat activity. Questionnaire surveys of boat users, and time-lapse video recordings have been used in the Great Barrier Reef region (Abbott 1995; Gilbert & Benzaken 1996). As I was most interested in where boats travel (as opposed to their destinations) I considered that questionnaires may not be an appropriate method of gaining the information I required. Time-lapse video recording was also dismissed due to the lack of suitable observation stations (especially in Missionary Bay), and the spatial scale of the areas that needed to be sampled. Consequently, I decided to observe boat movements from high vantage points and to record the boats' actual paths. Although very labour intensive, this approach provided valuable data on where boats travel.

Boat movements were recorded from two vantage points. A 430 m high cliff-face near the northern side of Hinchinbrook Island provided uninterrupted views of most of Missionary Bay, while a 211 m fire tower behind Cardwell allowed boat movements to be observed in the northern Hinchinbrook Channel.

Boat traffic was monitored in Missionary Bay for two 3-day periods. Boats were monitored from sunrise to sunset on Sunday 8, Monday 9 (a public holiday) and Tuesday 10 June 1997. In October 1997, boats were observed on Friday 24 (1130-1700 h), Saturday 25 (0530-1730 h) and Sunday 26 (0530-1400 h). A strong wind warning persisted throughout the June period, with forecast southeasterly winds of 25–30 kn. There were also showers and squalls. Although the forecast for the October period was for 15–20 kn winds, conditions were as rough as, and wetter, than the June period. Consequently, the level of boat traffic was probably suppressed.

Boat traffic was monitored from the Fire Tower from sunrise to sunset on four days 1n 1997: Saturday 28 and Sunday 29 June; Sunday 12 October; and Sunday 16 November 1997. Weather conditions were fair in June, very good in October and fair to poor in November (10–20 kn NE winds).

Boats were categorised by type based on their size, speed, mode of propulsion and hull type. Despite the use of binoculars, size and speed could not be accurately estimated due to the distances to some boats. The following categories were used:

Speedboat: typically a single-hulled, outboard powered boat from approximately 4 to 7 m long. Includes aluminium dinghies.
Passenger ferry: individually recognisable powerboats used to transport clients to: (i) the Cape Richards resort or (ii) Cape Richards resort, Macushla or the No. 7 Creek/Thorsborne Walking Trail. These boats are approximately 10 m long and powered by inboard or multi-outboard motors. These boats are able to travel at high speed, even in rough conditions.

Large planing hull/cruiser: fast single- or multi-hulled powerboats longer than approximately 7 m, and powered by inboard, stern drive or single- or multi-outboard engines.
Sailboat: any boat designed primarily for sailing. Supplementary power typically provided by an inboard or small outboard engine.
Displacement hull/trawler: slower, non-planing boats, typically powered by a diesel, inboard engine.
Houseboat: charter boat with accommodation built onto a wide multi-hull and propelled relatively slowly by outboard engines.
Cruise ship: large single or multi-hulled passenger ship.

The paths of boats were recorded at intervals of 15 minutes or less throughout the periods of observation. Boat paths were subsequently assigned to a reduced number of stylised boat paths for analysis. Anchored boats and boat movements within about 2 km of popular destinations (e.g. Cardwell, Scraggy Point, Goold Island, Macushla etc.) were not included in the analysis. Therefore, our data provide information on significant boat movements, not on the number of boats using the area.

RESULTS

Satellite Tracking

Dugongs were tracked over a 19-month period from May 1997 to November 1998. Thirteen dugongs were tracked for an average of just over six months, with a range of 25 to 551 days (table 1). An average of 412 locations were received from each dugong (range: 98–690; table 1). Over 92% of all locations had a quality rating of > 0 (table 1). Twenty-three percent were quality 1, 35% quality 2 and 34% quality 3. Hence, most of the locations (69%) had a high quality rating. The number of locations received daily from dugongs ranged from 1.08 to 6.09, with an average of 2.75. This difference was due partly to differing duty cycles of the transmitters used, and partly to individual differences in the behaviour of dugongs.

For a successful location to be generated a number of criteria must be met. A satellite must be passing overhead, the transmitter must be operating (the duty cycle means that it is not 'on' for most of the time), and the transmitter must successfully send at least four transmissions in the 15-minute window when the satellite is overhead. The transmitters sent a signal at 60-second intervals. Hence, a transmitter must be at the surface for much of the time when a satellite is passing to successfully generate a location. When a dugong is in relatively deep water (> 3 m), the transmitter spends very little time at the surface. Consequently, relatively few locations are received from dugongs in areas of deep water (> 3 m). This was particularly apparent for dugongs like 'Arthur' and 'Mudskipper' who, respectively, spent months at a time in a deep part of Hinchinbrook Channel and in the northeast of Missionary Bay and who frequently did not produce a location for days at a time. The result of this bias is that the tracking data under-represents the use of deeper areas, and over-represents the use of very shallow areas, where the transmitter is at the surface most of the time.

Locations from tagged dugongs are plotted in figures 4a and 4b. Most locations were received from Missionary Bay, where 10 of the 13 dugongs were tagged. The highest density of locations occurred within the relatively shallow southern part of Missionary Bay. Water depth in this area ranged from shallow intertidal down to about 3.8 m (at mean sea level). Other areas of relatively heavy use by dugongs around Hinchinbrook Island were the Mangrove point area of Hinchinbrook Channel, Shepherd Bay, the band between Goold Island and Hecate Point on Hinchinbrook Island, and the nearshore areas off Cardwell and Lucinda (figure 4b). One dugong tagged in Missionary Bay spent approximately five months in Princess Charlotte Bay, half way up Cape York Peninsula, before returning to Missionary Bay.

The dugongs tagged in Cleveland Bay spent most of their time in a relatively small area of eastern Cleveland Bay, as well as part of Bowling Green Bay (figure 4b).

The tracking has established that most of the waters around Hinchinbrook Island are part of the Hinchinbrook dugongs' habitat. Although most (eight of the 10) dugongs tagged in Missionary Bay spent most of their time in the greater Missionary Bay area (the area contained by a line drawn from Hecate Point around Goold Island to Cape Sandwich; see figure 1), most also moved beyond that area for varying periods of time. For example, seven of the 10 dugongs used Hinchinbrook Channel at some time, although one of these spent 90% of her time outside the Hinchinbrook area and only visited the channel once. On average, the other six dugongs made 7.1 (se 2.4) trips between Missionary Bay and the northern channel during the periods they were tracked (table 1). Although there is not a high density of locations in much of northern Hinchinbrook Channel (figure 4b), suggesting relatively little use of the area, there is considerable movement of dugongs through this area, as they move between feeding areas in Missionary Bay and different areas of the channel (figure 5a).

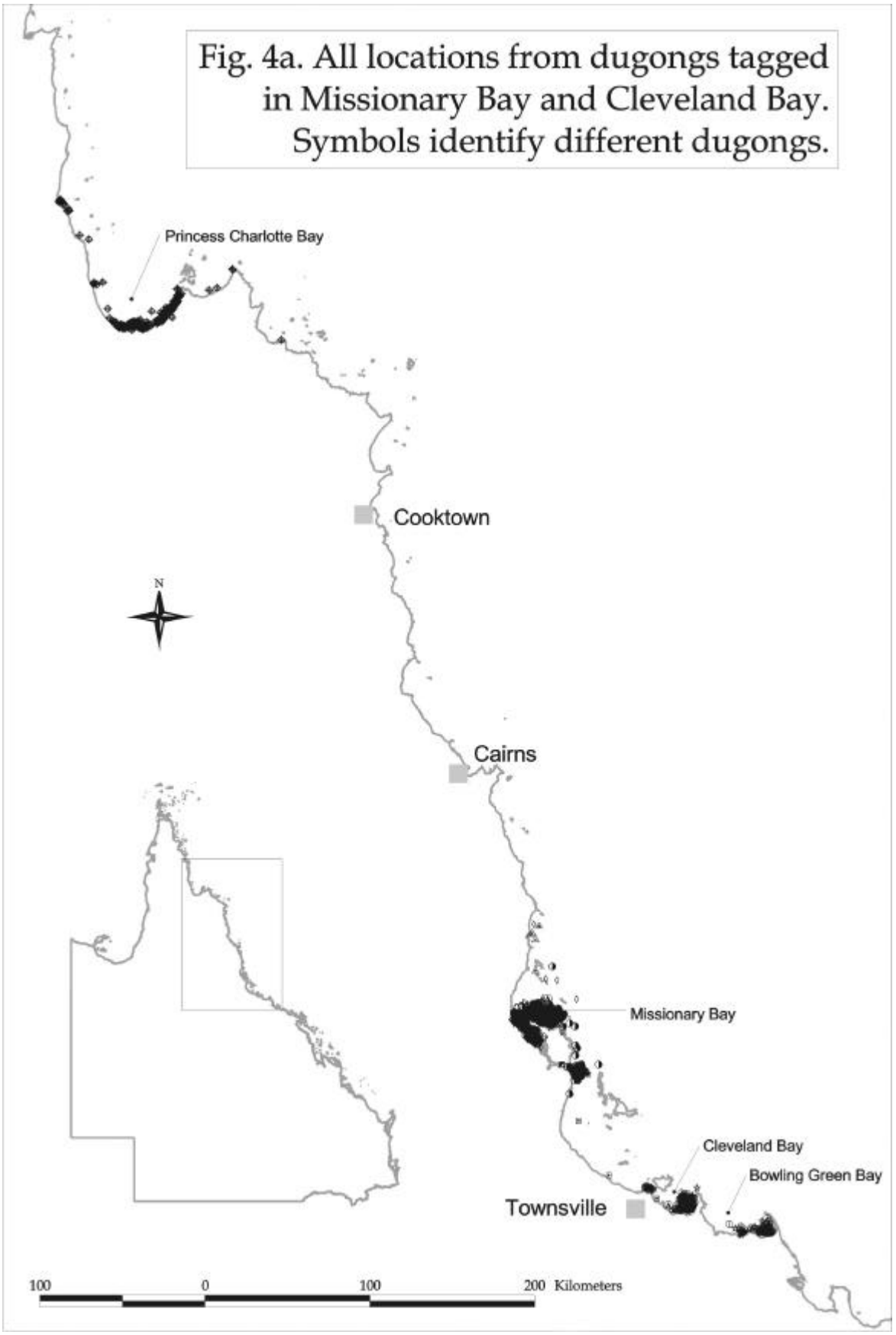
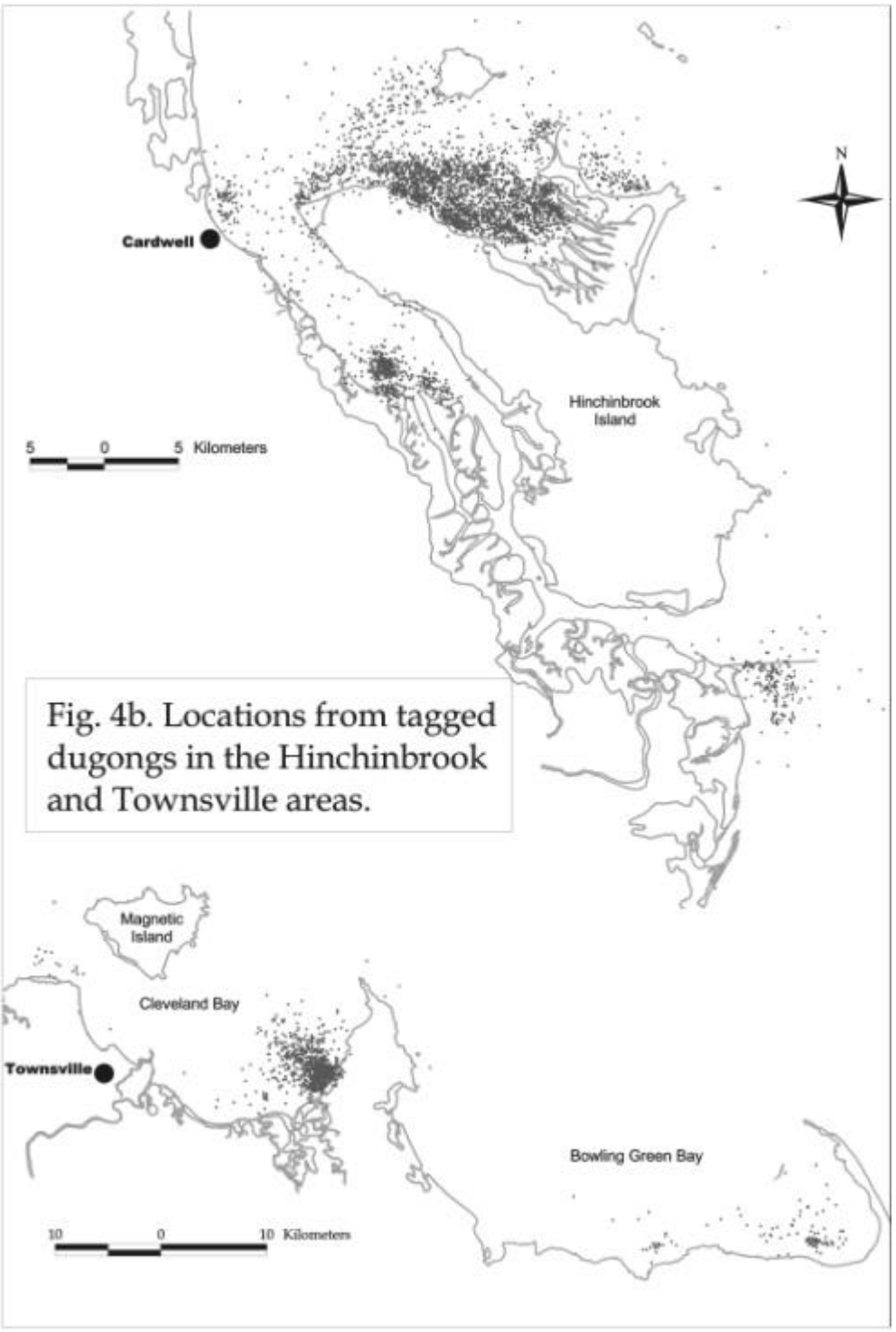


Fig. 4a. All locations from dugongs tagged in Missionary Bay and Cleveland Bay. Symbols identify different dugongs.



Trips between Missionary Bay and commonly used areas of the channel are 20–30 km in length. Many of the dugongs made trips of greater length. Three dugongs made between two and eight trips between the northern end of Hinchinbrook Island and the Lucinda area, a one-way distance of 53 km (table 5). One of these trips is known to have been through the channel. The others apparently traversed the eastern shore of Hinchinbrook Island (figure 5b). Two dugong also made brief visits to the Kurrimine area, some 57 km to the north (table 5). Four of the Hinchinbrook dugongs also travelled between Missionary Bay and Cleveland Bay, a distance of 165 km (figure 5b). This trip was made one to four times by these dugongs. One of the dugongs that visited Townsville, 'MT' also travelled in the opposite direction as far as Colmer Point (Rocky River), which is about 700 km north of Missionary Bay (figure 4a). 'MT', therefore, spanned about 860 km of coast while she was being tracked.