GREAT BARRIER REEF
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RESEARCH PUBLICATION No. 67

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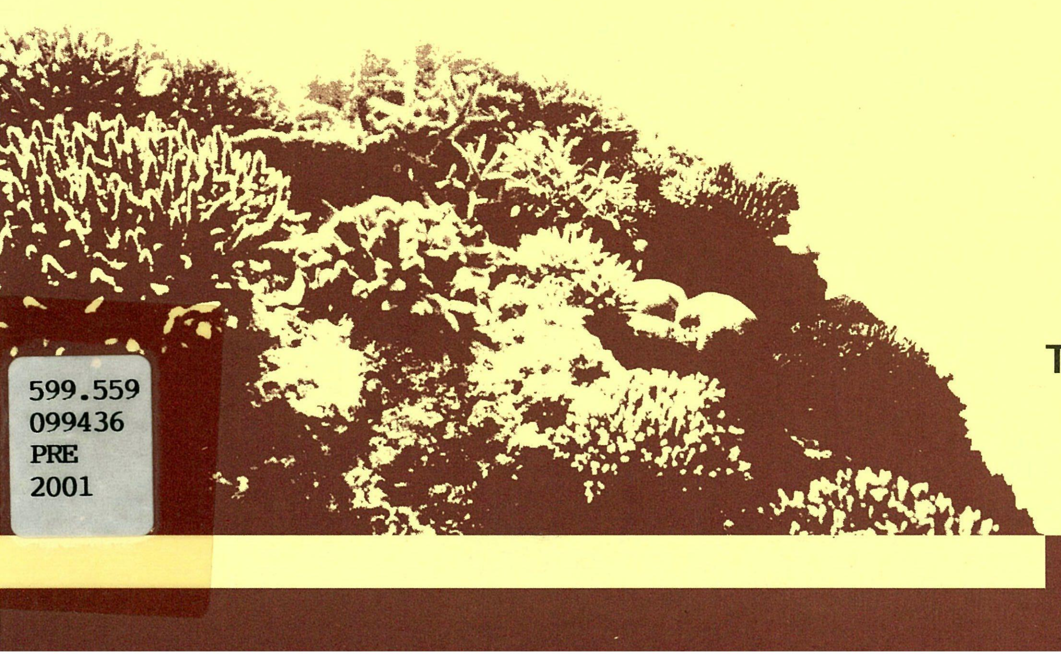

Tony Preen

Reef

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June 2000

CRC Reef Research Centre

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MARINE PARK AUTHORITY

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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 Marine 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 channelling vessel use will be monitored and altered if required.

Recommendation	GBRMPA comment
	The Great Barrier Reef Ministerial Council has asked the Queensland Parks and Wildlife Service (QPWS) to cease the issuing of permits for speed ski races and boat races or associated practices where speeds of 40 knots will be exceeded. The Ministerial Council has also asked the Qld Government to restrict boat speeds to 40 knots, including boat races, in the Hinchinbrook region. As Hinchinbrook Channel is in Queensland State waters, management arrangements for cruise ships are being developed by the State Government in consultation with the Authority.
3. Install channel markers in the northern end of Hinchinbrook Channel to encourage boaters to use a single corridor down the channel.	**3. Supported and implemented.** In conjunction with the Queensland Department of Transport, navigational aids and channel markers identifying the transit lanes have been installed in the Hinchinbrook Channel and Missionary Bay to encourage boaters to use the lanes.
4. Require boat-based commercial dugong watching to operate under a permit system.	**4.** In mid-2000 the Authority granted a permit for commercial dugong watching in the Hinchinbrook Region of the Great Barrier Reef Marine Park. The Authority has decided to use the currently permitted activity as a pilot scheme and to seek a report on the activities of the permittee prior to consideration of any further permit applications.
5. Operators of commercial passenger craft should be required, as a condition of their permit, to report suspected boat strikes to Queensland Environmental Protection Agency and GBRMPA. Passengers should also be actively encouraged to report suspected strikes.	**5. Supported for specific dugong watching permits.** For operators issued with dugong watching permits, it is proposed that mandatory reporting of boat strikes be a condition of the permit. For general commercial boaters, the intent of the recommendation will be achieved through the general public awareness program.
6. The boat traffic management plan should be reviewed at set intervals.	**6. Supported.** Management agencies will be seeking a report from the monitoring program assessing boater compliance with voluntary transit lanes after two years of operation.
Additional recommendation: In the executive summary and conclusions, the author recommends that the Hinchinbrook DPA 'A' be extended south to encompass the existing DPA 'B' zone off Lucinda, and that the Cleveland Bay DPA 'A' be extended to encompass the Bowling Green Bay DPA 'B' zone.	**Additional recommendation:** **Noted but not supported at present.** The success or otherwise of Dugong Protection Areas (DPAs) are periodically assessed by the Great Barrier Reef Ministerial Council.

Hon Virginia Chadwick
Chair

CONTENTS

FIGURES

TABLES

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.

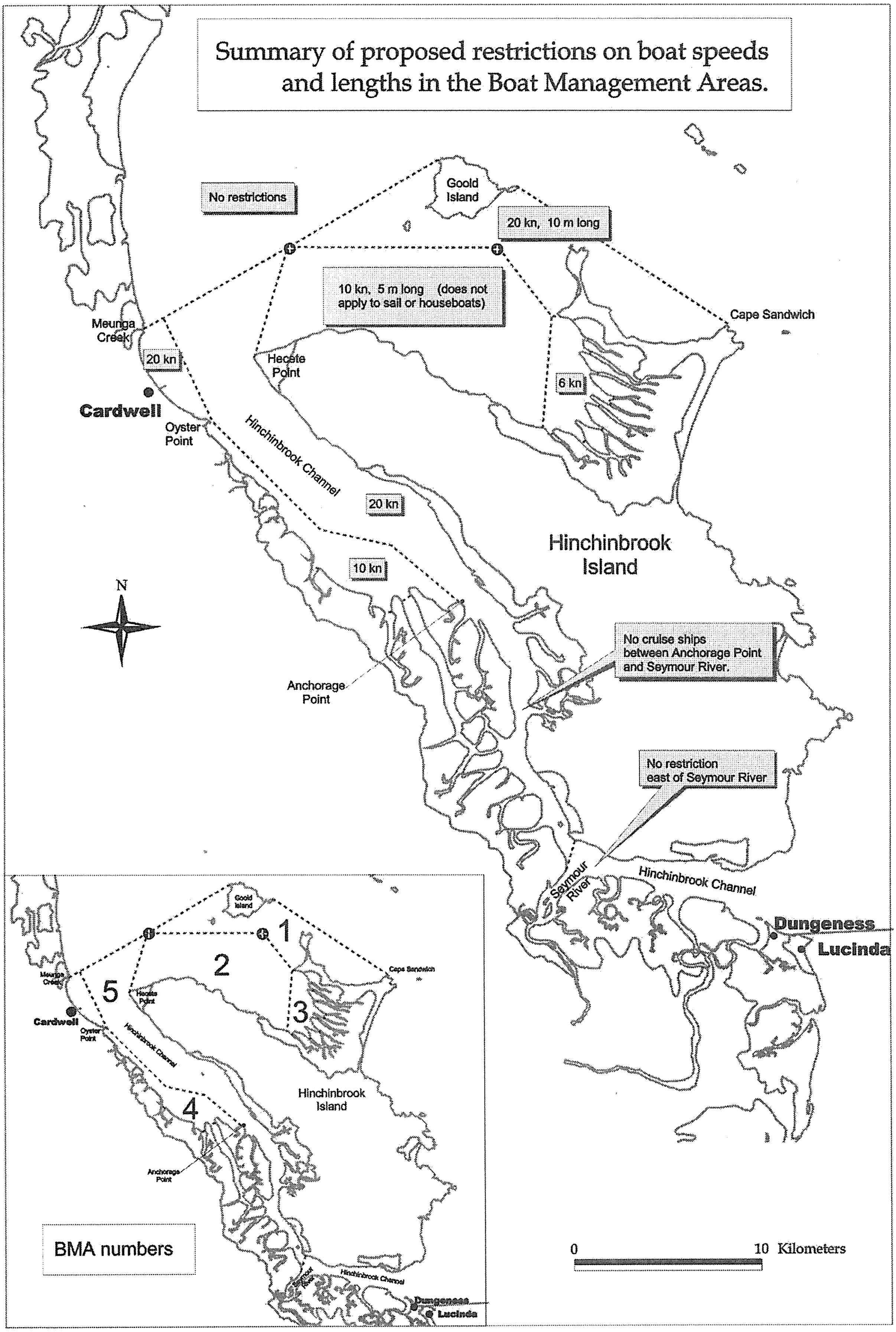
Fast commercial passenger ferries operating between Cardwell and Cape Richards, Macushla and the No. 7 Creek/Thorsborne Trail accounted for 15% of boat movements in Missionary Bay. During weekdays this percentage increased considerably (to 39% during our sample periods).

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
Anchorage Point
No cruise ships between Anchorage Point and Seymour River.
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.

CONTEXT OF THIS REPORT

In August 1996, Senator Hill, Federal Environment Minister, gave his consent to the 'Port Hinchinbrook' marina resort and residential development proposed for Oyster Point in Hinchinbrook Channel. In making this decision, Senator Hill acknowledged concerns about regional impacts associated with developments in the Hinchinbrook area. Consequently, the Federal and Queensland Governments initiated the Hinchinbrook Region Coastal Management Plan to give guidance for the protection, conservation, rehabilitation and ecologically sustainable development of the area (Littleproud 1996).

A prominent concern at the time was the impact of boat traffic generated by marina developments, particularly the 'Port Hinchinbrook' marina, on the local dugong population. Accordingly, Senator Hill stated that the Regional Plan '*...will provide specifically for the protection of Dugongs, turtles and other marine animals in Hinchinbrook Channel*' (Hill 1996a). Further, the Plan will provide for '*the regulation of boating activity, including speed limits where appropriate to protect marine animals*' (Hill 1996b). This plan '*will be in place prior to the Port Hinchinbrook Resort coming into operation*' (Hill 1996a).

Senator Hill continued '*This work will be supported by scientific research conducted by James Cook University into dugong movements which will be funded by the Commonwealth. This research will inform the regional planners who will draw on it when making appropriate arrangements for controlling boats*' (Hill 1996a). This report summarises that research.

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.

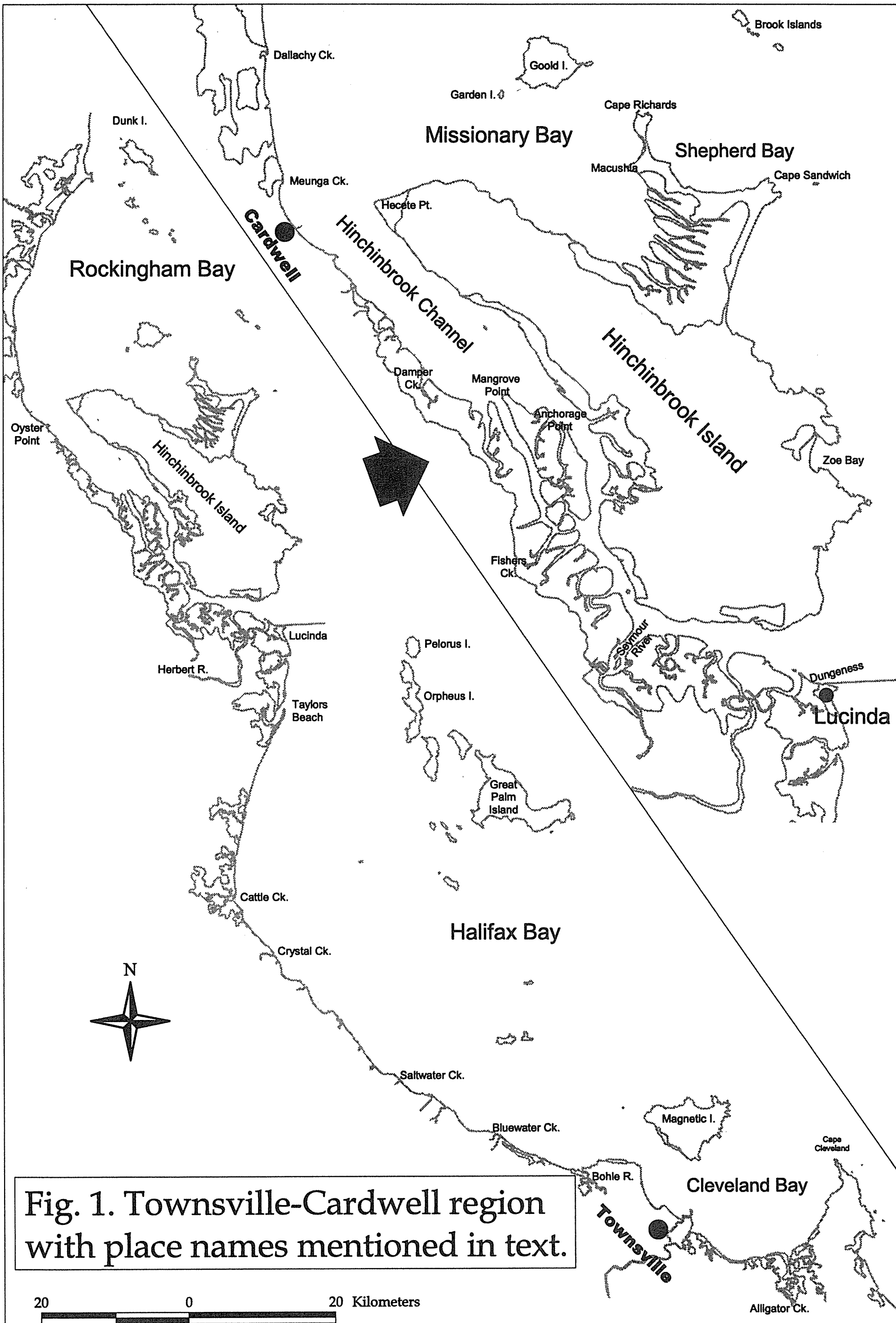


Fig. 1. Townsville-Cardwell region with place names mentioned in text.

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).

METHODS

Study Area

Although the study was initiated to address issues in the Hinchinbrook Dugong Protection Area, the study area encompassed the coastal waters of the Townsville-Cardwell region, with an emphasis on the waters around Hinchinbrook Island (figure 1). The expansion of the study area beyond the Hinchinbrook area was based on the expectation that dugongs would move between the Hinchinbrook and Townsville areas, as well as the practical consideration that aerial surveys would originate and terminate at Townsville. The dugong tracking subsequently demonstrated the links between the two ends of the Townsville-Cardwell region.

Cardwell (18.26^0 S, 146.02^0 E) is located towards the southern end of the wet tropics, while Townsville (19.26^0 S, 146.6^0 E), approximately 135 km to the southeast, is in the wet/dry tropics. Most rainfall occurs during the summer months under the influence of monsoonal weather patterns. The dominant winds blow from the southeast, particularly during the drier winter and spring. Cyclones occur in the region during summer.

The coastline of this region is made up of two very large, open and exposed bays: Halifax Bay, north of Townsville and Rockingham Bay, north of Cardwell. There are two smaller, protected bays: Cleveland Bay near Townsville, and Missionary Bay on the northern side of Hinchinbrook Island. The 46 km long channel between Hinchinbrook Island and the mainland provides another area of very protected waters. The largest river in the region, the Herbert, flows into the southern end of Hinchinbrook Channel through the Seymour River and other channels.

An estimated 259 km^2 (+/- 30) of seagrass have recently been mapped in the region, with most occurring in the protected waters in and around Missionary and Cleveland Bays (Lee Long et al. 1998). Seagrasses in Missionary Bay and the adjacent Shepherd Bay are dominated by communities made up of *Halophila spinulosa*, *Halophila ovalis*, *Halodule uninervis* and *Halophila decipiens*. Seagrass communities around Cardwell and Hinchinbrook Channel are composed predominantly of *H. ovalis, H. uninervis*, *H. decipiens* and *Halophila tricostata*. In Cleveland Bay the main species are *H. spinulosa*, *H. ovalis* and *Cymodocea serrulata* (Lee Long et al. 1998). *Halodule uninervis* and species of *Halophila*, especially *H. ovalis*, are favoured foods of dugongs (Preen 1995a, b).

Satellite Tracking

Fifteen dugongs were captured and tagged with satellite transmitters. Two transmitters came off or stopped working within five days. Of the 13 dugongs that provided useful information, 10 were tagged in Missionary Bay (nine in May and one in October 1997) and three were tagged in Cleveland Bay (March and April 1998). One dugong was recaptured after 7.5 months to change transmitters. Five dugongs were male and eight were female. Of the females, four had calves at the time of capture, and a fifth gave birth during the tracking period (table 1).

The dugongs were captured using a hand-held cone-shaped net (like a large butterfly net) after a short speedboat chase. A padded tail-rope held the dugong after the removal of the net and during the tagging operation, which took place in the water. The buoyant transmitters were attached by a 3 m flexible tether to a padded, custom-fitted tail belt. The belt contained a weak link and a timer attached to a small detonator designed to release the belt after a pre-set period. A buoyant transmitter is necessary because saltwater attenuates the signal if the aerial is underwater. A 3 m tether allows the transmitter to function when the dugong is feeding or resting in less than 3 m of water.

The satellite-monitored transmitters broadcast information on location, activity and temperature throughout their duty cycles. Some transmitters also provide information on dive activity. The transmitters were programmed to operate for specified periods of the day. These duty cycles were designed to maximise the number of satellite passes that could be intercepted, while minimising battery drain. Transmitters operated on duty cycles that totalled 7.5 to 15 h operation each day. Further details of the transmitters can be found in Marsh & Rathbun (1990).

Table 1. Details of dugongs tracked in the Townsville-Cardwell region in 1997–98.

Name	Sex	Calf	Capture Location	Days tracked	Number of locations: Total	Number of locations: Quality >0 (%)	One-way trips between Missionary Bay and Channel
Peggy	F	✓	Missionary Bay	25	98	88.8	8
K2	F	✓	Missionary Bay	94	572	92.8	15
Liz	F	✗	Missionary Bay	105	359	94.4	6
Jeremy	M		Cleveland Bay	112	316	94.3	na
Vito	M		Missionary Bay	125	348	86.8	19
Moby	M		Cleveland Bay	135	413	86.4	na
Ray	M		Cleveland Bay	142	241	94.2	na
Noelene	F	✓	Missionary Bay	156	263	92.4	0
MT	F	✗	Missionary Bay	210	323	94.7	2
Shirley	F	✗	Missionary Bay	222	690	94.9	0
MM	F	✓	Missionary Bay	236	769	94.7	18
Arthur	M		Missionary Bay	287	310	96.1	12
Mudskipper	F	✓	Missionary Bay	551	683	91.7	0
			Mean	184.6	414.2	92.5	
			se	36.1	55.9	0.9	

na: not appropriate - dugongs based in Cleveland Bay

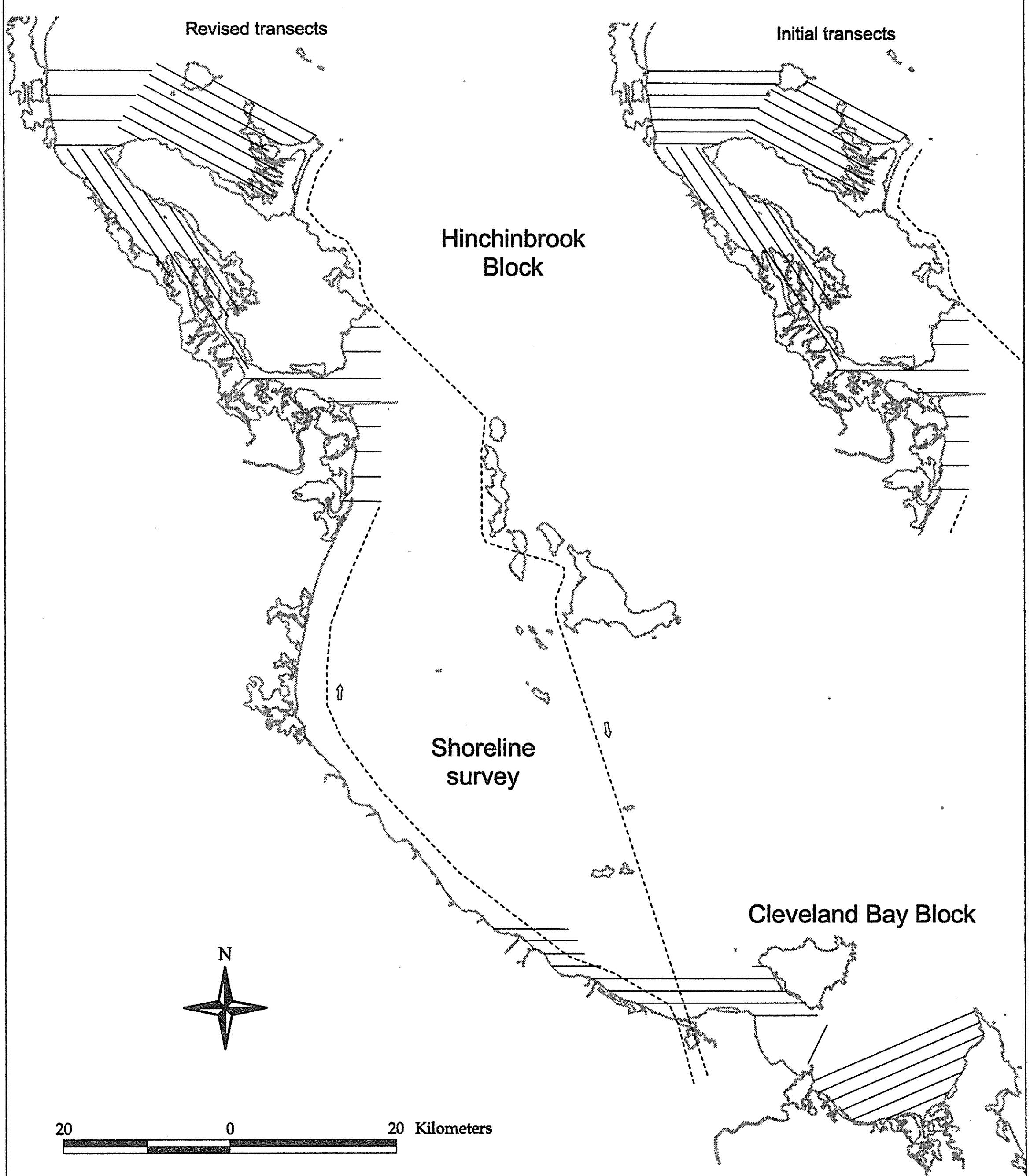
Service Argos, which operates the satellite location system, provides a quality rating for locations. Sixty-eight percent of location quality (LQ) 3 fixes are estimated to fall within 150 m of the true location. For LQ 2 the radius is 350 m, and for LQ 1 it is 1000 m (New Argos Location 1994). Independent tests suggest these radii are 361 m, 903 m and 1188 m for LQ 3, 2 and 1, respectively (Keating et al. 1991). No estimate of accuracy is provided for LQ 0 locations, although they are generally within 5000 m of the true location (Gos 1994). I deleted from the data set all locations that were clearly incorrect. Between one and seven locations (average = 3.4, se = 0.6) from each dugong were deleted because they occurred > 1000 m from water, or because they were implausible due to their time and distance from preceding and subsequent locations.

Aerial Surveys

The Hinchinbrook-Townsville region was regularly surveyed by air between March 1997 and April 1998 using a combination of shoreline and strip-transect aerial surveys to monitor the distribution and abundance of dugongs. Sightings of turtles, cetaceans and boats were also recorded.

The survey design was based on an initial detailed shoreline survey of the whole area in March 1997 as well as the results of Heinsohn's shoreline surveys of the 1970s (see below) and Marsh's three transect surveys of 1987, 1992 and 1994 (Marsh et al. 1996). The region was divided into three survey areas: Townsville/Cleveland Bay, Halifax Bay, and Cardwell/Hinchinbrook. The Townsville block (from Cape Cleveland to Saltwater Creek) and the Cardwell block (from Taylors Beach to Dallachy Creek) were surveyed along fixed transects (figure 2). The Halifax Bay block (including eastern Hinchinbrook Island) was surveyed by flying along a standardised flight path (shoreline survey), that replicated Heinsohn's previous surveys of this area (figure 2). Transect surveys are used to plot distribution of sightings throughout the whole survey block and to derive estimates of the number of animals (or boats) in the survey area. The shoreline surveys only provide information on distribution and relative abundance along the flight path, but they can focus on the known or expected areas of importance, and are much cheaper to conduct.

Fig. 2. Flight paths of strip-transect and shoreline aerial surveys flown in 1997 and 1998.



The transect surveys were flown at an altitude of 550' (167 m) at a speed of 90–100 kn (166–185 km/h). Transect markers attached to the wing struts marked a search area 250 m wide on each side of the aircraft. Observations within these transects were recorded on audiotape for subsequent analysis. Observations of conspicuous dugong and dolphin groups and boats seen outside the transect were also noted. Transects were flown with the aid of a GPS, to ensure repeatability. The Cardwell block was divided into four zones (Lucinda, Channel, Missionary Bay and Dallachy Creek). Parallel transects in these zones were 3 km or 1.5 km apart (figure 2), depending on the expected abundance of dugongs in the area. The final survey coverage averaged 23.6% in Cleveland Bay and 29.7% around Hinchinbrook Island (table 2).

Table 2. Survey effort. The actual percentage of each survey block covered by transects during each aerial survey. See table 3 for dates of surveys.

		Survey number											
		Coverage (%)											
Survey Block	Block area (km^2)	1	2	3	4	5	6	7	8	9	10	11	Mean
Cleveland Bay	402	23.5			24.0			23.8	23.8	23.6	23.7	22.8	23.6
Hinchinbrook	486	30.2	na*	30.7		29.3	29.5	30.0	30.3	29.5		28.1	29.7
TOTAL	888	27.2						27.2	27.4	26.8		25.7	26.8

* Not analysed (weather deteriorated to an unacceptable level during survey)

The shoreline surveys were flown at an altitude of 650' (198 m) at approximately 100 kn (185 km/h). There was no fixed transect width, although most observations of wildlife were made within a strip approximately 800 m either side of the aircraft. Boats were much more conspicuous and were recorded within a strip approximately 1.5 km wide. Boats were recorded in the following categories: small- to medium-sized powerboats (speed boats and outboard-powered aluminium dinghies (known as 'tinnies')), large planing hulled powerboats, displacement hulled boats (including trawlers), sailing boats, house boats, cruise ships and jet skis. These categories are more precisely defined in the section on Boat Traffic (below).

All the surveys used a Cessna 172 aircraft. The strip-transect surveys were essentially the same as the now standard dugong surveys (described by Marsh & Sinclair 1989a, b). The main differences were that we used two instead of four observers, which means that we could not calculate a perception bias correction factor (see below). We also flew at 550' rather than 450'. This difference was largely a safety concession because of our single-engine aircraft. The advantages of our surveys were that:

- the smaller aircraft was significantly cheaper to operate, and therefore,
  - ➢ we could do more surveys;
  - ➢ we could increase our survey coverage to improve the accuracy of the distribution data and the population estimates (compared with the standard surveys of those areas we increased coverage by 26% in Cleveland Bay and 61% around Hinchinbrook)
- as only two observers were used, we were able to use the same experienced observers on every survey, increasing the reliability of observations; and
- we had the manoeuvrability to effectively break transect to circle dolphin groups to get positive identifications, something that is difficult to do with the larger aircraft used on the standard dugong surveys.

The Townsville-Hinchinbrook area was usually surveyed over two consecutive days. However, due to weather and other constraints, not all areas were surveyed every time. The Townsville survey block was surveyed on seven occasions, the Cardwell block was surveyed on nine occasions (although data from one survey were not analysed for population estimates due to the poor weather), and both blocks were surveyed together on five occasions (table 3). Shoreline surveys of Halifax Bay were flown on 10 occasions, although on one occasion the return leg was abandoned due to poor weather, while on another survey the return leg followed the path of the north-bound leg (along the coast) due to a military closure of the offshore waters.

After four surveys of the Hinchinbrook area it became apparent that the boundary between the Missionary Bay and Dallachy Creek survey zones was inappropriately located, as it coincided with an area heavily used by dugongs. Furthermore, most of the Dallachy Creek zone had a low density of dugongs sightings. Consequently, I redesigned the transects - extending the Missionary Bay zone westward to incorporate all of the feeding area, and halving the density of transects in the Dallachy zone. Although the revised design (figure 2) is an improvement, the results of the first four surveys (of which one was not analysed) cannot be compared statistically with the subsequent five surveys (table 3).

Table 3. Details of transect aerial surveys: days of week and months of surveys of each survey-block; version of transects flown in the Hinchinbrook survey-block; and results of analyses of variance comparing results of different surveys. Anova results in vertical boxes relate to the surveys enclosed in horizontal boxes. Anova results are presented with and without the inclusion of covariates related to survey conditions. Detailed Anova results are presented in appendices 2 and 3.

Survey	1	2	3	4	5	6	7	8	9	10	11
Month	Apr	Apr	May	July	Aug	Oct	Oct	Dec	Feb	Mar	Apr
Year	1997	1997	1997	1997	1997	1997	1997	1997	1998	1998	1998
Day of Week	Thu, Wed	Wed	Wed	Tue	Fri	Tue	Fri, Sat	Thu, Fri	Fri, Sat	Sat	Fri, Mon
Transect version[1]	1	1	1	1	1	2	2	2	2	2	2
Cleveland Bay	▲			▲			▲	▲	▲	▲	▲
Hinchinbrook	▼	×	▼		▼	▼	▼	▼	▼		▼

	Cleveland Bay (7 surveys)	Hinchinbrook - ver. 1 transects (3 surveys)	Hinchinbrook - ver. 2 transects (5 surveys)	Cleveland Bay plus Hinchinbrook ver.2 transects (4 surveys)
Dugongs				
Anova	Sig. (0.020)	Sig. (0.034)	NS (0.356)	Sig. (0.027) No interaction
Anova + covariates	~ Sig. (0.049)	NS (0.879)	Sig. (0.006)	Sig. (0.002) No interaction
Turtles				
Anova	Sig. (0.004)	Sig. (0.000)	Sig. (0.000)	Sig. Sig. Interaction
Anova + covariates	Sig. (0.016))	NS (0.593)	Sig. (0.000)	Sig. Sig. Interaction

[1] version of transects flown in Hinchinbrook area: 1: initial design; 2: revised design
×: survey not analysed.

For analysis of the transect surveys, Cleveland Bay and Hinchinbrook were considered as two survey blocks within the one area. As the transects were of variable length, the Ratio Method (Jolly 1969) was used to estimate the density, population size and associated standard errors for each block. The population estimates were based on the estimated number of animals, in groups of fewer than 10, for each transect, calculated using the appropriate corrections for availability bias and mean group size. The standard errors were adjusted to incorporate the error associated with each correction factor (table 4), as outlined in Marsh & Sinclair (1989a). Herds of $\geq$10 dugongs are excluded from the calculation of population estimates, and added to the population estimate as a separate stratum, as suggested by Norton-Griffiths (1978). Population estimates were calculated for dugongs, turtles and boats. On most surveys too few groups of cetaceans were sighted to calculate meaningful population estimates.

Availability correction factors were derived to adjust for the number of animals not at the surface, and hence less likely to be available to observers, at the time the plane passed over (Marsh &

Sinclair 1989b; table 4). For dugongs, the proportion of sightings at the surface was compared to the proportion 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

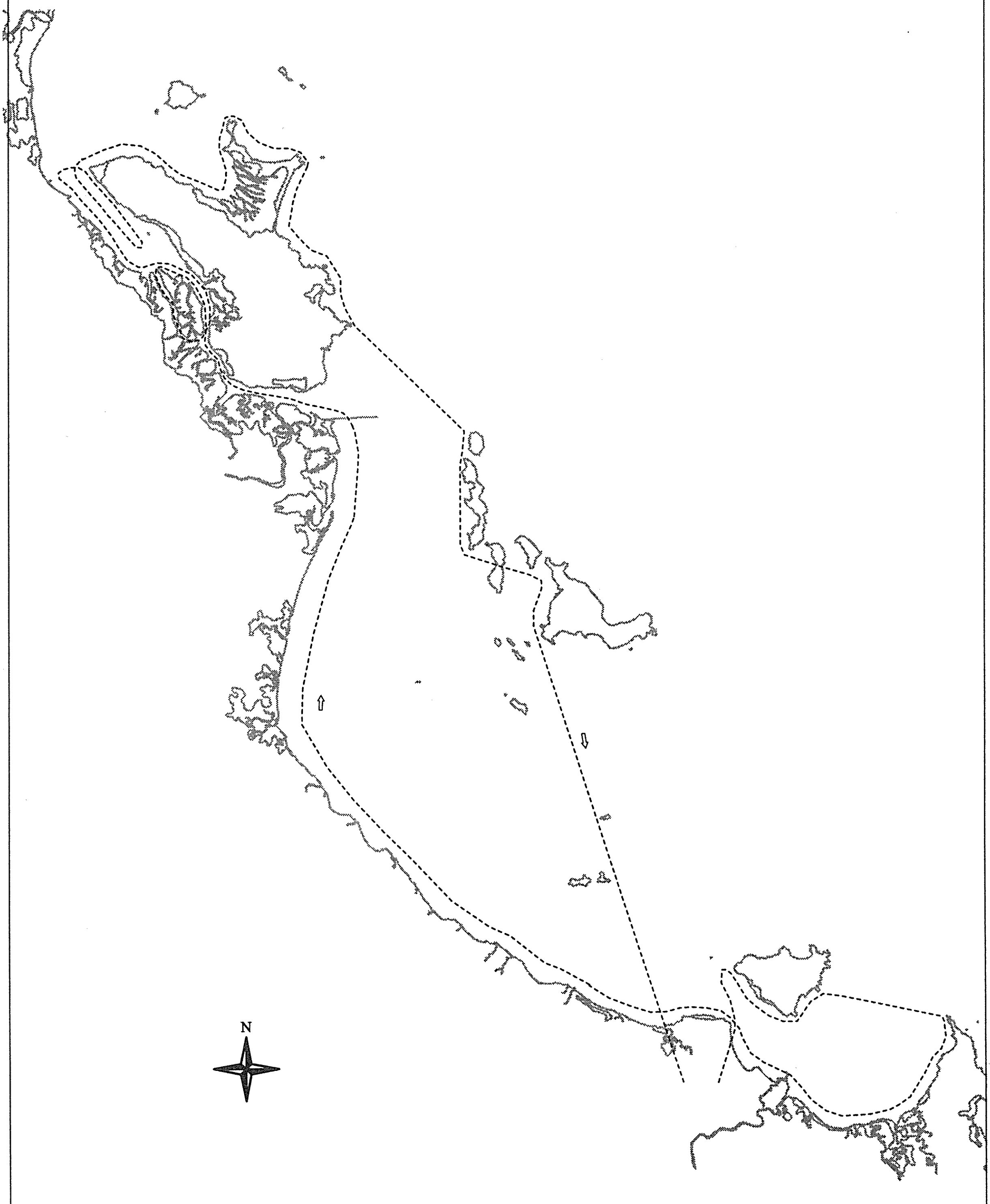
Between 1974 and 1981, Dr George Heinsohn and colleagues from James Cook University conducted 26 shoreline aerial surveys between Townsville and Hinchinbrook Island. Raw data from the Heinsohn surveys were processed to provide a comparison of sightings in the 1970s with those of the present study.

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.

Fig. 3. Typical path of George Heinsohn's shoreline aerial surveys flown between 1974 and 1981.



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).

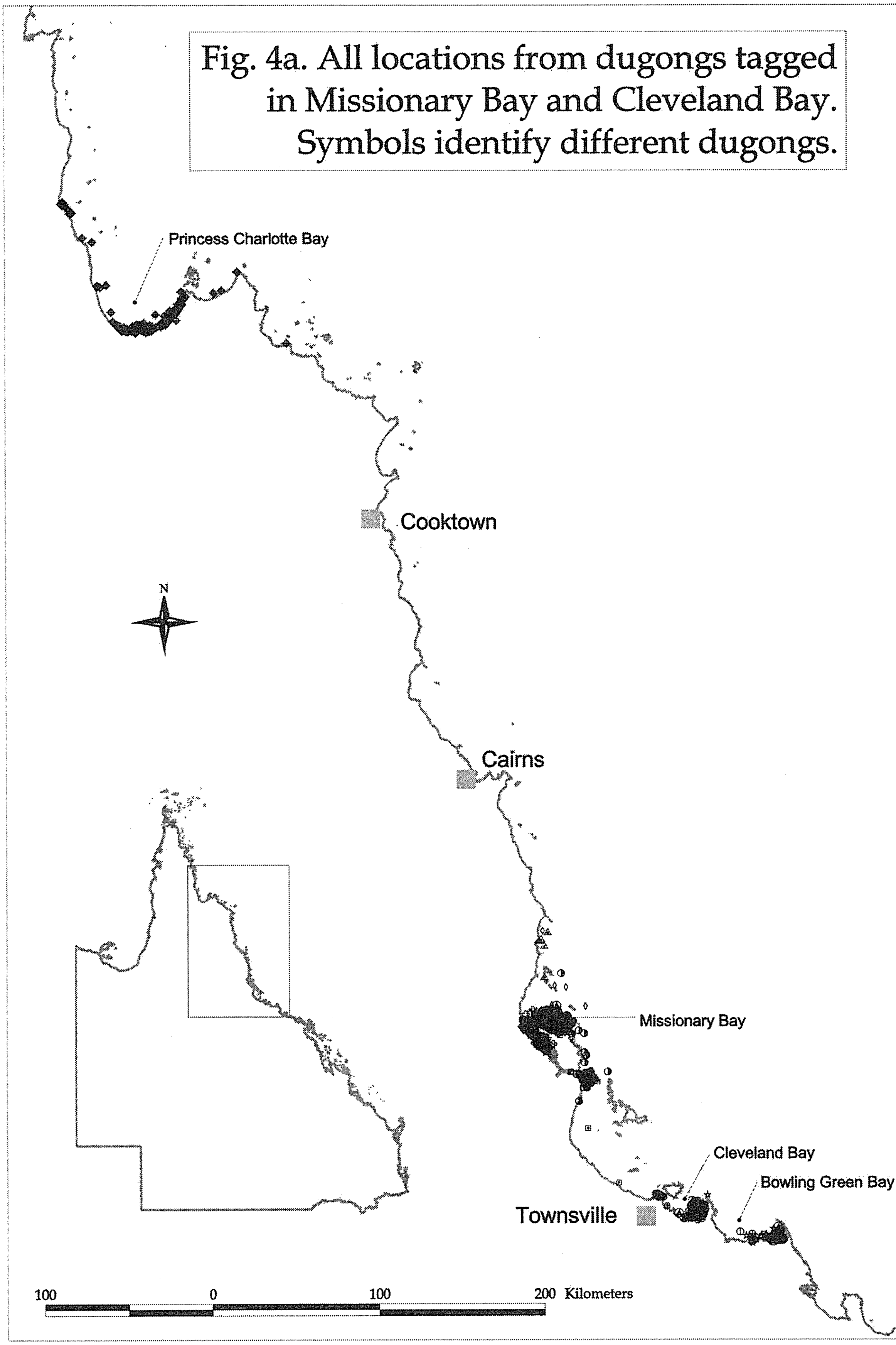


Fig. 4a. All locations from dugongs tagged in Missionary Bay and Cleveland Bay. Symbols identify different dugongs.
Princess Charlotte Bay
Cooktown
N
Cairns
Missionary Bay
Cleveland Bay
Bowling Green Bay
Townsville
100
0
100
200 Kilometers

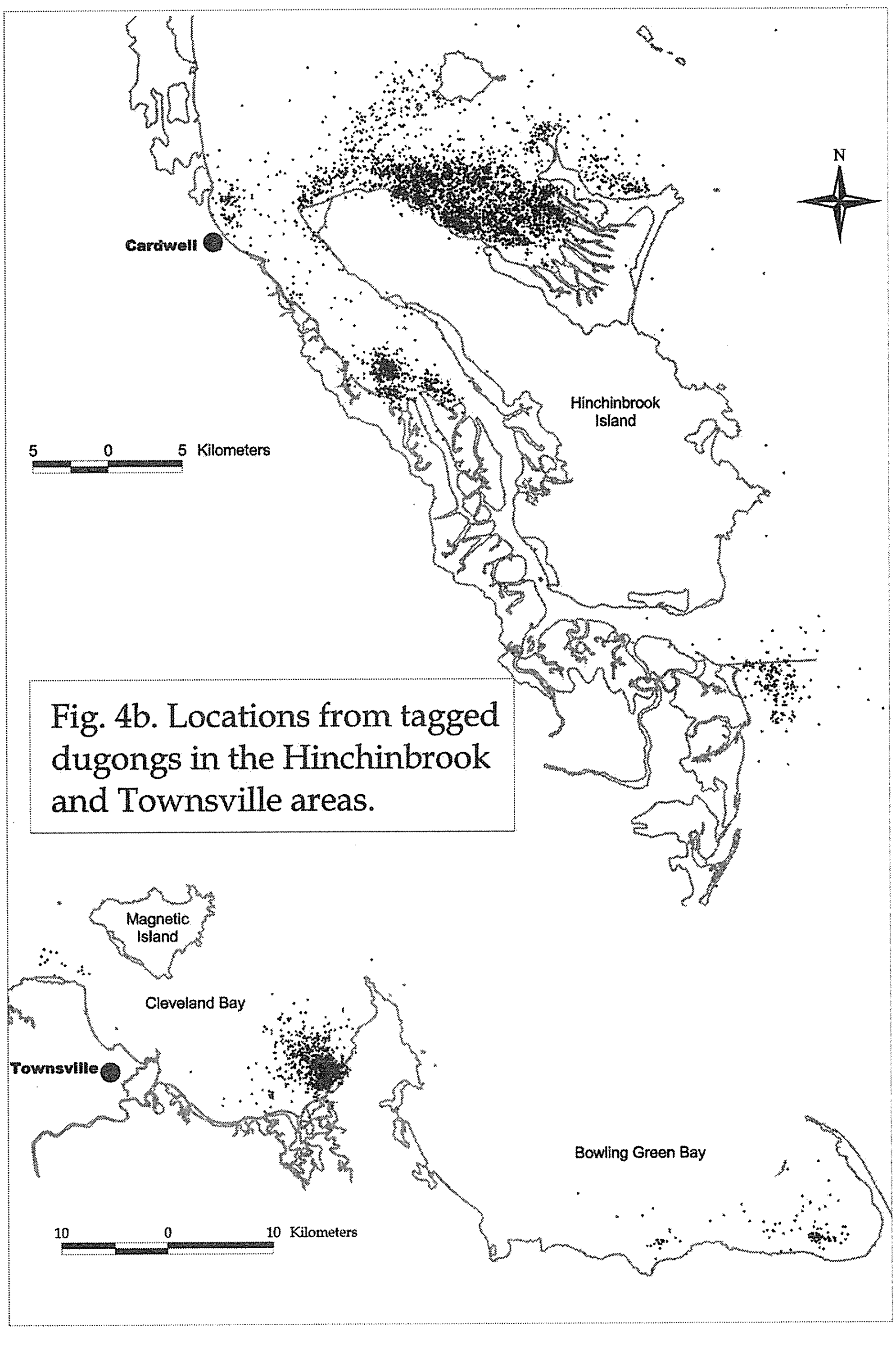


Fig. 4b. Locations from tagged dugongs in the Hinchinbrook and Townsville areas.

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.

Of the three dugongs tagged in Cleveland Bay, one ('Ray') visited Missionary Bay. However, all three visited Bowling Green Bay to the south, making the 60 km trip between two and 10 times (table 5; figure 5b).

Table 5. Number of trips of more than 50 km undertaken by tracked dugongs

Dugong	Tagged in[1]	Movement between		1-way trips[2]	1-way swim distance (km)
MT	MB	Missionary Bay	& Princess Charlotte Bay	2	600
Arthur	MB	Missionary Bay	& Cleveland Bay	1	165
MT	MB	Missionary Bay	& Cleveland Bay	2	165
Noelene	MB	Missionary Bay	& Cleveland Bay	2	165
Ray	CB	Cleveland Bay	& Missionary Bay	2	165
Shirley	MB	Missionary Bay	& Cleveland Bay	4	165
Jeremy	CB	Cleveland Bay	& Bowling Green Bay	10	60
Moby	CB	Missionary Bay	& Bowling Green Bay	2	60
Ray	CB	Cleveland Bay	& Bowling Green Bay	8	60
Liz	MB	Missionary Bay	& Kurrimine	2	57
MM	MB	Missionary Bay	& Kurrimine	2	57
K2	MB	Missionary Bay	& Lucinda	2	53
Mudskipper	MB	Missionary Bay	& Lucinda	8	53
Noelene	MB	Missionary Bay	& Lucinda	3	53

[1] MB: Missionary Bay, CB: Cleveland Bay
[2] Two 1-way trips constitute a return trip, but not all dugongs returned before their transmitters came off.

The movements summarised in table 5 are essentially single-hop movements, rather than incremental movements along the coast (hence, the large movement by 'MT' is 600 km to Princess Charlotte Bay, and does not include the subsequent 100 km travelled to the north). As such, they indicate purposeful movement within a known range. The motivation for these movements is not clear, although it is likely that some are socially driven. Several dugongs spent up to four days travelling from Missionary Bay to Cleveland Bay, only to stay a day or less before making the return trip. A similar pattern was observed with tagged dugongs in the western Gulf of Carpentaria (Preen, unpublished data).

Aerial Surveys

Dugongs

Relatively few dugongs were seen on the shoreline surveys between the Cleveland Bay and Hinchinbrook areas. Most occurred at the southern end of Halifax Bay, an area covered by the Townsville transect surveys. Only six groups were seen outside transect blocks: one off Cattle Creek, one off Great Palm Island and three off the exposed eastern coast of Hinchinbrook Island (figure 6a). In contrast, the transect surveys found that dugongs were common in sheltered areas around Cleveland Bay and Hinchinbrook Island. The locations of dugong groups seen on transects during each survey are plotted in figure 6b and 6c, and the approximate locations of those groups seen outside the transects are plotted in figure 6d. The cumulative results of the surveys provide a picture of dugong distribution and habitat use in these areas over the course of one year. In the Townsville area, the great majority of sightings were in the eastern part of Cleveland Bay, south of Cape Cleveland. The area of secondary importance was off the western shore of Magnetic Island (figure 6c, 6d). In the Hinchinbrook area, greater Missionary Bay (the area contained by a line from Hecate Point around Goold Island to Cape Sandwich) was the most important area, with most sightings in a band running southwest from Goold Island to Hinchinbrook Island, and in Shepherd Bay (figure 6b, 6d). Only three sightings occurred in the Lucinda zone, and these were all outside the transects. Relatively few sightings were made in the Hinchinbrook Channel and in the Dallachy Creek zone to the north and similar numbers were seen on and off the transects in these areas.

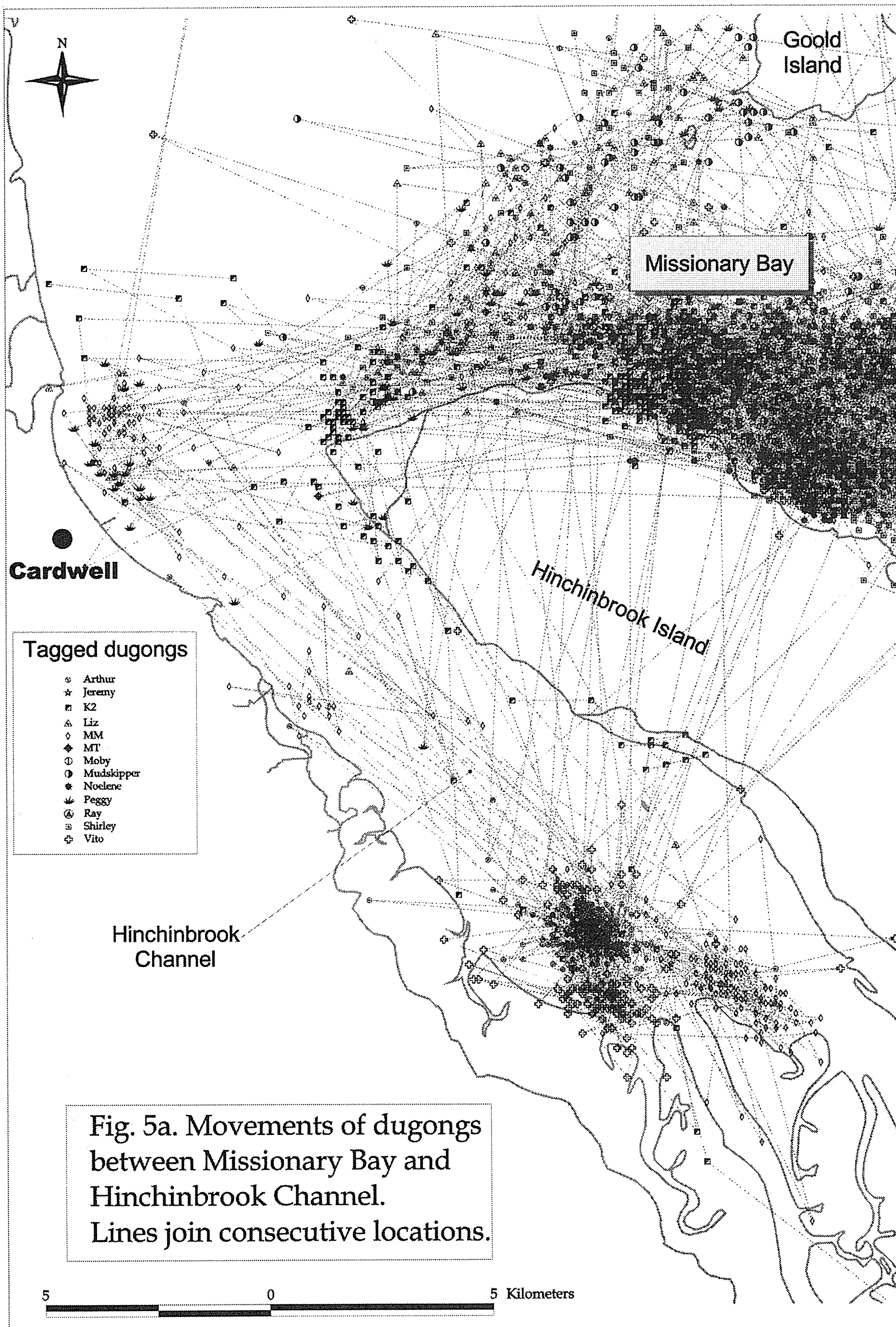
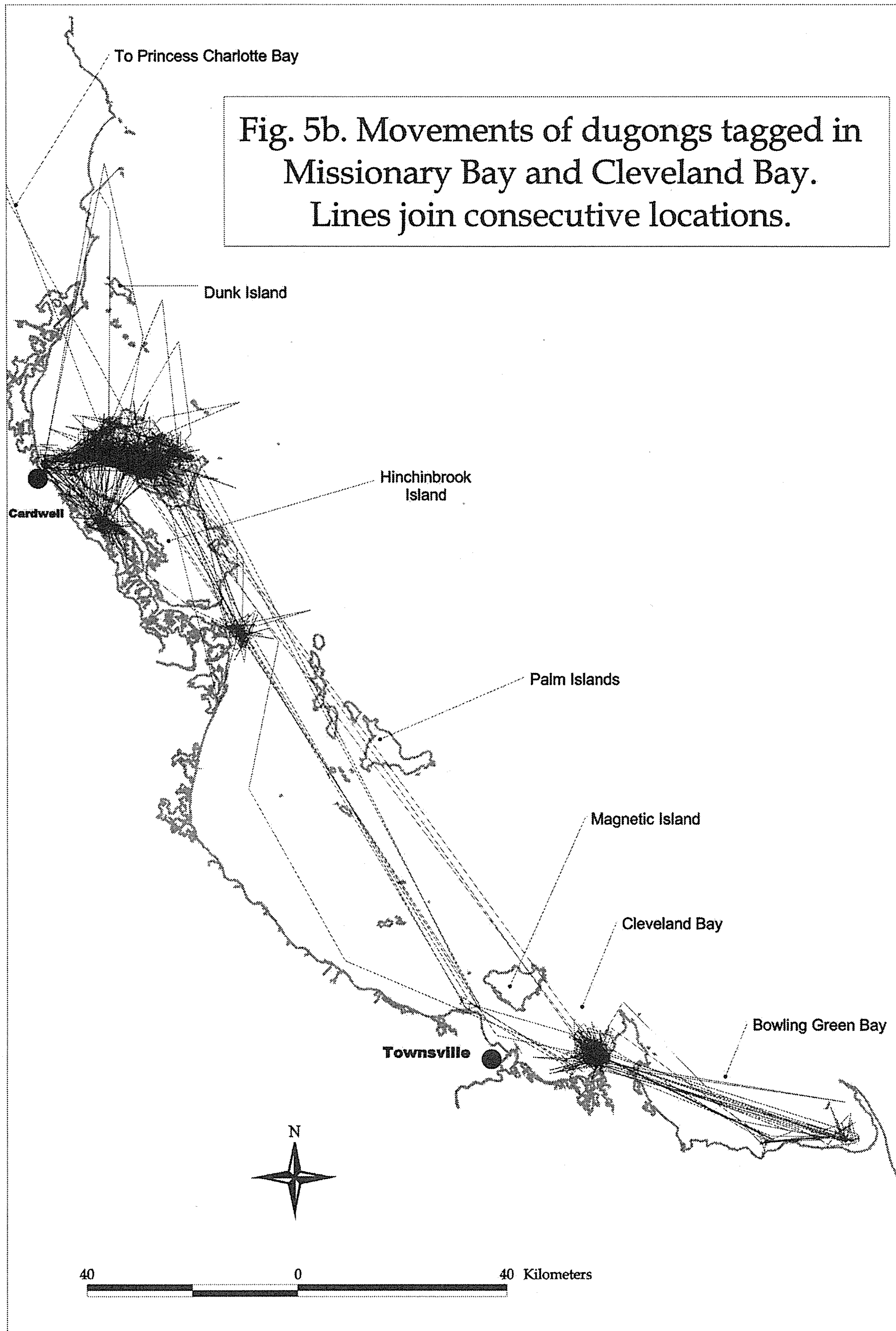


Fig. 5a. Movements of dugongs between Missionary Bay and Hinchinbrook Channel. Lines join consecutive locations.


To Princess Charlotte Bay
Fig. 5b. Movements of dugongs tagged in Missionary Bay and Cleveland Bay. Lines join consecutive locations.
Dunk Island
Hinchinbrook Island
Cardwell
Palm Islands
Magnetic Island
Cleveland Bay
Bowling Green Bay
Townsville
N
40
0
40 Kilometers

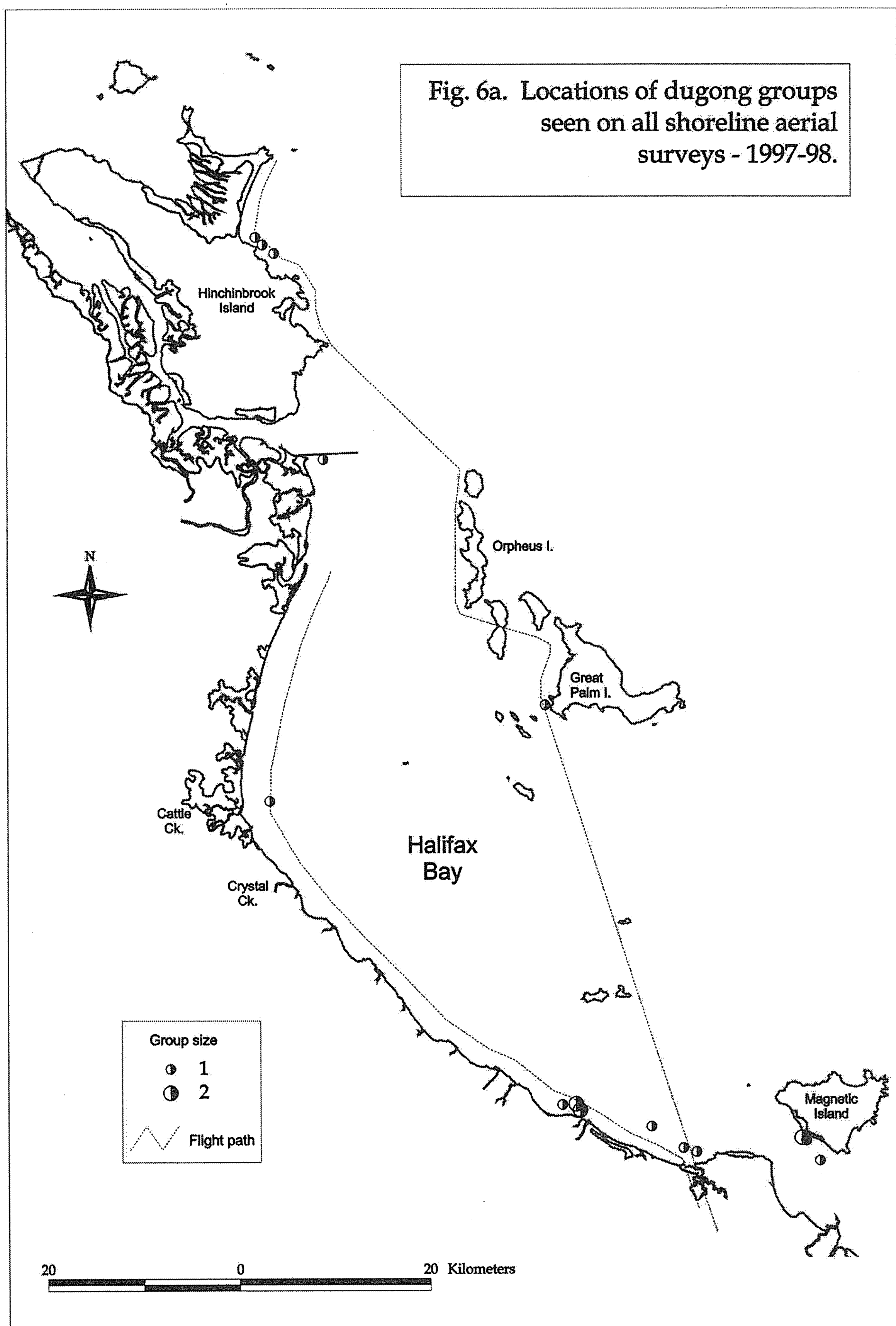
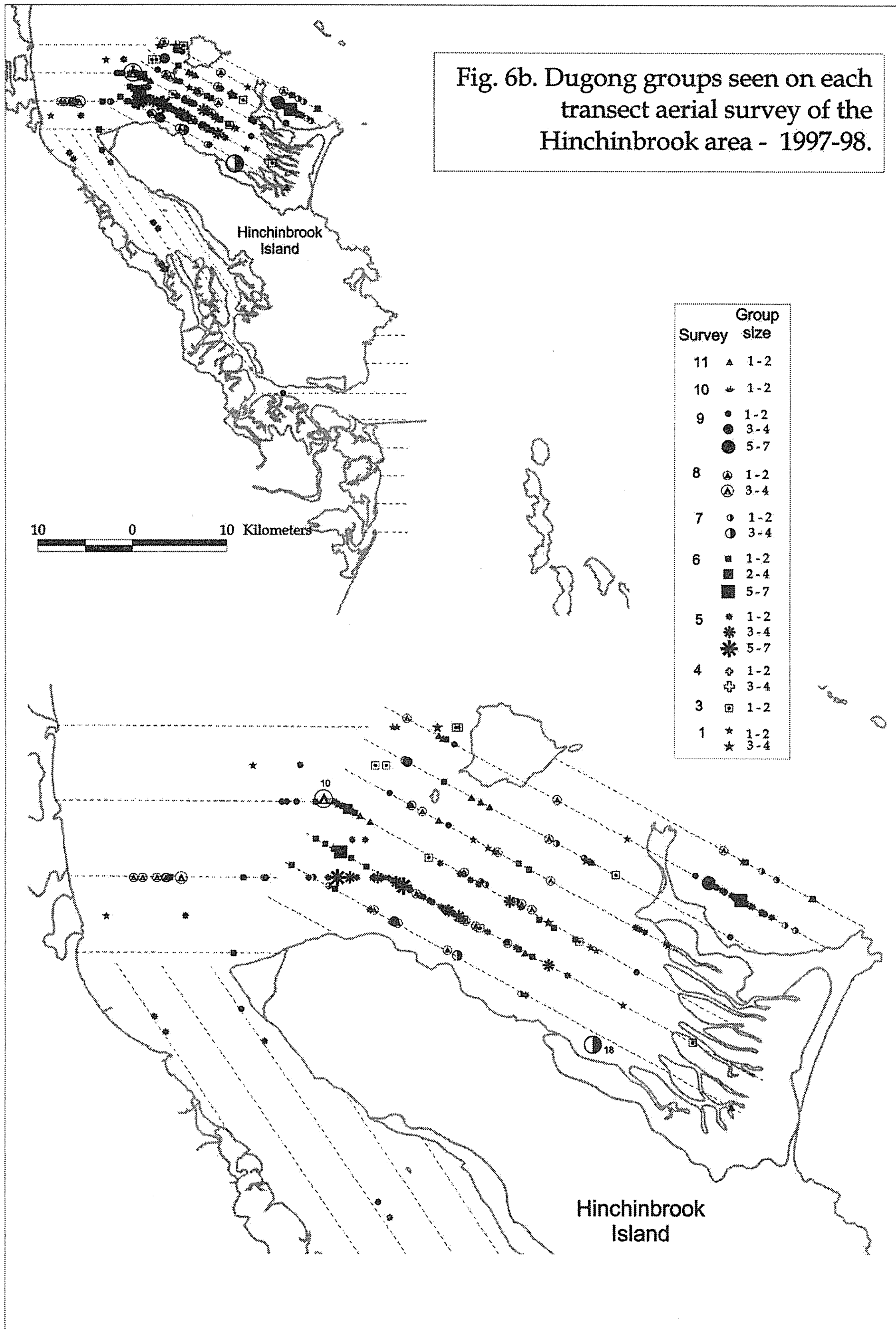


Fig. 6a. Locations of dugong groups seen on all shoreline aerial surveys - 1997-98.



Low-altitude strip-transect surveys typically do not identify larger, diffuse dugong herds, and most sightings are usually recorded as single dugongs. Only three large identifiable groups were seen on the transect surveys: herds of approximately 100, 64, 50, all in the same area of Cleveland Bay (figure 6c). Excluding groups $\geq$ 10, the mean group size was 1.58 (se 0.05).

Five transect surveys included both the Cleveland Bay and Hinchinbrook blocks. Population estimates from these surveys ranged from 503 (se 142) to 748 (se 218) dugongs, with an average of 664 (se 180, cv 27.1%; table 6). The seven surveys of Cleveland Bay resulted in population estimates ranging from 167 (se 60) to 400 (se 97). The average was 266 (se 81, cv 30.4%; table 6). The Hinchinbrook area was surveyed on eight occasions, resulting in population estimates ranging from 306 (se 108) to 1186 (se 458). The average estimate was 523 dugongs (se 231, cv 44%; table 6).

The average dugong density was 0.66 dugongs/km^2 in the Townsville survey block, 1.08/km^2 in the Cardwell block, and 0.75/km^2 for both blocks (Table 6).

Table 6. Estimates of dugong numbers in the Cleveland Bay (Block 1) and Hinchinbrook (Block 2) aerial survey blocks. Population estimates include the herds ≥10 that were seen on surveys. The percentage of dugong sightings that were calves is also presented.

		Survey number										
	Block	1	3	4	5	6	7	8	9	10	11	**Mean**
Dugongs in	1			100			73			50		
herds ≥10	2						18	10				
Population	1	247.6		399.9			179.5	299.5	381.1	176.6	176.5	265.8
estimate	2	482.6	312.5		1186.3	650.3	473.9	448.4	305.7		326.6	523.3
	Total	730.2					653.4	747.9	686.8		503.1	664.3
Estimate se	1	57.8		96.8			38.7	130.7	90.1	60.3	51.6	80.8
	2	164.0	154.4		458.4	248.5	207.5	174.6	108.0		132.3	230.6
	Total	173.9					211.1	218.1	140.7		142.0	18.2
cv (%)	1	23.4		24.2			21.6	43.7	23.7	34.1	29.3	30.4
	2	34.0	49.4		38.6	38.2	43.8	38.9	35.3		40.5	44.1
	Total	23.8					32.3	29.2	20.5		28.2	27.1
Density	1	0.616		0.995			0.447	0.745	0.948	0.439	0.439	0.66
	2	0.993	0.643		2.441	1.338	0.975	0.923	0.629		0.672	1.08
	Total	0.822					0.736	0.842	0.773		0.566	0.75
Density se	1	0.144		0.241			0.096	0.325	0.224	0.150	0.128	0.19
	2	0.337	0.318		0.943	0.511	0.427	0.359	0.222		0.272	0.42
	Total	0.196					0.238	0.246	0.158		0.160	0.20
Calf %		27.1	29.4	23.1	15.3	18.8	15.2	28.8	17.5	42.9	12.9	23.1

Comparing the four surveys that included both survey blocks (and used the revised Hinchinbrook transects), there was a significant difference in population estimates between surveys. This difference existed with or without the inclusion of covariates, and there were no significant interactions (table 3; appendix 2). Similarly, there was a significant difference between the seven population estimates of Cleveland Bay, although the significance was marginal when the covariates were included. The five surveys of Hinchinbrook that used the revised transects were significantly different when the covariates were included, but not significant when they were ignored. The population estimates resulting from three surveys of the Hinchinbrook areas that used the initial transects were significantly different, although this significance was lost when the covariates were included in the analysis (table 3; appendix 2).

Any small dugong very closely associated with a large dugong was considered to be a calf. Averaged across all surveys, calves represented 23.1% of all sightings (table 6). The lowest estimate (12.9%) is suspected to be too low due to marginal weather when Missionary Bay was surveyed. The highest estimate (42.9%) is likely to be too high as it was based on a very small sample size. Excluding these two estimates, the range of the remaining eight estimates was 15.2% to 29.4%, with an average of 21.9% (table 6). The proportions of calves jumped from 15.3%, 18.8% and 15.2% between August and October 1997 to 28.8% in December, when it was noted that many calves were very small. These data suggest a peak in calving in this area in November and December.

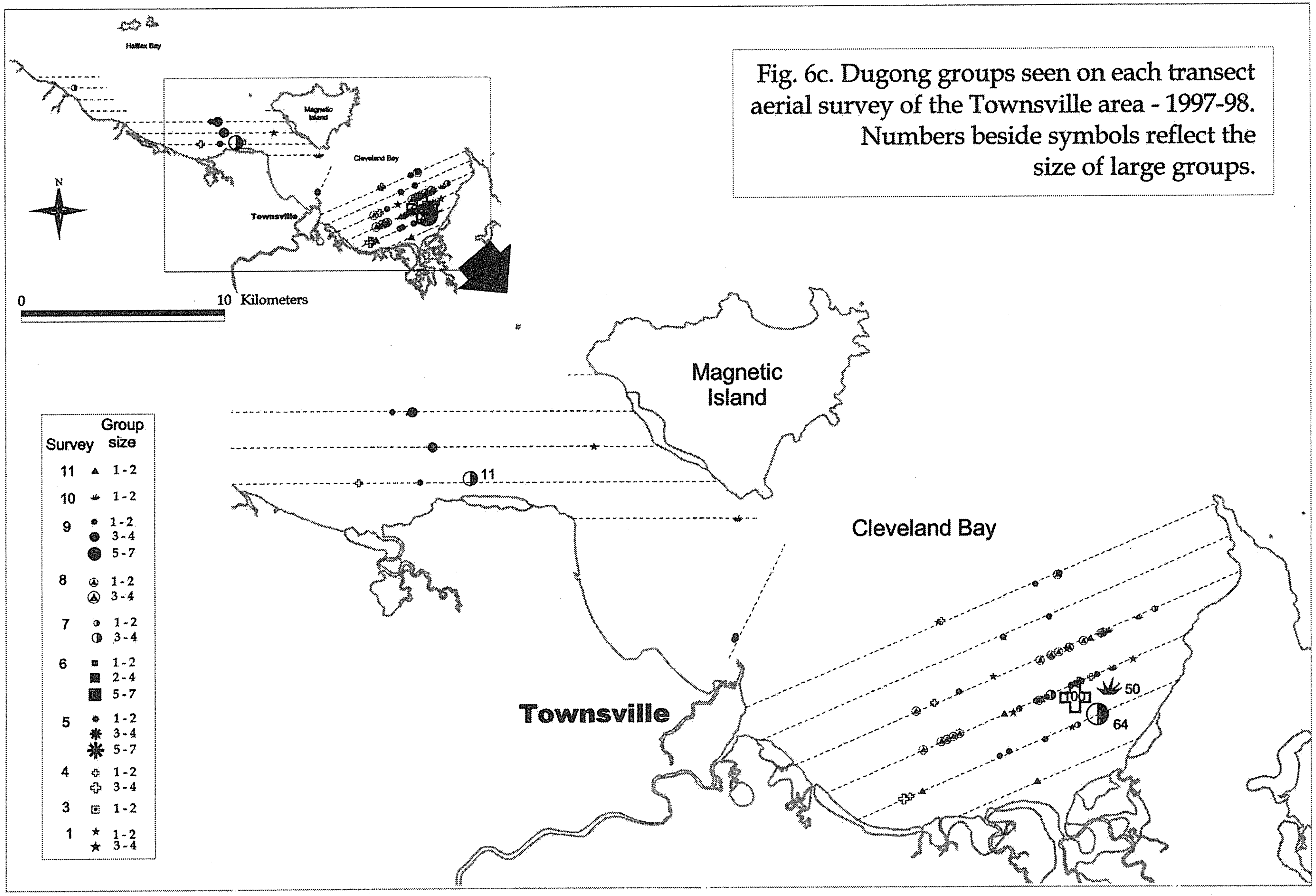


Fig. 6c. Dugong groups seen on each transect aerial survey of the Townsville area - 1997-98. Numbers beside symbols reflect the size of large groups.

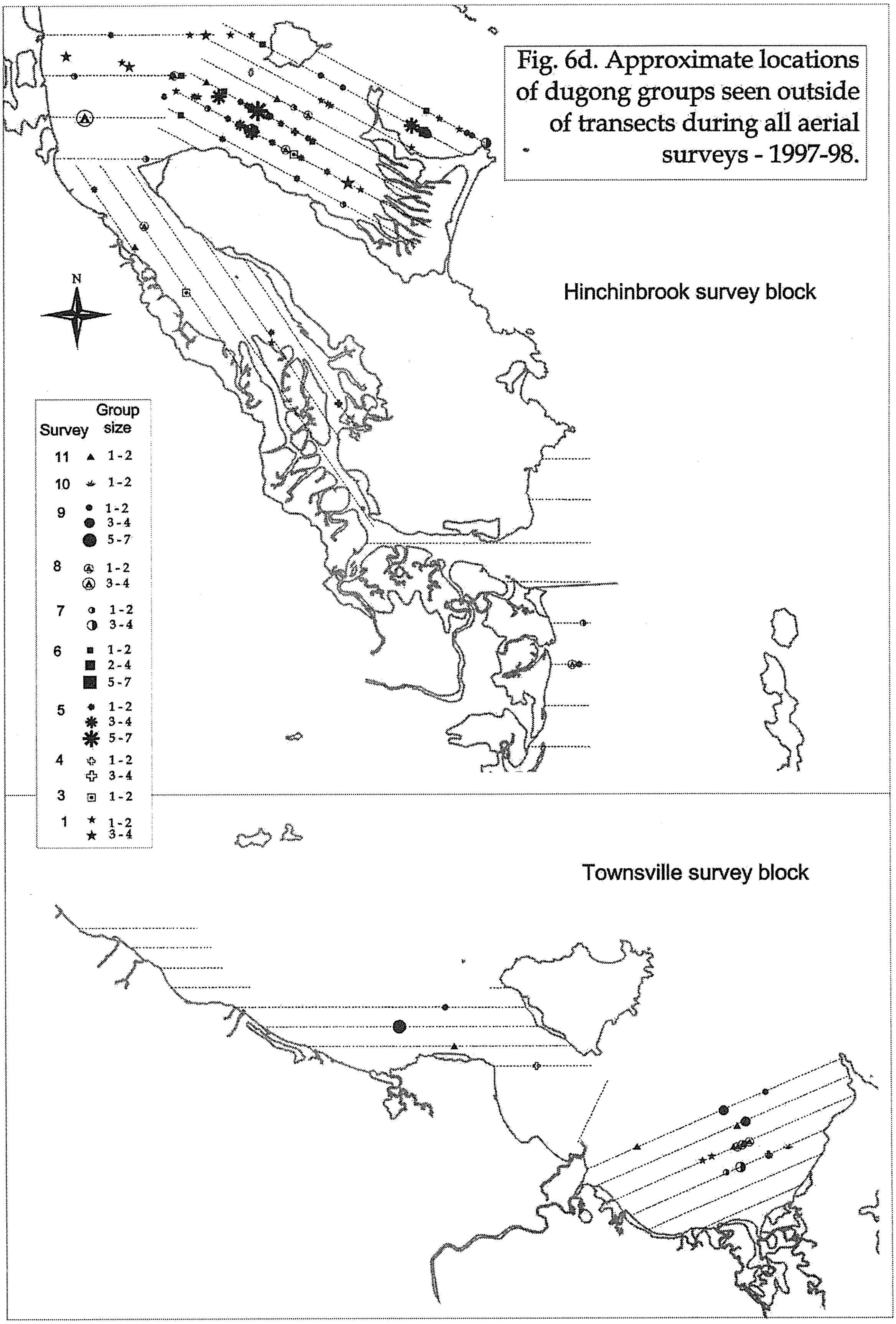


Fig. 6d. Approximate locations of dugong groups seen outside of transects during all aerial surveys - 1997-98.
Hinchinbrook survey block
Townsville survey block
N
Survey
Group size
11 1-2
10 1-2
9 1-2
3-4
5-7
8 1-2
3-4
7 1-2
3-4
6 1-2
2-4
5-7
5 1-2
3-4
5-7
4 1-2
3-4
3 1-2
1 1-2
3-4

Turtles

Although turtles are generally difficult to identify from the survey altitude, most of those sighted are believed to have been green turtles (*Chelonia mydas*).

Turtles were recorded along most parts of the shoreline survey, although they were most commonly seen in the Crystal Creek-Cattle Creek areas, and along the west coast of Great Palm Island (figure 7a). On the transect surveys, turtles were particularly common in eastern Cleveland Bay and in Missionary and Shepherd Bays (figure 7b).

Turtles are not normally socially gregarious, and the average group size recorded on the transect surveys was 1.13 (se 0.02).

Minimum population estimates of turtles in Townsville and Cardwell survey blocks ranged from 519 (se 112) to 1235 (se 228), with an average of 1007 (se 187, cv 18.6%). In Cleveland Bay, the estimates from seven surveys ranged from 110 (se 44) to 630 (se 127), with an average of 416 (se 105, cv 22.7%). Estimates from the eight surveys of the Cardwell block varied widely, from just 65 (se 56) to 898 (se 237), averaging 519 (se 157, cv 30.3%; table 7). For the reasons previously explained, these are believed to be substantial underestimates of the number of turtles in these areas.

The analyses of variance comparing the various population estimates varied significantly in most cases, with or without the inclusion of the environmental covariates (table 3; appendix 3). However, the analysis comparing the four surveys that included both survey blocks (using the revised transects of the Cardwell block) showed a significant interaction between block and survey, reflecting apparent changes in the relative abundance in the two blocks at different times.

Table 7. Estimates of turtle numbers in the Cleveland Bay (Block 1) and Hinchinbrook (Block 2) aerial survey blocks.

		Survey number										
Turtles	Block	1	3	4	5	6	7	8	9	10	11	**Mean**
Population estimate	1	575.7		561.2			381.9	517.0	629.5	110.1	453.5	461.3
	2	659.5	127.3		651.7	897.6	841.8	713.0	196.8		65.1	519.1
	Total	1235.2					1223.7	1229.9	826.4		518.6	1006.7
Estimate se	1	148.2		116.8			72.3	82.4	127.4	44.3	106.4	105.0
	2	173.6	46.0		157.3	237.4	218.8	182.2	40.4		36.3	157.1
	Total	228.2					230.5	199.9	133.7		112.4	187.4
cv (%)	1	25.7		20.8			18.9	15.9	20.2	40.2	23.5	22.8
	2	26.3	36.1		24.1	26.4	26.0	25.6	20.5		55.7	30.3
	Total	18.5					18.8	16.3	16.2		21.7	18.6
Density	1	1.432		1.396			0.950	1.286	1.566	0.274	1.128	1.15
	2	1.357	0.262		1.341	1.847	1.732	1.467	0.405		0.134	1.07
	Total	1.391					1.378	1.385	0.931		0.584	1.13
Density se	1	0.369		0.291		0.488	0.180	0.205	0.317	0.110	0.265	0.25
	2	0.357	0.095		0.324		0.450	0.375	0.083		0.075	0.28
	Total	0.257					0.260	0.225	0.151		0.127	0.20

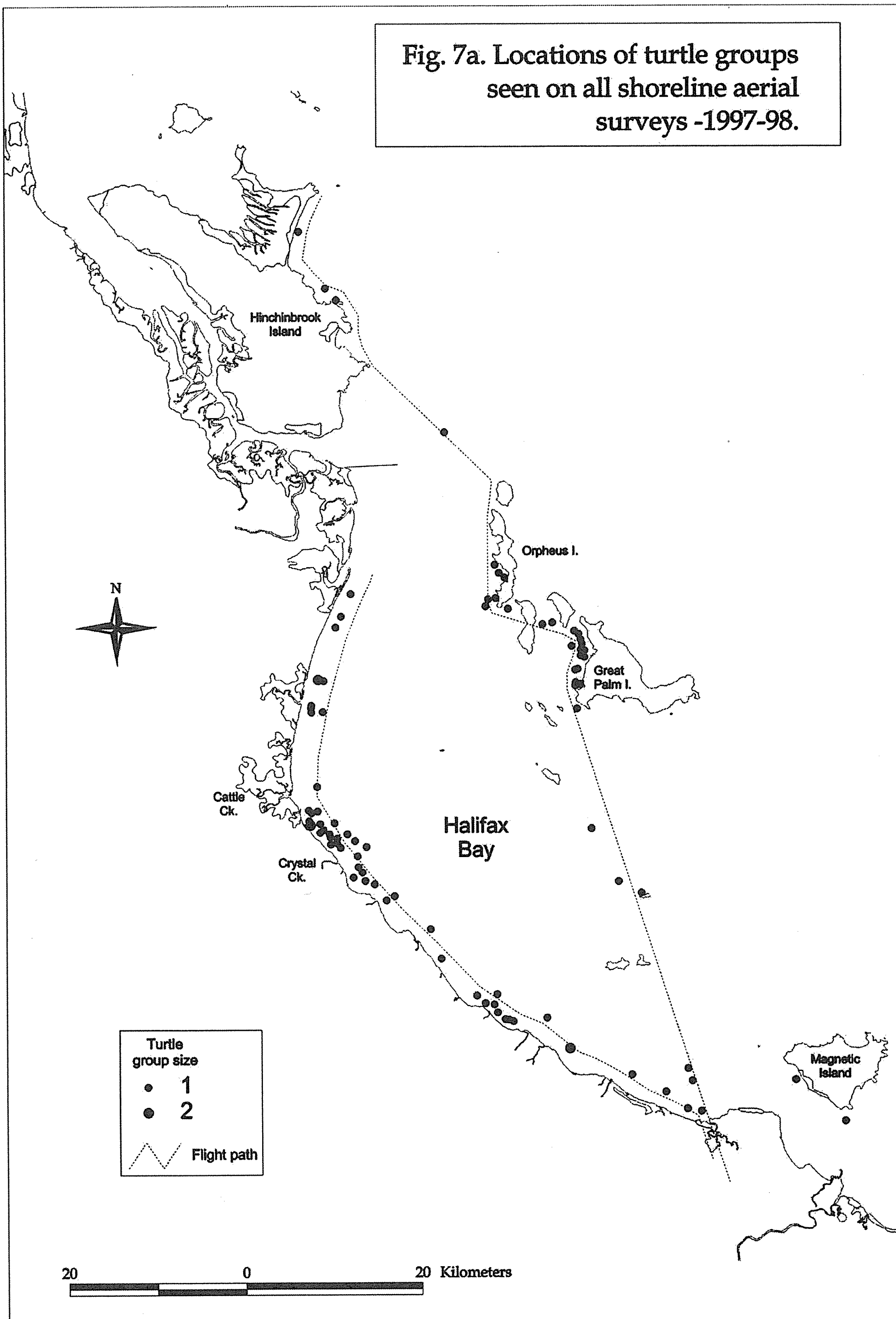
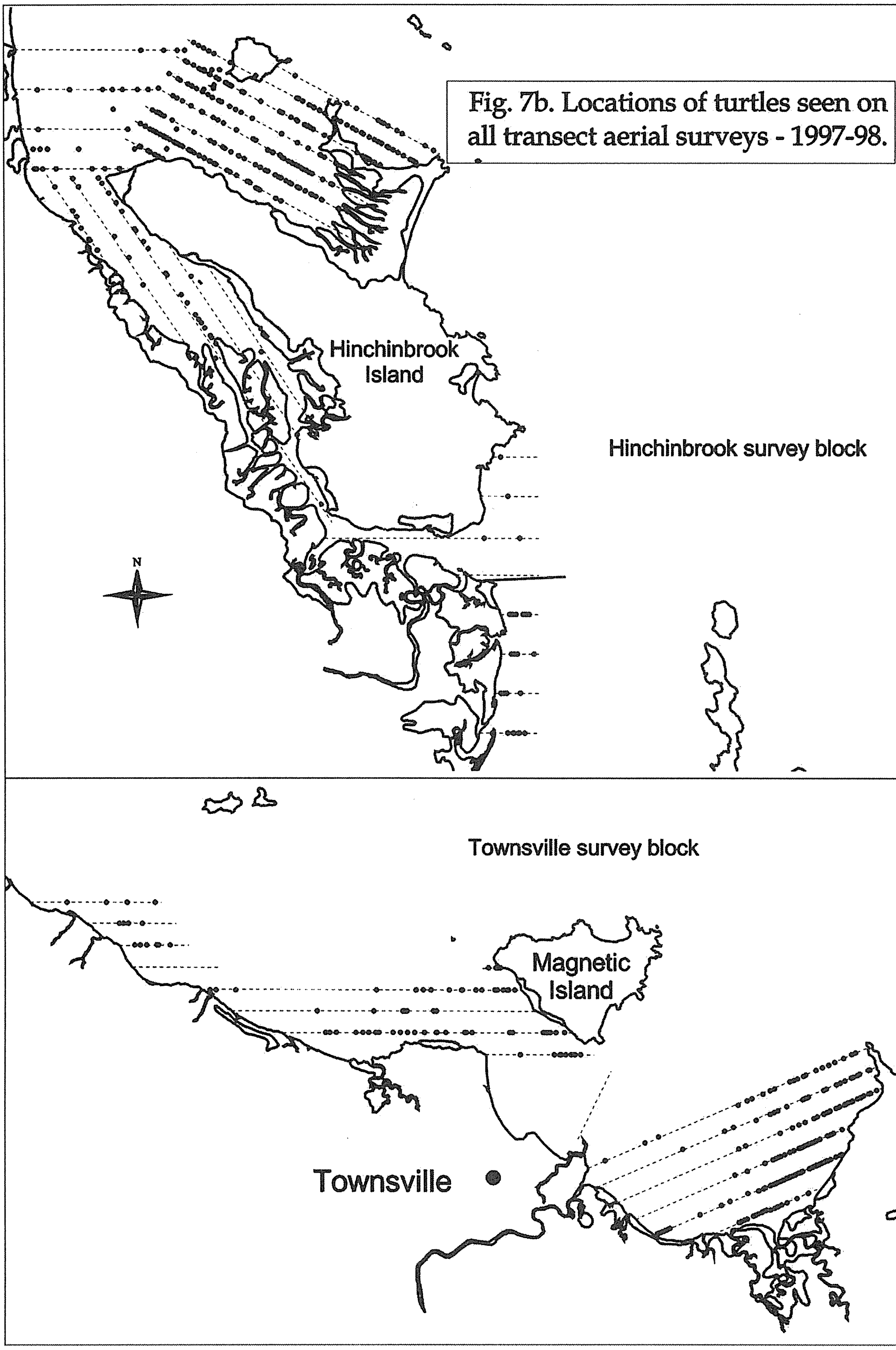


Fig. 7a. Locations of turtle groups seen on all shoreline aerial surveys -1997-98.



Boats

Boats were common throughout the survey area, especially close to the coast, or near islands. Combining shoreline and transect surveys, 873 boats were recorded. This total does not include the

20–40 permanently moored boats at Cardwell and at Dungeness, or boats moored around the Townsville marina or Ross River or Ross Creek. The most common type of boat was the small to medium sized outboard powered speedboat. This category accounted for more than half (55.2%) of all boats, and was particularly common in the Hinchinbrook area (table 8). Displacement hulled boats, predominantly trawlers, made up 26.3% of the total and were most common in Cleveland and Halifax Bays. Sailing boats represented 12.9% of all boats seen. Sailing boats were more common in Hinchinbrook and Halifax Bay than in Cleveland Bay. Large planing hulled vessels, including large catamarans and cruisers, represented 3.3% of the total, while jet skis, house boats, cruise ships and barges made up the remaining 2.2% (table 8).

Within Halifax Bay (the shoreline survey area), speedboats were common in the nearshore waters, especially off the mouths of creeks, particularly Crystal Creek. Speedboats were also common along the protected (western) coast of Orpheus and Pelorus Islands (figure 8a). In the Hinchinbrook area, speedboats were common in southern Hinchinbrook Channel, in Missionary Bay around Garden Island and Macushla, and in the Missionary Bay creeks. In Cleveland Bay, these boats were most common in the southeast of the bay, around the mouths of Crocodile, Alligator and Cocoa Creeks (figure 8a).

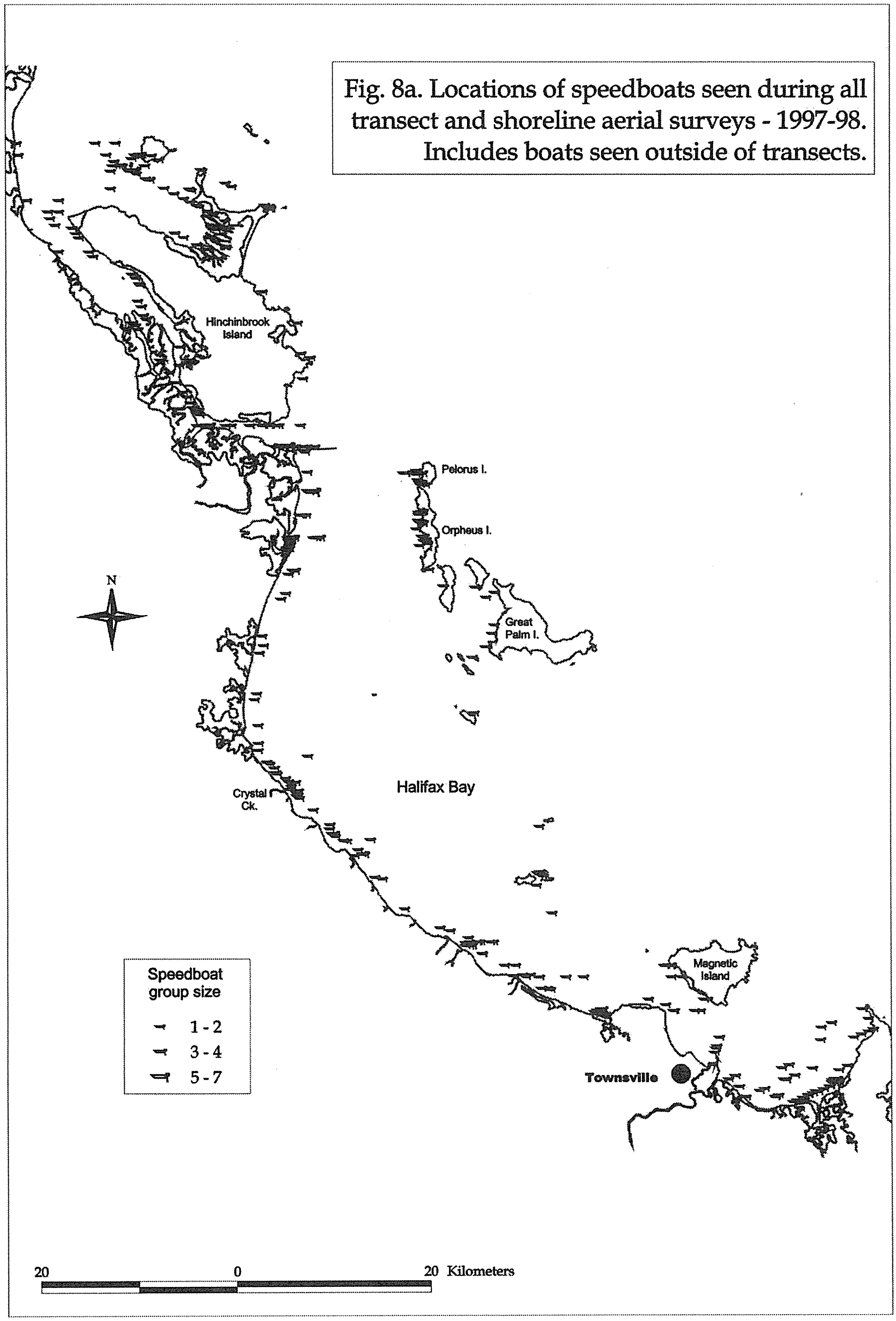
Displacement hulled boats (mostly trawlers) were common at protected anchorages around the western coasts of islands in Halifax Bay and protected areas of Cleveland Bay and around Hinchinbrook Island (figure 8b). In most cases trawlers were at anchor, although they were frequently seen working off Saunders beach, and to a lesser degree in Cleveland Bay. Most of the displacement hulled boats seen in Hinchinbrook Channel (except around Dungeness) and in Missionary Bay were not trawlers.

Table 8. Percentage of boat types recorded in each survey area. Data from all surveys combined.

Boat type	%			
	Cleveland Bay	Hinchinbrook	Halifax Bay	Total
Speedboat	51.8	61.5	49.5	55.2
Displacement hull/trawler	31.2	17.8	33.2	26.3
Sailboat	8.8	13.9	14.0	12.9
Large planing hull/cruiser	3.5	4.9	2.0	3.3
Houseboat		1.9		
Jet ski	3.5			
Cruise ship			1.3	
Other	1.2			2.2
Total	100	100	100	100
n	170	309	394	873

Favoured locations for sailing boats were the Palm Islands, Zoe Bay on eastern Hinchinbrook Island, and Hinchinbrook Channel (figure 8c). Large powerboats were most common in Missionary Bay and Cleveland Bay (figure 8d). Cruise ships were seen at Pelorus Island (figure 8d), Cruise ships were seen in Hinchinbrook Channel on other occasions, but not during the aerial surveys. House boats were seen only in Hinchinbrook Channel and Missionary Bay, and jet skis were seen off the west cost of Magnetic Island (figure 8d).

Fig. 8a. Locations of speedboats seen during all transect and shoreline aerial surveys - 1997-98. Includes boats seen outside of transects.



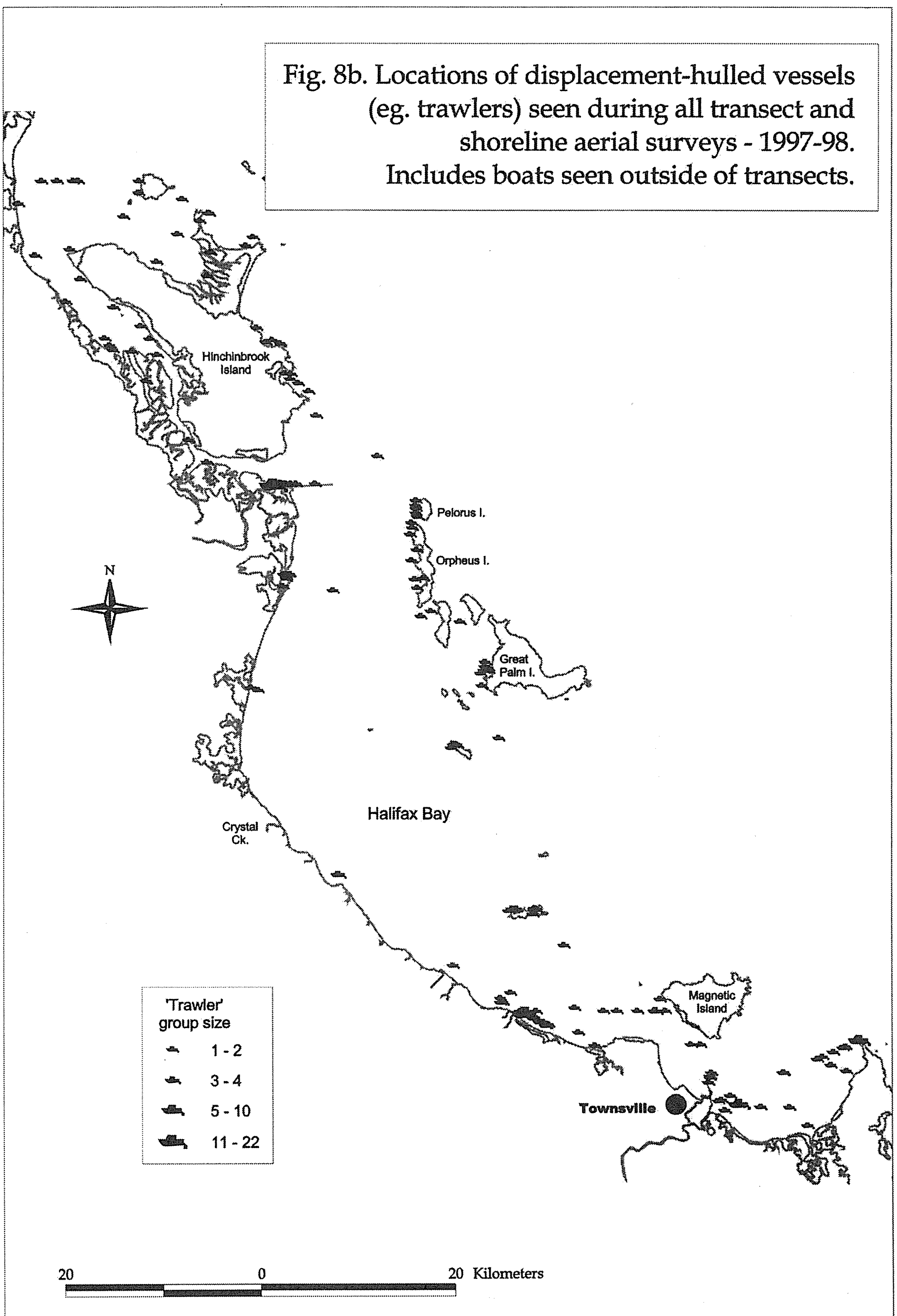
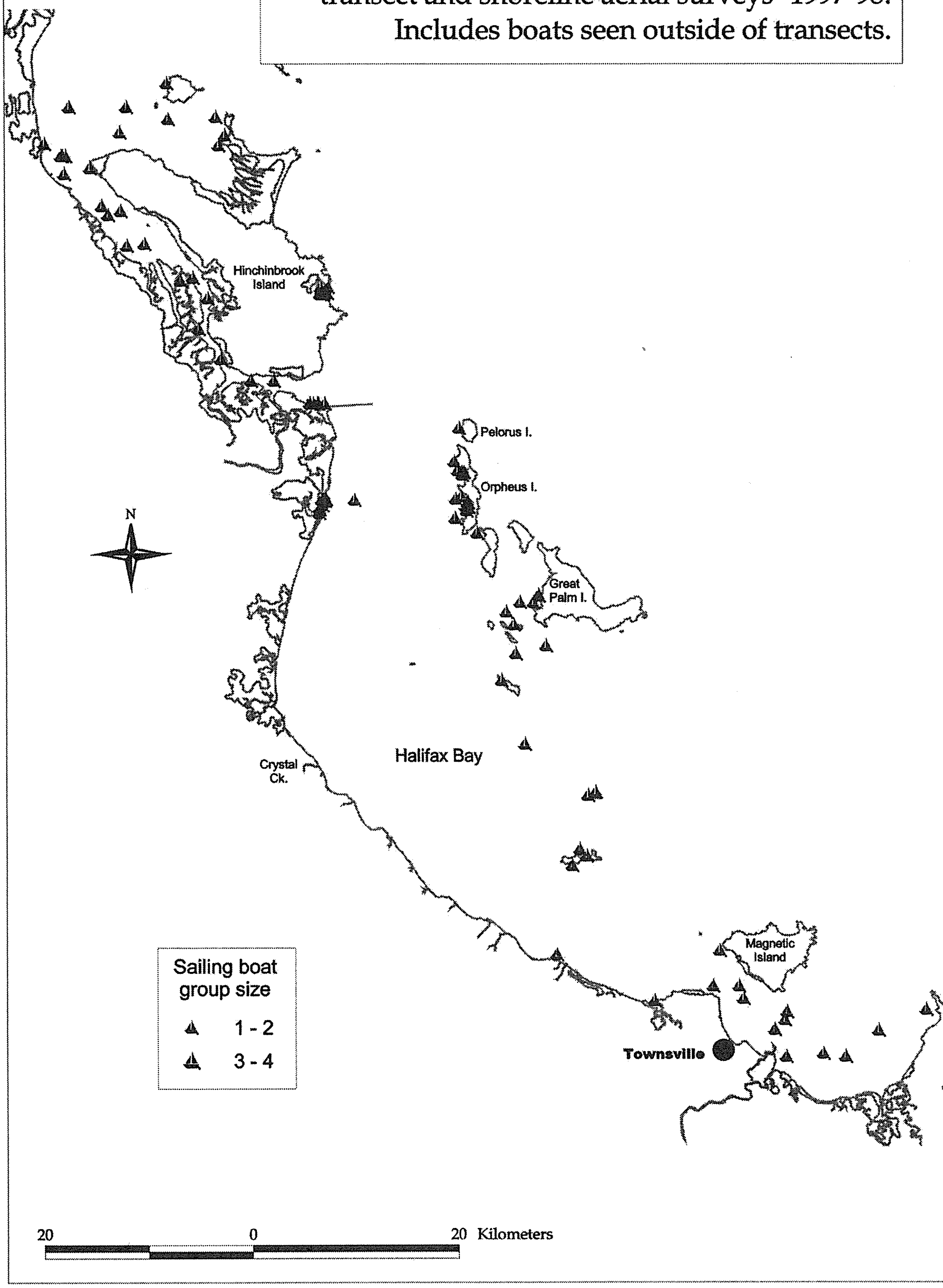
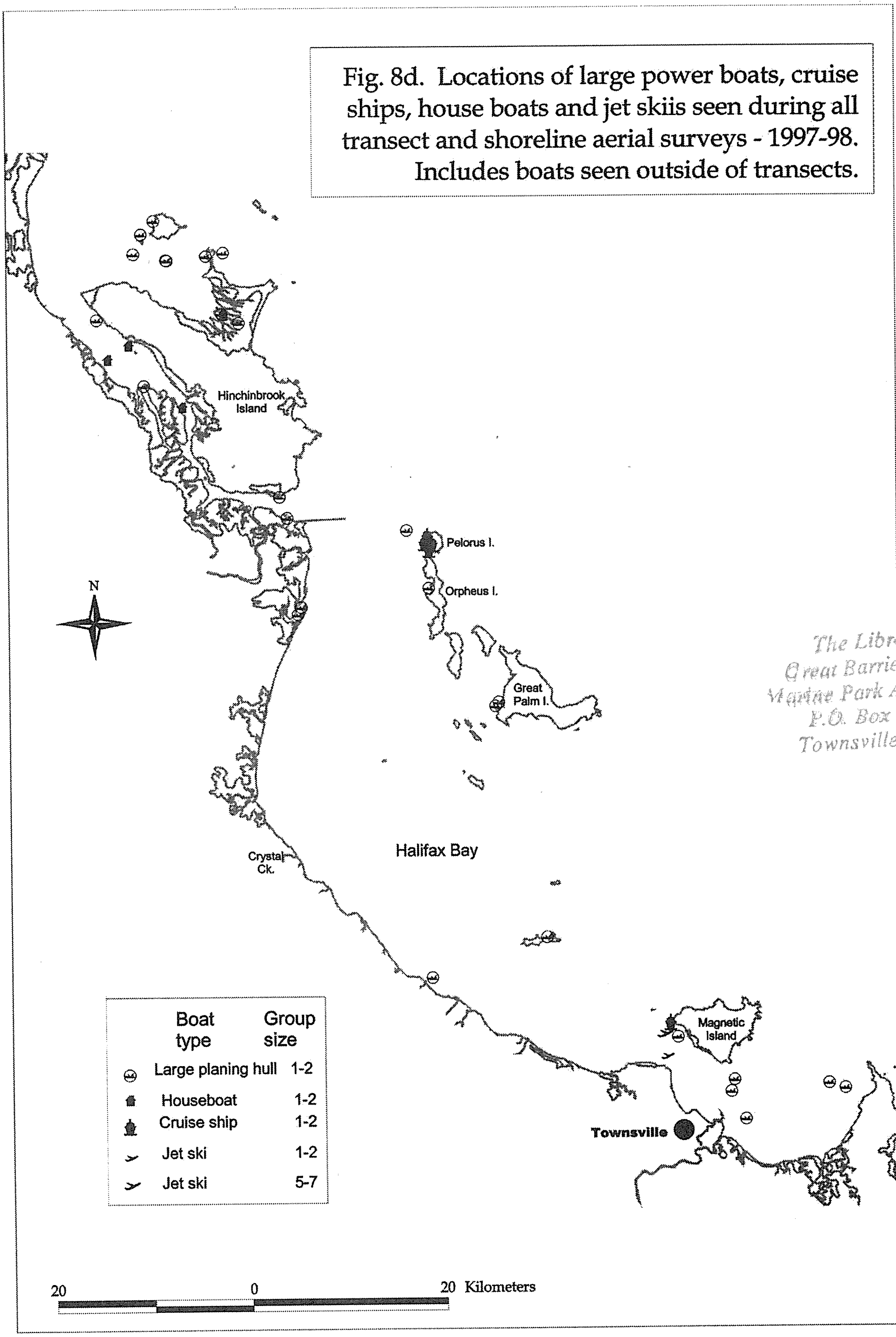


Fig. 8b. Locations of displacement-hulled vessels (eg. trawlers) seen during all transect and shoreline aerial surveys - 1997-98. Includes boats seen outside of transects.
Hinchinbrook Island
Pelorus I.
Orpheus I.
N
Great Palm I.
Halifax Bay
Crystal Ck.
Magnetic Island
Townsville
'Trawler' group size
1 - 2
3 - 4
5 - 10
11 - 22
20
0
20 Kilometers

Fig. 8c. Locations of sailing boats seen during all transect and shoreline aerial surveys -1997-98. Includes boats seen outside of transects.





Estimates of boat numbers within the Cleveland Bay and Hinchinbrook survey blocks were calculated from the sightings of boats within transects. Estimates for Cleveland Bay varied from 4 (se 3) to 88 (se 17), with an average of 42 (se 10, cv 24.9%; table 9). Estimates for Hinchinbrook ranged from 13 (se 9) to 63 (se 29), also with an average of 42 (se 21, cv 50.2%). Comparing the total number of boats recorded during each transect survey (including those seen outside the transect) with the estimated boat population resulted in an average discrepancy of 35%. In most cases (7 of 9) the number seen was fewer than the number estimated. From the population estimates, the density of boats in the Cleveland Bay and Hinchinbrook blocks averaged 0.11 and 0.09 boats/km^2, respectively.

Table 9. Estimates of boat numbers in the Cleveland Bay (Block 1) and Hinchinbrook (Block 2) aerial survey blocks and the number of boats seen during each survey (inside and outside transects).

		Survey number										
Boats	Block	1	3	4	5	6	7	8	9	10	11	**Mean**
Population estimate	1	31.4		87.6			20.9	4.0	69.5		39.4	42.1
	2	48.6	36.0		57.8	60.8	39.9	13.1	62.7		18.0	42.1
	Total	80.0					60.8	17.1	132.2		57.4	69.5
Estimate se	1	8.9		17.4			6.2	3.0	12.5		8.6	10.5
	2	17.9	12.5		16.1	40.1	14.6	9.0	29.1		9.2	21.1
	Total	20.0					15.8	9.5	31.7		12.6	19.5
cv (%)	1	28.3		19.9			29.6	74.6	18.0		21.7	24.9
	2	36.8	34.8		27.8	66.1	36.6	68.7	46.4		51.1	50.2
	Total	25.0					26.1	55.4	23.9		21.9	28.0
Density	1	0.078		0.218			0.052	0.010	0.173		0.098	0.10
	2	0.100	0.074		0.119	0.125	0.082	0.027	0.129		0.037	0.09
	Total	0.090					0.068	0.019	0.149		0.065	0.08
Density se	1	0.022		0.043			0.015	0.007	0.031		0.021	0.02
	2	0.037	0.026		0.033	0.083	0.030	0.019	0.060		0.019	0.04
	Total	0.022					0.018	0.011	0.036		0.014	0.02
Boats seen		99	33	52	49	29	53	20	89	18	51	

Cetaceans

Eighty groups of cetaceans were recorded on the aerial surveys, representing 313 individuals. Over 86% of groups were identified. Of these, 75% were classified as 'certain', 20% as 'probable', and 4% as 'uncertain' (table 10).

Four species of cetacean were identified. Humpback dolphins (*Sousa chinensis*) made up 36.3% of groups (35.5% of individuals), Bottlenose dolphins (*Tursiops truncatus*) accounted for 32.5% of groups (30.4% individuals) and Irrawaddy dolphins (*Orcaella breviceps*) made up 16.3% of groups and 27.8% of individuals. A single cow-calf pair of Humpback whales was also seen (table 10).

Of the three species of dolphin, Humpback dolphins were the most common species seen on the transects (51% of groups), but least common on the shoreline surveys (13%; figure 9a). Conversely, Bottlenose dolphins were the most common on the shoreline surveys (45.2%) and the least common on the transects (24.5%) (table 10; figure 9c). The abundance of Irrawaddy dolphins was similar on both surveys (18.4% and 12.9%; figure 9b). Locations of unidentified dolphins, and Humpback whales are shown in figure 9d.

Manta Rays and Gill Nets

Figure 10 shows the locations of gill nets and manta rays seen during the aerial surveys. Gill nets were most frequently seen in southern Halifax Bay. Some were set as inshore nets, very close to the beach, while others were set as offshore drift nets, up to 1.6 km long.

Manta rays were most commonly seen in the nearshore waters between Crystal and Palm Creeks. On several occasions the mantas were seen in very shallow water (< 2 m), very close to the beach.

Table 10. Number of dolphins (groups and individuals), and the certainty of their identity, seen on all transect surveys of Cleveland Bay and Hinchinbrook (Blocks 1 & 2) and on all shoreline surveys of Halifax Bay.

	Number of groups					
	Blocks 1&2		Halifax Bay		Total	
	n	%	n	%	n	%
Humpback dolphin	25	51.0	4	12.9	29	36.3
Irrawaddy dolphin	9	18.4	4	12.9	13	16.3
Bottlenose dolphin	12	24.5	14	45.2	26	32.5
Unidentified dolphin	3	6.1	8	25.8	11	13.8
Humpback whale			1	3.2	1	1.3
Total	49	100	31	100	80	100

	Number of individuals					
	Blocks 1&2		Halifax Bay		Total	
	n	%	n	%	n	%
Humpback dolphin	94	47.5	17	14.8	111	35.5
Irrawaddy dolphin	59	29.8	28	24.3	87	27.8
Bottlenose dolphin	40	20.2	55	47.8	95	30.4
Unidentified dolphin	5	2.5	13	11.3	18	5.8
Humpback whale			2	1.7	2	0.6
Total	198	100	115	100	313	100

	Certainty of Identification			
	Number of Groups			
	Total	Certain	Probable	Uncertain
Humpback dolphin	29	22	6	1
Irrawaddy dolphin	13	13	0	0
Bottlenose dolphin	26	16	8	2
Unidentified dolphin	11			
Humpback whale	1	1		
Total	80	52	14	3

Historical Aerial Surveys

The approximate locations of dugongs, turtles, dolphins, manta rays and gill nets sighted by Heinsohn are shown in figures 11a, b and c. Generally, the patterns of distribution are similar to those detected during the current study. In the Townsville area, most sightings of dugongs occurred in the east of Cleveland Bay, with a second band of sightings occurring west from Magnetic Island. In the Hinchinbrook area, dugongs were commonly seen around the perimeter of Missionary Bay (the centre was not surveyed), and in Shepherd Bay. Dugongs were very common in Hinchinbrook Channel, particularly in the central section from the mouth of the Seymour River to Damper Creek (figure 11). Dugongs occurred throughout all areas of Halifax Bay, including offshore areas, but were most commonly seen along the mainland coast south of Crystal Creek.

Fig. 9a. Locations of Humpback dolphins seen during all aerial surveys - 1997-98.

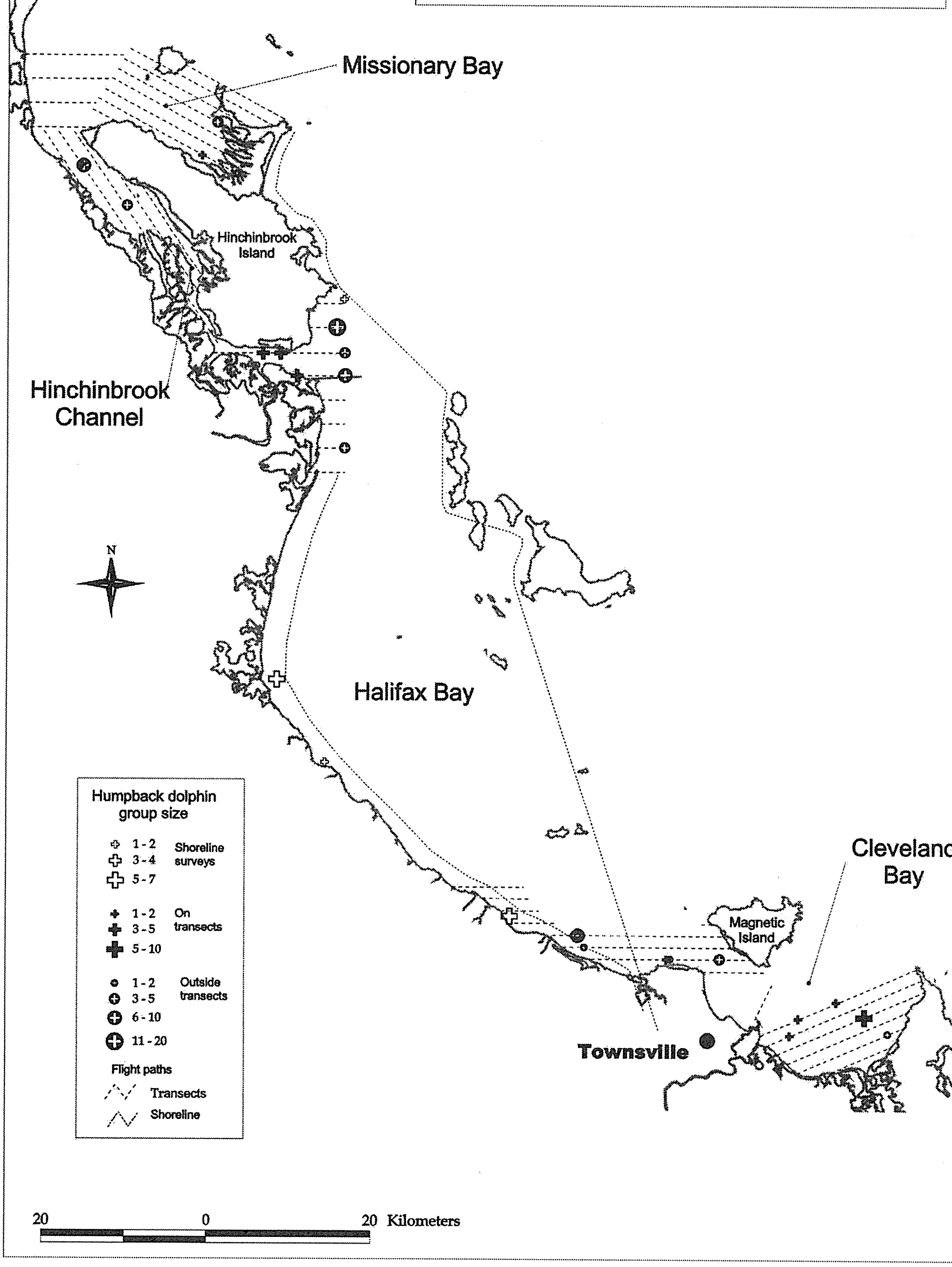
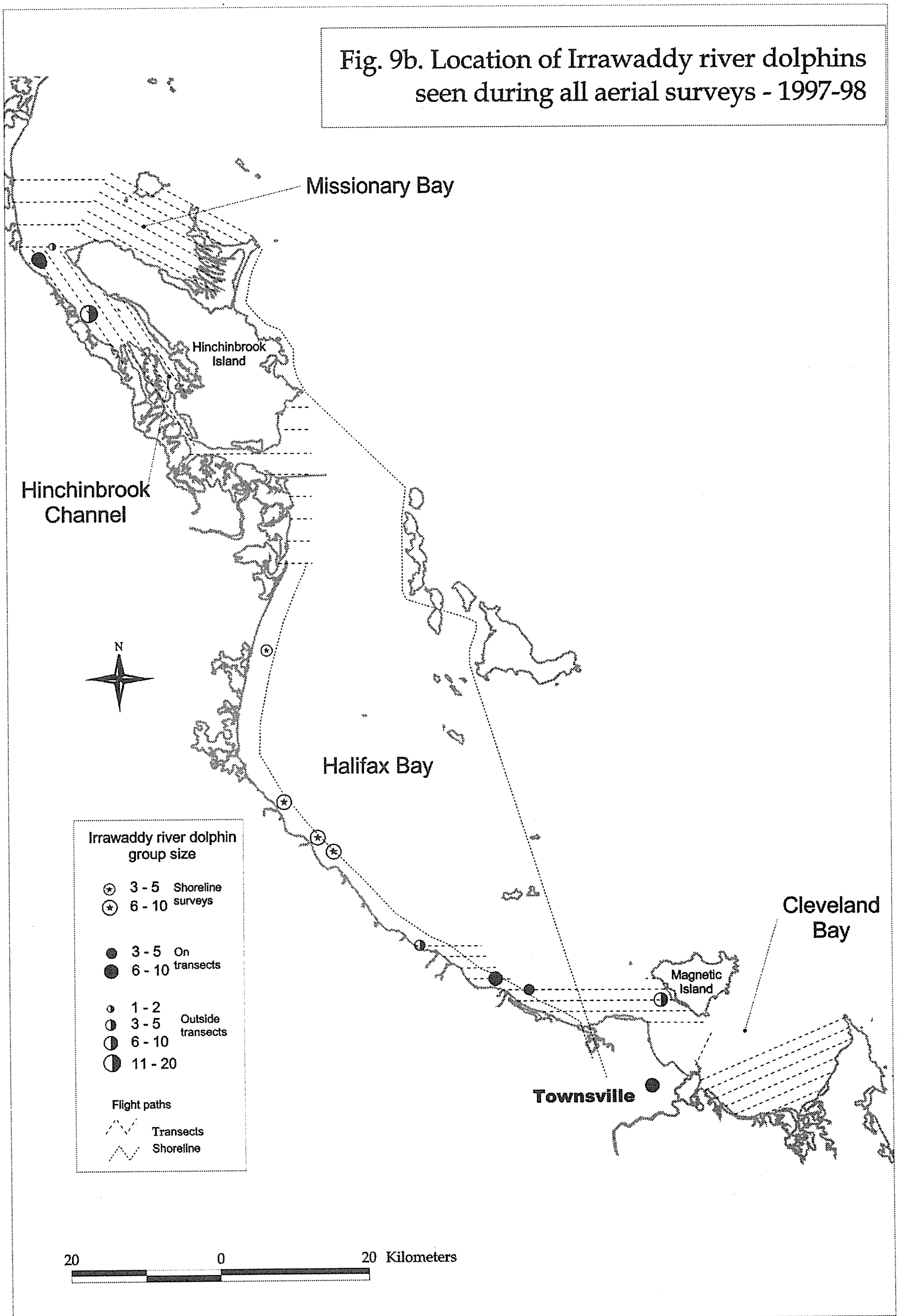


Fig. 9b. Location of Irrawaddy river dolphins seen during all aerial surveys - 1997-98



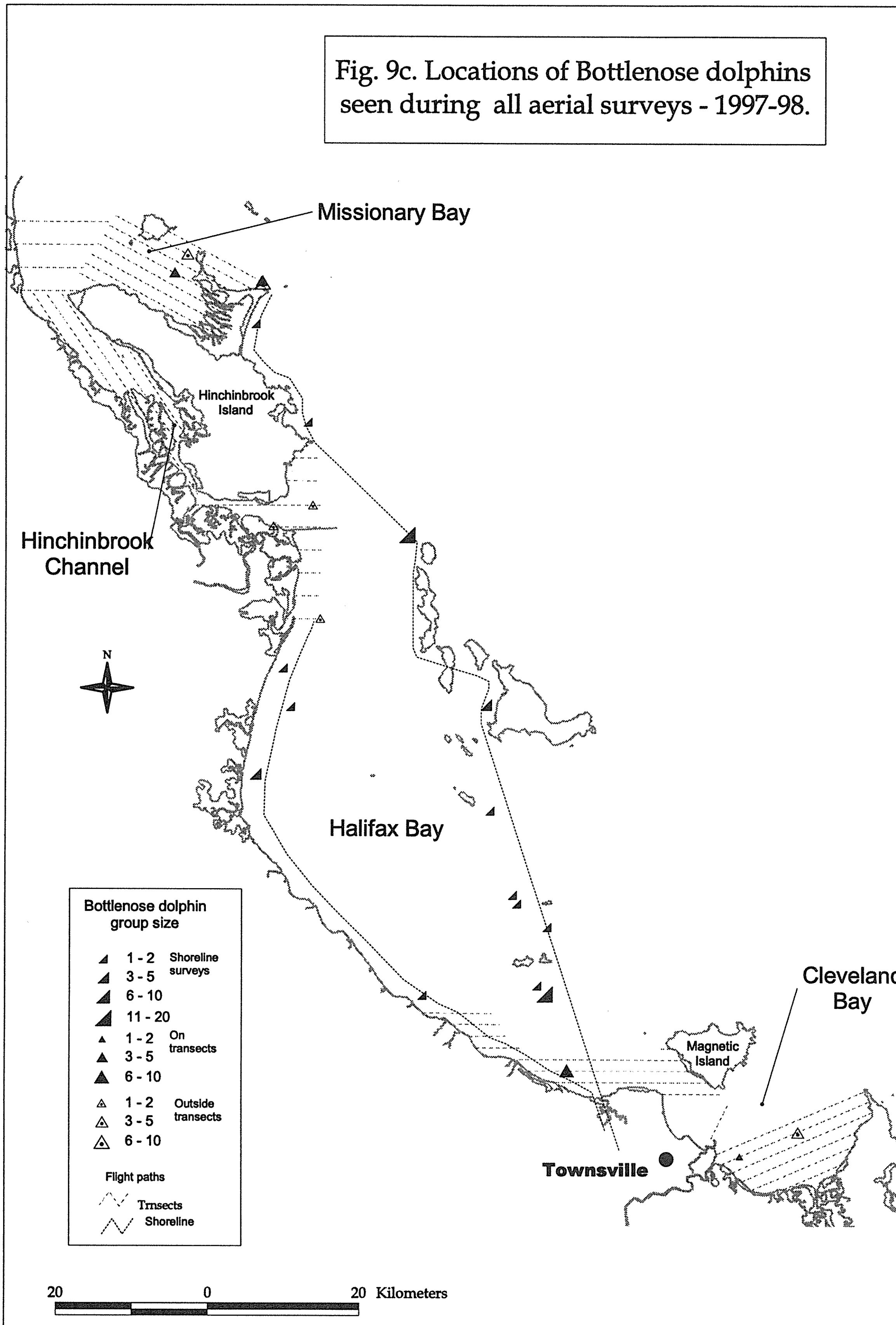
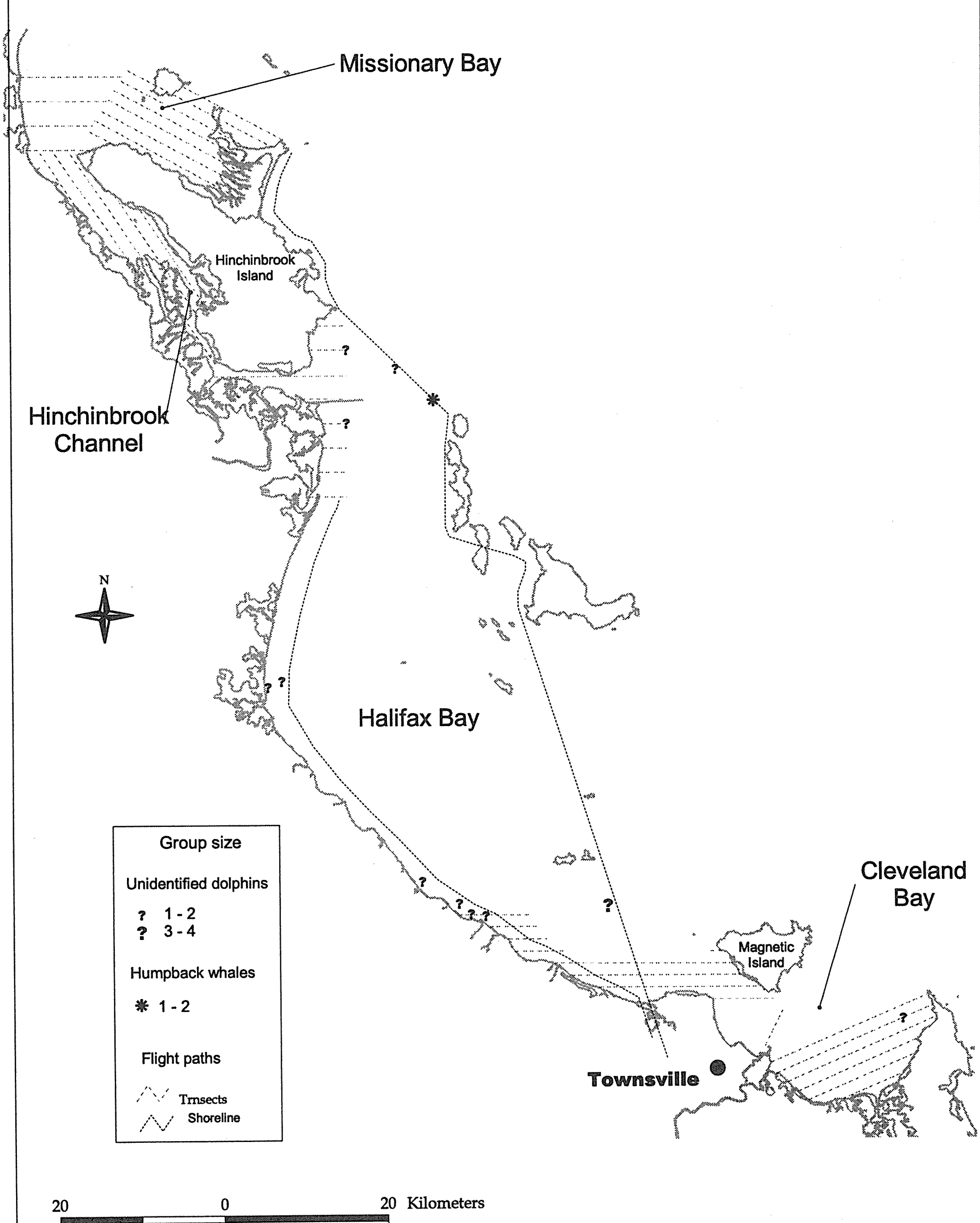


Fig. 9c. Locations of Bottlenose dolphins seen during all aerial surveys - 1997-98.

Fig. 9d. Locations of unidentified dolphins and whales seen on all aerial surveys - 1997-98.



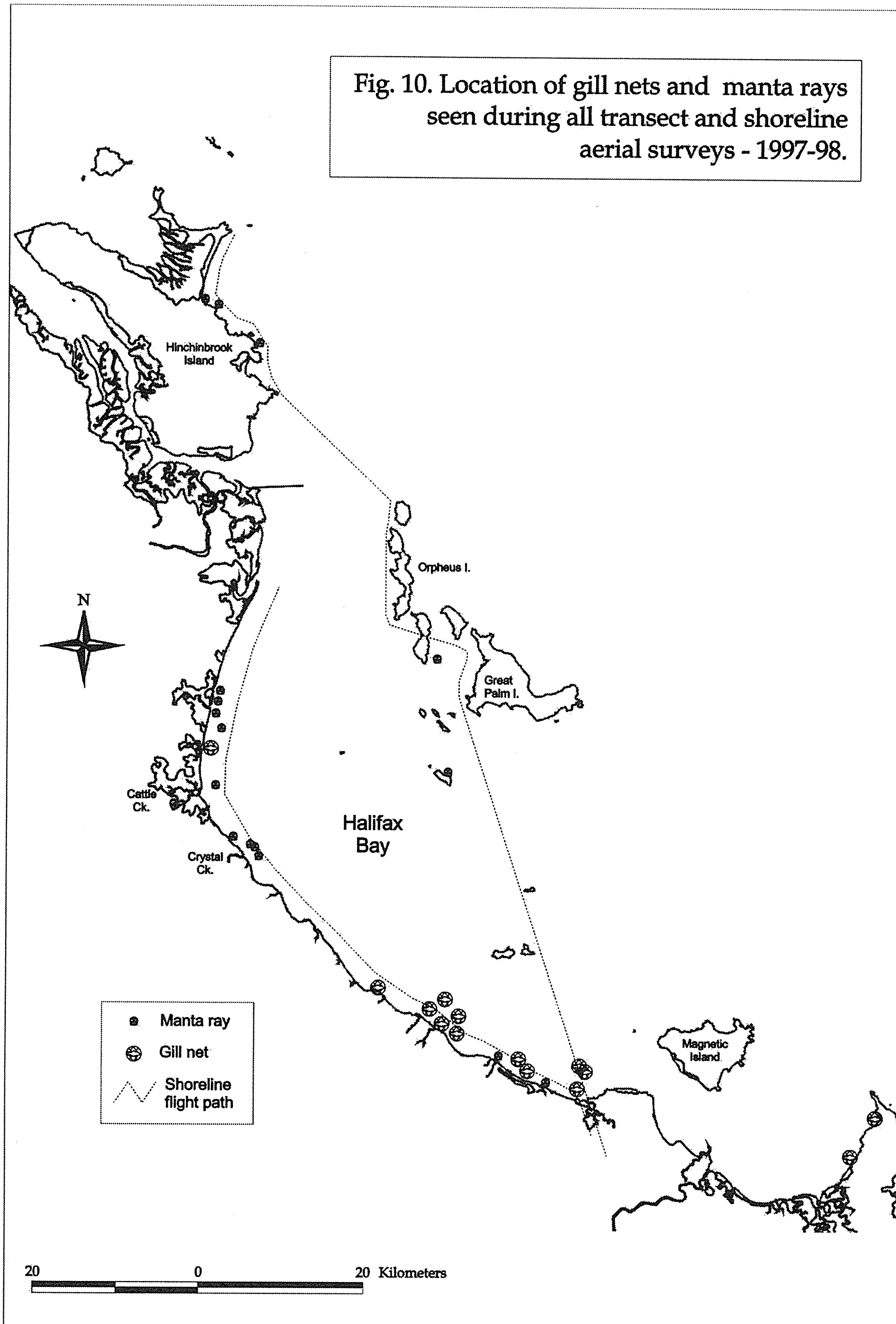


Fig. 10. Location of gill nets and manta rays seen during all transect and shoreline aerial surveys - 1997-98.

Turtle distribution in Cleveland and Missionary Bays was similar to current patterns. In the Hinchinbrook Channel, however, turtles appeared to have been relatively more abundant in the central area than they are now (compare figures 7b and 11b). In Halifax Bay, a focus of turtle activity occurred around the mouth of Crystal Creek during both sets of surveys.

Heinsohn saw relatively few cetaceans in Cleveland or Missionary Bays, although they were reasonably common in Halifax Bay (figure 11c). The distribution pattern of different species has not been plotted as only 30% of dolphin groups were identified.

Manta rays were most common along the mainland coast between Crystal Creek and Lucinda (figure 11c), parallelling the pattern seen in the recent surveys (figure 10). Gill nets and shark nets were seen in Cleveland Bay, around the mouths of some creeks in Halifax Bay and in Hinchinbrook Channel (figure 11c).

The overall sighting rate (all surveys combined) of animals and gill nets differed substantially between Heinsohn's and the recent surveys, although partly due to the large variation in sighting rates between individual surveys, not all the differences were significant (table 11). Dolphins, turtles, manta rays and gill nets were sighted at a greater rate during the surveys of 1997–98, than during Heinsohn's surveys in the 1970s. In contrast, the sighting rate of dugongs was less during the recent surveys than during Heinsohn's (table 11). In Hinchinbrook Channel there was a significant difference in the sighting rates of dugongs and dolphins. Dugongs were seen 4.15 times more frequently in the 1970s, but dolphins were seen 2.5 times more frequently in 1997–98 (table 11). (The sighting rate differences for dugongs and dolphins are also significant if sighting rate is calculated as groups seen/km flown, rather than individuals seen/km).

Table 11. Comparison of sightings and sighting rates in Halifax Bay and Hinchinbrook Channel during Heinsohn's aerial surveys in the 1970s and during the current study.

	Halifax Bay						Hinchinbrook Channel			
	Total sightings (all surveys combined)									
	km flown	Dugongs	Dolphins	Turtles	Mantas	Nets	km flown	Dugongs	Dolphins	Turtles
1970s	4604	131	114	123	10	6	1960	149	38	105
1997–98	1664	13	113	84	10	7	927	17	44	56[1]
		Overall sighting rate (total sightings/total km flown)								
1970s		0.0285	0.0248	0.0267	0.0022	0.0013		0.0760	0.0194	0.0536
1997–98		0.0078	0.0679	0.0505	0.0060	0.0042		0.0183	0.0475	0.0604
		Ratio of sighting rates (greater rate/lesser)								
Greater in 1970s by:		3.64						4.15		
Greater in 1997–98 by:			2.74	1.89	2.77	3.23			2.45	1.13
		Results of Kruskal-Wallis one-way nonparametric analyses of variance								
n		24, 9	24, 9	24, 9	24, 9	24, 9		26, 9	26, 9	26, 9
p		0.2009	0.5045	0.0303	0.1487	0.1035		0.0106	0.0361	0.3939
Significance		-	-	Sig.	-	-		Sig.	Sig.	-

[1] Only turtles occurring within the 250 m wide transects were recorded during 1997–98.

Public Sighting Records

A total of 71 sighting sheets were returned. Most were from the public. Some came from individuals in Government Departments (particularly the Queensland Environment Protection Agency). Only a single commercial operator (charter fisher) returned sightings. No sighting information was received from passenger ferry operators, even though one operator encounters dugongs frequently enough to conduct impromptu dugong watching during scheduled trips through Missionary Bay.

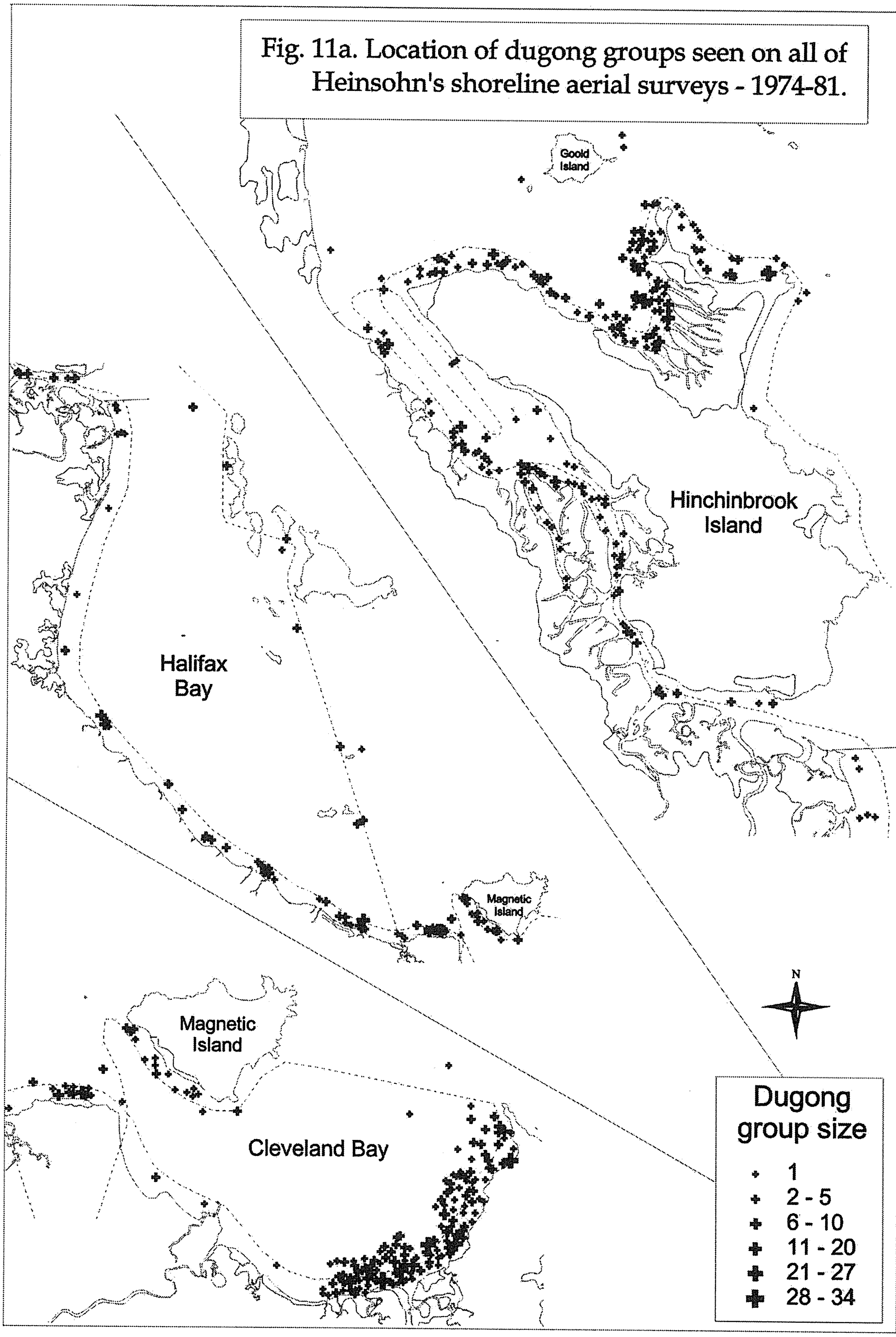
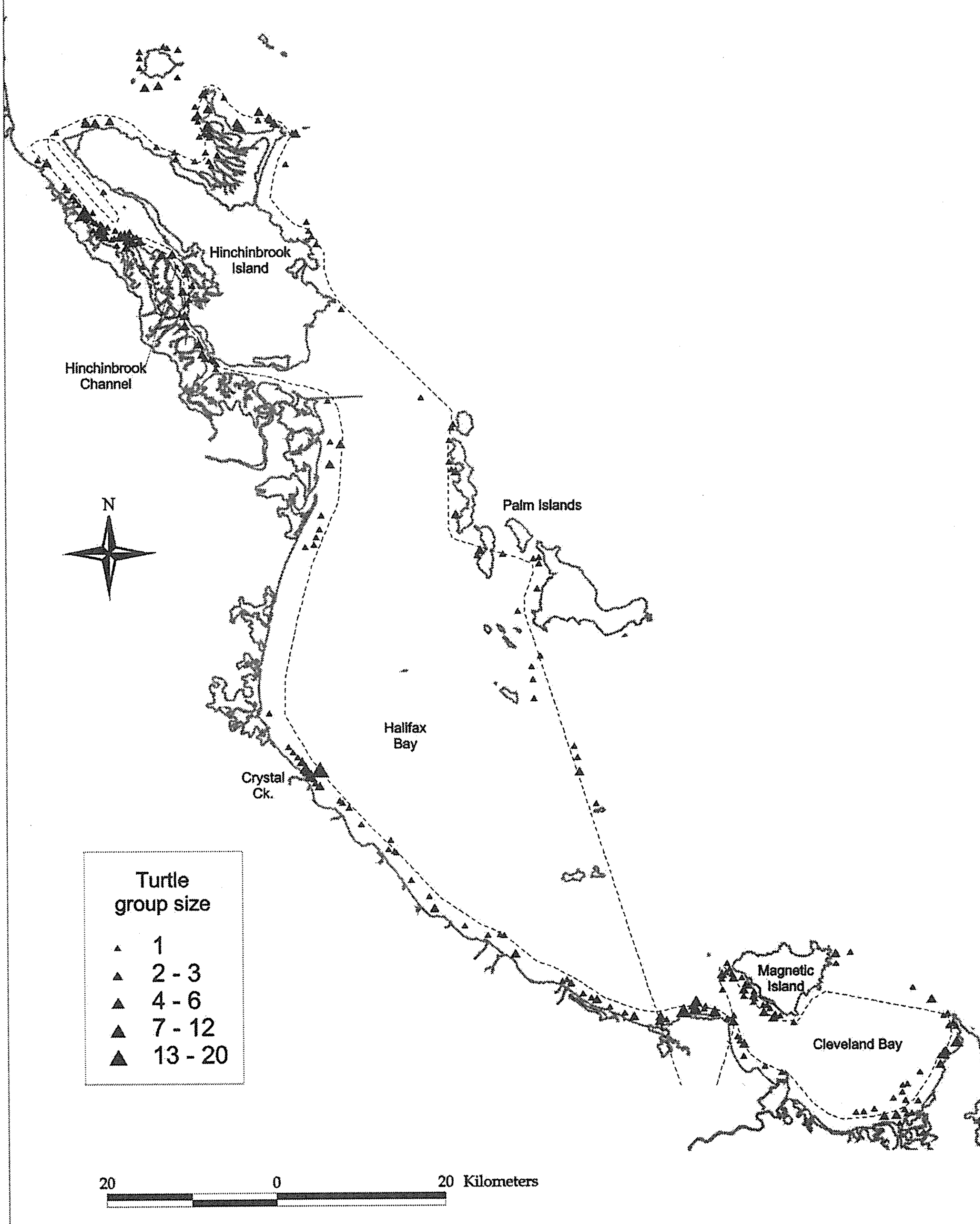
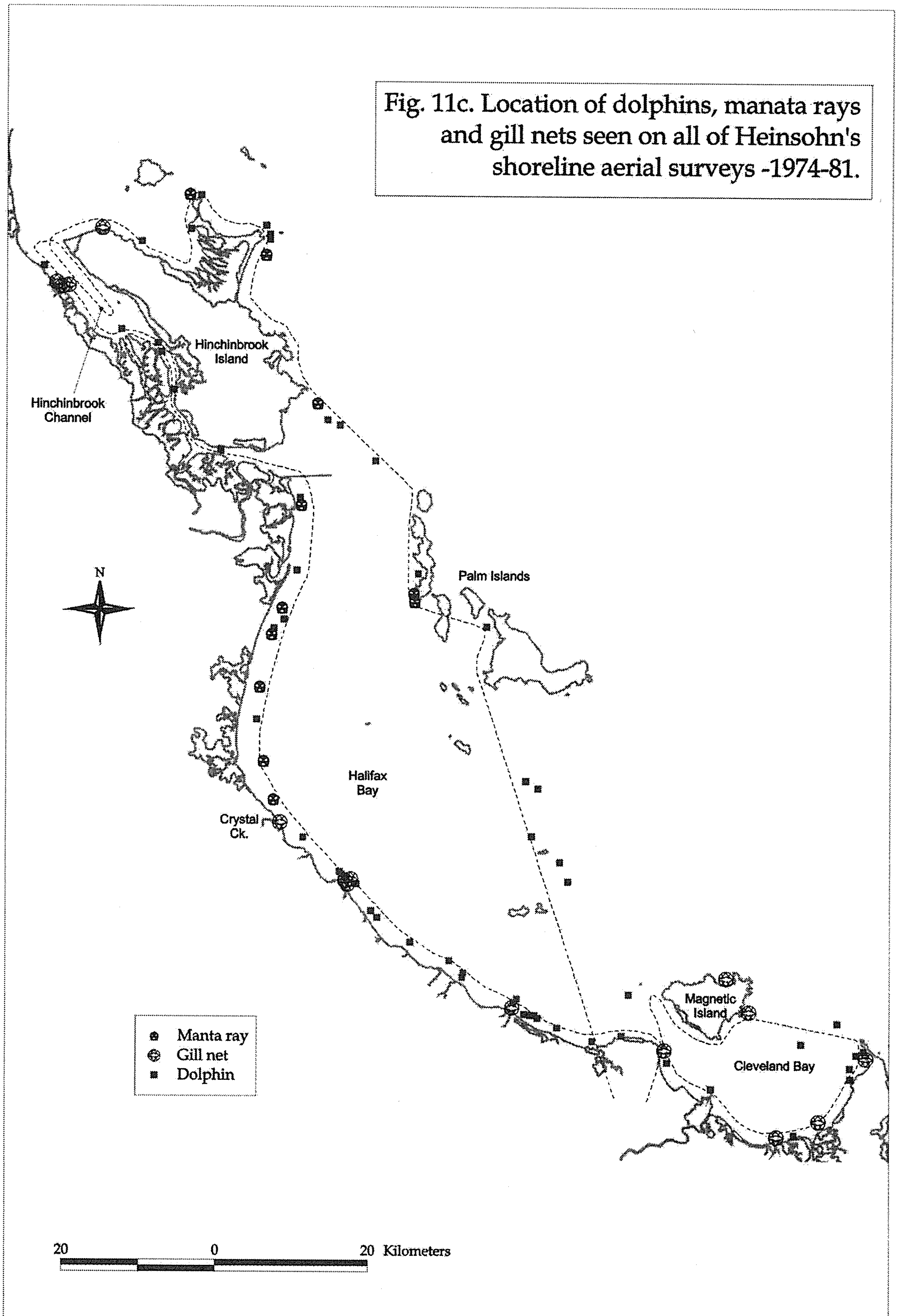


Fig. 11a. Location of dugong groups seen on all of Heinsohn's shoreline aerial surveys - 1974-81.

Fig. 11b. Locations of turtle groups seen on all of Heinsohn's shoreline aerial surveys - 1974-81.





A total of 116 sightings representing 331 marine mammals were reported. The most commonly reported species was the dugong, with 96 groups made up of 253 individuals. Also reported were eight groups of Humpback dolphin (34 individuals), seven groups of Irrawaddy dolphin (25 individuals), four groups of Bottlenose dolphin (11 individuals) and a single group of eight False killer whales (*Pseudorca crassidens*). Ninety-seven percent of dugong groups were identified as 'certain'. Sixty percent of dolphins were identified as 'certain', 20% as 'pretty sure' and 20% as 'not certain'.

Sightings were reported from Cleveland Bay to Dunk Island, but the great majority came from the Hinchinbrook area (where the survey was distributed). Dugongs were commonly seen throughout much of the Hinchinbrook area, particularly near the Cardwell foreshore, in Missionary Bay, along the Lucinda coast and in Hinchinbrook Channel, especially the southern half (figure 12a). Most sightings of dolphins occurred at the northern and southern ends of Hinchinbrook Channel (figure 12b).

Feeding Trail Surveys

Feeding trails were common at 22 of the 24 areas surveyed between Meunga Creek and Oyster Point (figure 13; table 12). One of the sites without feeding trails (site 1) was also devoid of seagrass, so 22 of 23 sites with seagrass displayed discernible feeding trails, indicating widespread grazing of this large seagrass meadow.

Table 12. Abundance of dugong feeding trails within (10 m^2) quadrats (Q1-Q3) on intertidal seagrass meadows between Meunga Creek and Oyster Point.

Site	Date	Latitude		Longitude		Feeding trail score				Est. age of feeding trails[1]
						Q1	Q2	Q3	Mean	
1	12-Nov-97	18	14.19	146	1.402	0	0	0	0.0	
2	12-Nov-97	18	14.319	146	1.391	3	3	3	3.0	<1 month
3	12-Nov-97	18	14.368	146	1.334	3	2	2	2.3	>= 1 month
4	12-Nov-97	18	14.422	146	1.277	2	3	3	2.7	>= 1 month
5	12-Nov-97	18	14.469	146	1.123	3	3	2	2.7	>= 1 month
6	12-Nov-97	18	14.483	146	1.139	3	3	3	3.0	<1 month
7	12-Nov-97	18	14.72	146	1.001	3	3	2	2.7	<1 month
8	12-Nov-97	18	14.841	146	1.006	3	3	3	3.0	>= 1 month
9	12-Nov-97	18	15.004	146	1.039	3	3	3	3.0	>= 1 month
10	12-Nov-97	18	15.11	146	1.12	3	3	3	3.0	<1 month
11	12-Nov-97	18	15.249	146	1.212	3	3	3	3.0	<1 month
12	12-Nov-97	18	15.453	146	1.318	3	3	3	3.0	<1 month
13	12-Nov-97	18	15.589	146	1.469	3	3	3	3.0	>= 1 month
14	12-Nov-97	18	15.872	146	1.62	2	2	2	2.0	>= 1 month
15	12-Nov-97	18	15.987	146	1.717	3	2	3	2.7	<1 month
16	12-Nov-97	18	16.091	146	1.901	2	2	2	2.0	<1 month
17	12-Nov-97	18	16.13	146	2.015	3	2	0	1.7	<1 month
18	12-Nov-97	18	16.204	146	2.095	3	3	2	2.7	<1 month
19	12-Nov-97	18	16.212	146	2.286	3	3	2	2.7	<1 month
20	12-Nov-97	18	16.25	146	2.356	3	3	3	3.0	<1 month
21	12-Dec-97	18	16.518	146	2.928	2	2	2	2.0	<1 month
22	12-Dec-97	18	16.472	146	2.835	3	2	3	2.7	<1 month
23	12-Dec-97	18	16.432	146	2.685	0	0	0	0.0	
24	12-Dec-97	18	16.37	146	2.537	2	2	1	1.7	>= 1 month
25[2]	12-Dec-97	18	16.245	146	2.41	0	0	0	0.0	>= 1 month
26[3]	12-Dec-97	18	16.212	146	2.311	0	0	0	0.0	>= 1 month

[1] Based on a comparison with feeding trails of known age near Cardwell jetty (see text).
[2] resampling of the area near site 20. [3] resampling of the area near site 19

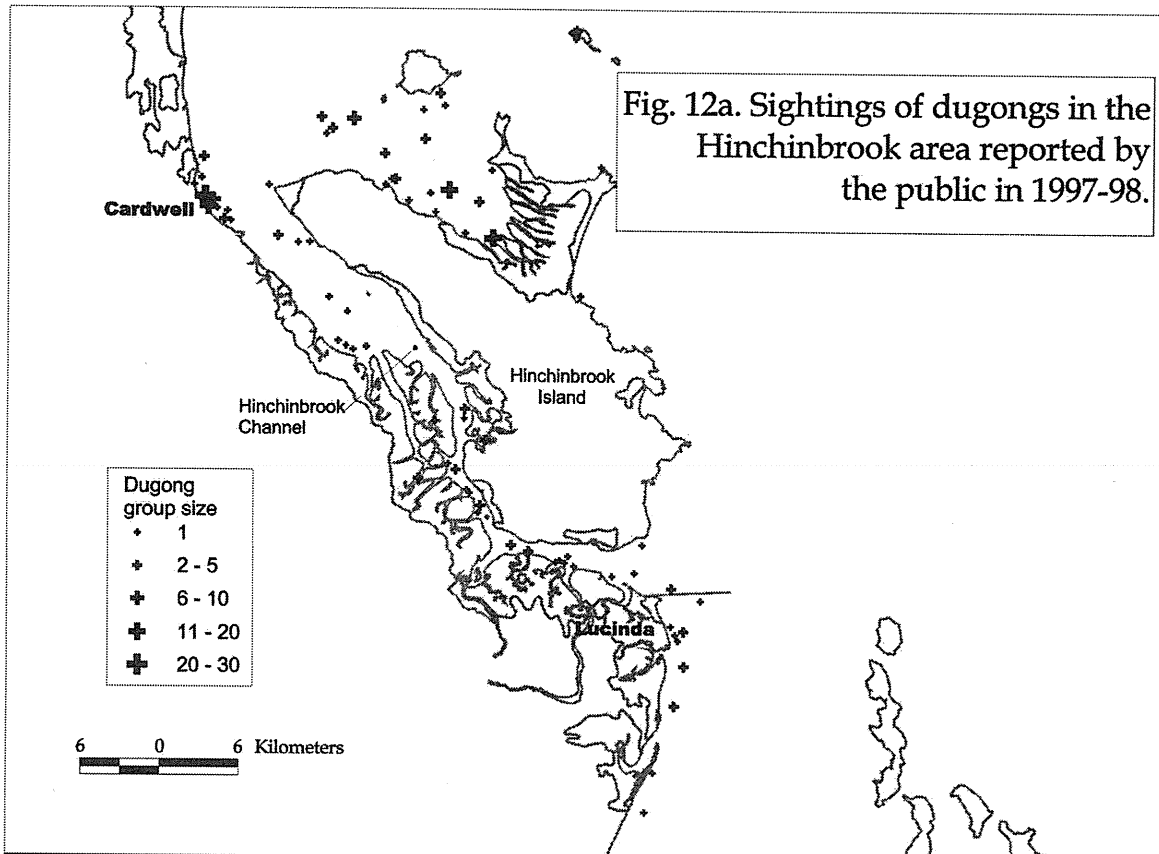


Fig. 12a. Sightings of dugongs in the Hinchinbrook area reported by the public in 1997-98.

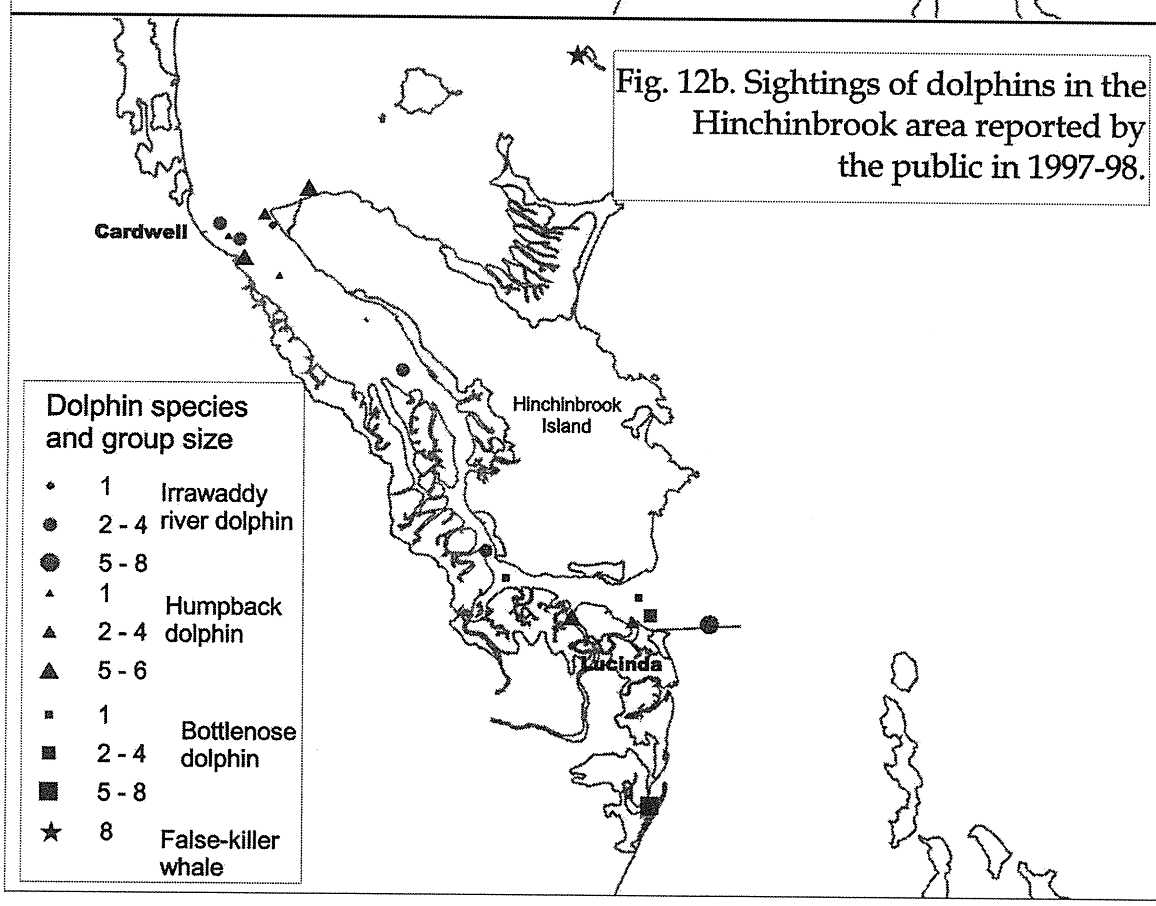


Fig. 12b. Sightings of dolphins in the Hinchinbrook area reported by the public in 1997-98.

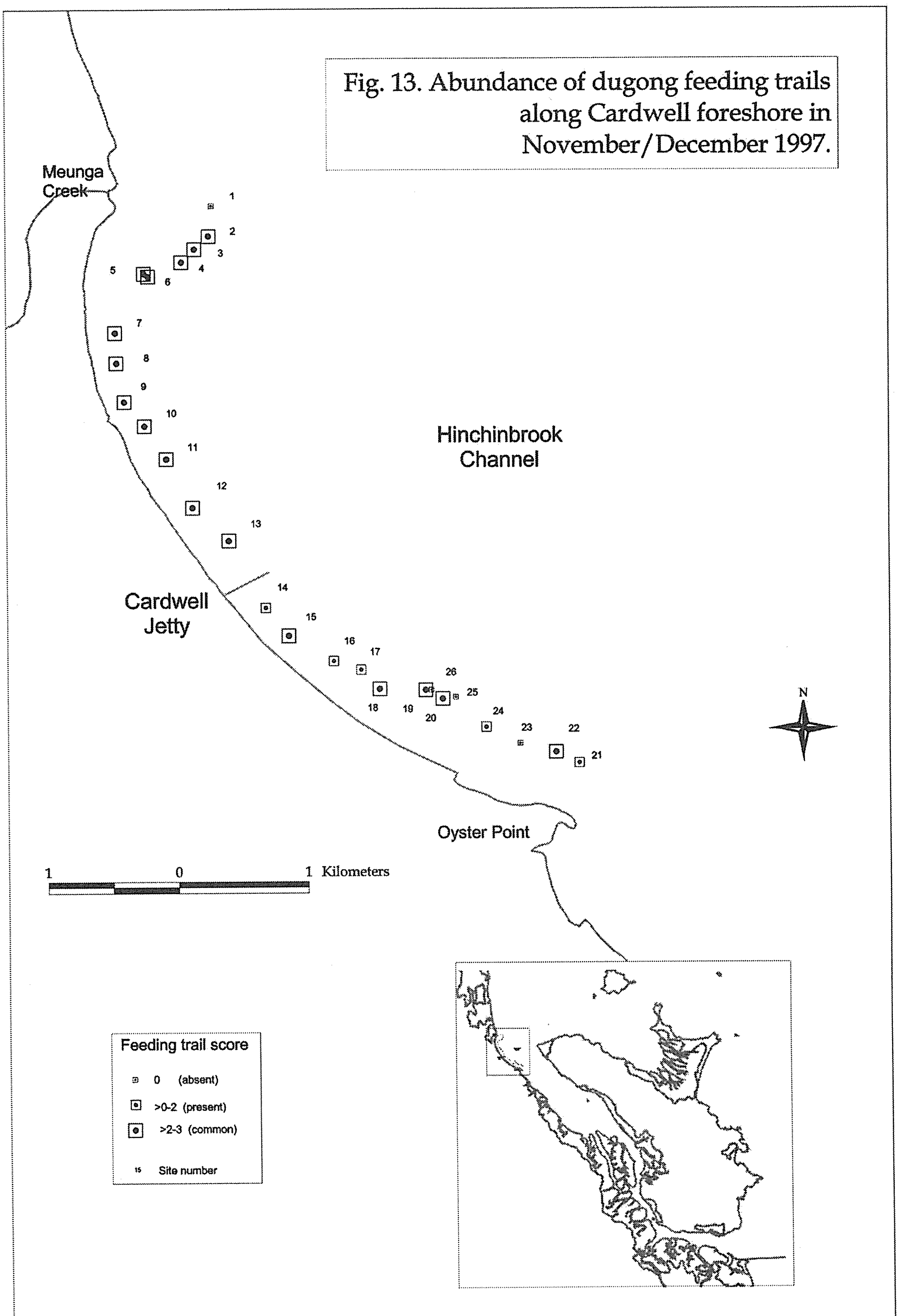


Fig. 13. Abundance of dugong feeding trails along Cardwell foreshore in November/December 1997.

More than half of all sites had been grazed within the previous month (table 12). Feeding trails were common and relatively fresh (< 1 month old) at sites 19 and 20 on 12-11-97 (table 12). One month later feeding trails were rare in these same areas (sites 26 and 25; figure 13), suggesting substantial seagrass recovery within two months of grazing (at this time of year). Long-term monitoring of one seagrass site near the northern edge of Cardwell indicates that dugongs graze this area regularly throughout the year (Aragones 1997).

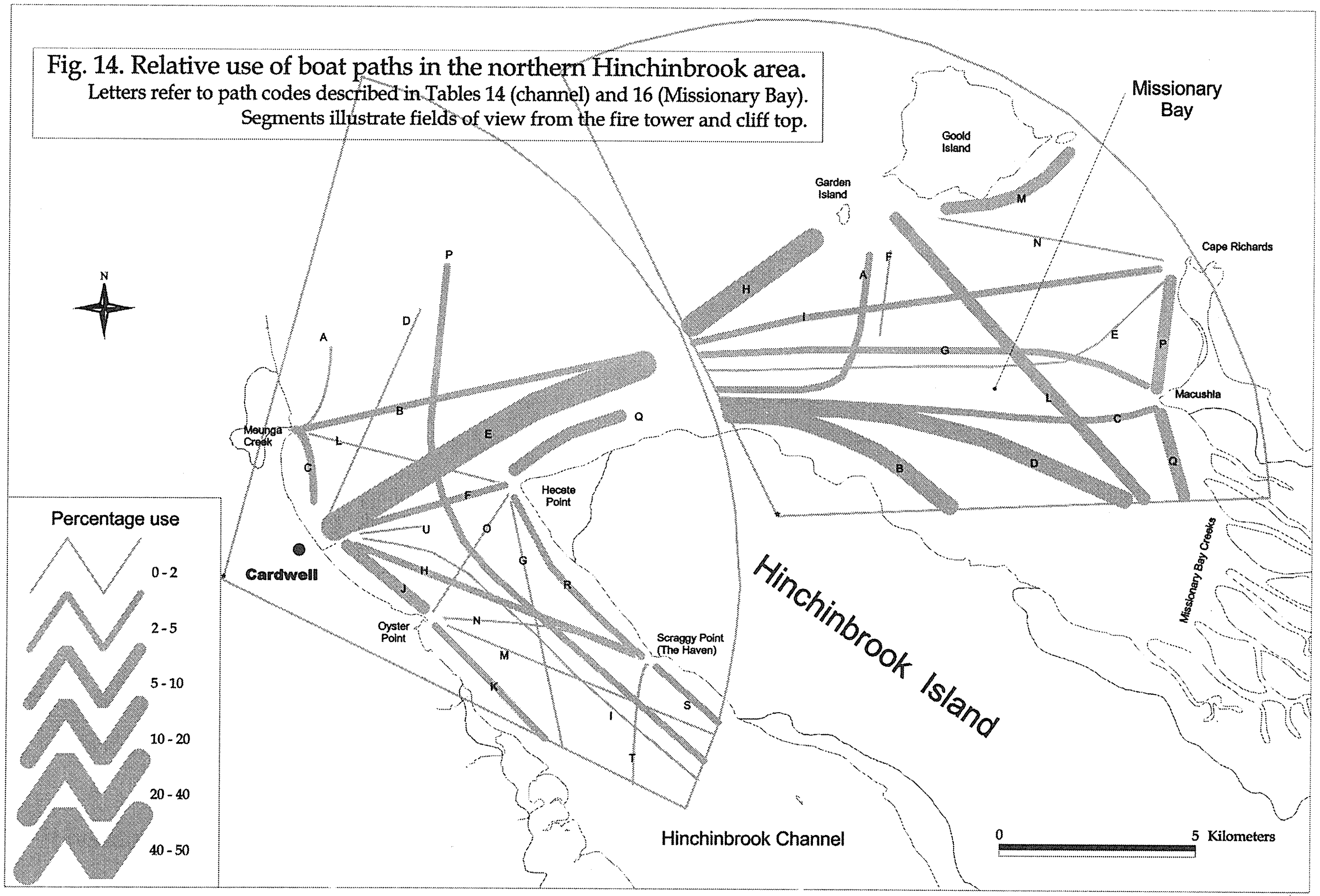


Fig. 14. Relative use of boat paths in the northern Hinchinbrook area.
Letters refer to path codes described in Tables 14 (channel) and 16 (Missionary Bay).
Segments illustrate fields of view from the fire tower and cliff top.

Boat Traffic

A total of 392 boat movements were plotted around the northern end of Hinchinbrook Island to document the pattern of boat movements in the northern channel and Missionary Bay.

Table 13. Type of boats used in northern Hinchinbrook Channel.

	Number of movements				
Boat type	12 Oct	28–29Jun	16 Nov	%	Sub-total
Speedboat	57	63	40	**63.7**	
Passenger ferry - Hinchinbrook Island	3	9	3	**6.0**	
Passenger ferry - Cp. Richards resort	3	5	2	**4.0**	
Large planing hull/cruiser	1	3	1	**2.0**	75.7
Sailboat	2	16	10	**11.2**	
Displacement hull/trawler	1	10	3	**5.6**	
Houseboat	5	4	4	**5.2**	
Cruise ship	2	2	2	**2.4**	
TOTAL	74	112	65	100	

Boat Movements in Northern Hinchinbrook Channel

From the fire tower behind Cardwell, the movements of 251 boats were recorded in northern Hinchinbrook Channel. Speedboats, including tinnies, made up 64% of the total number of movements, while speedboats and vessels with large planing hulls (i.e. fast powerboats) accounted for 76% of all movements (table 13).

The stylised paths of these boat movements are detailed in table 14 and plotted in figure 14. Most movements (56%) were between the Cardwell area and Missionary Bay (paths E, Q and B). About one quarter of all movements (26%) occurred within the northern channel between Meunga Creek and Scraggy Point. Fourteen percent of movements took boats into the channel south of a line between Oyster Point and Scraggy Point, while 2% of boats went north of Meunga Creek.

These data were collected before the opening of the boat ramp near Oyster Point. This boat ramp is at the end of a dredged canal, making the launching and retrieval of boats possible over a wider range of tide and weather conditions than previously possible in the Cardwell area. Consequently, the pattern of boat usage is likely to be significantly altered by this facility. The dominant boat path is now likely to run from Oyster Point into Missionary Bay.

Boat Movements in Missionary Bay

The movements of 321 boats were recorded in the Missionary Bay area. This total includes 180 boats recorded from the observation cliff overlooking Missionary Bay, and 141 boats recorded from the fire tower behind Cardwell that were entering or leaving Missionary Bay (table 15). Speedboats accounted for 66% of all boat movements in Missionary Bay. Powerboats (speedboats plus other large planning vessels) made up 84% of boat movements. Sailing boats, displacement-hulled boats and houseboats accounted for 10%, 3% and 2% of movements, respectively.

Two commercial operators (water taxis to Hinchinbrook Island and Cape Richards resort) accounted for 15% of all boat movements in Missionary Bay (table 15). During periods of bad weather, when recreational boating is reduced, the relative contribution of these commercial boats is increased. During the period 8–10 June, these vessels accounted for nearly 10% of movements, but during the period 24–26 October, when weather conditions were worse, these commercial vessels accounted for nearly 22% of all movements. Similarly, on weekends and public holidays, when recreational boating is greatest, commercial boats accounted for 13% of movements, compared with 39% on the two weekdays for which we have data (table 15).

Table 14. Boat movements in northern Hinchinbrook Channel. Paths of boats recorded from 211 m tower behind Cardwell on four days in June, October and November 1997. Path codes are illustrated in figure 14.

Movements between		Path	*n*	%	Sub-total
Cardwell	& Missionary Bay	E	111	44.2	
Hecate Point	& Missionary Bay	Q	20	8.0	
Meunga Creek	& Missionary Bay	B	10	4.0	56.2
Cardwell	& Oyster Point	J	18	7.2	
Cardwell	& Meunga Creek	C	12	4.8	
Cardwell	& Hecate Point	F	11	4.4	
Cardwell	& Scraggy Point	H	10	4.0	
Scraggy Point	& further down east channel	S	9	3.6	
Hecate Point	& Scraggy Point	R	9	3.6	
Oyster Point	& further down west channel	K	9	3.6	
Cruise ship route down channel	& return	P	7	2.8	
Cardwell	& towards Dunk Island	D	5	2.0	
Cardwell	& further down east channel	I	4	1.6	
Meunga Creek	& to north	A	4	1.6	
Oyster Point	& Hecate Point	O	2	0.8	
Oyster Point	& further down east channel	M	2	0.8	
Scraggy Point	& further down west channel	T	2	0.8	
Hecate Point	& further down west channel	G	2	0.8	
Meunga Creek	& Hecate Point	L	2	0.8	
Oyster Point	& Scraggy Point	N	1	0.4	
Cardwell	& mid-Channel	U	1	0.4	
	Total		251	100	

Table 15. Type of boats used in Missionary Bay in 1997. Boats recorded from Cardwell were going to or coming from Missionary Bay.

Boat type	Recorded from: Cardwell, 12 Oct	Cardwell, 28-29 Jun	Cardwell, 16 Nov	Missionary Bay, 24-26 Oct	Missionary Bay, 8-10 Jun	TOTAL		Weekdays		Weekends /Holidays	
	#	#	#	#	#	#	%	#	%	#	%
Speedboat	32	39	19	27	94	211	**65.7**	6	**33.3**	205	67.7
Passenger ferry - Hinch. Island	3	8	3	10	8	32	**10.0**	7	**38.9**	25	8.3
Passenger ferry - Cape Richards	3	5	2	0	5	15	**4.7**	0	**0**	15	5.0
Large planing hull/cruiser	1	3	1	2	6	13	**4.0**	0	**0**	13	4.3
Sailboat	1	7	5	4	16	33	**10.3**	1	**5.6**	32	10.6
Displacement hull/trawler	1	5	0	0	4	10	**3.1**	3	**16.7**	7	2.3
Houseboat	1	2	0	3	1	7	**2.2**	1	**5.6**	6	2.0
TOTAL	42	69	30	46	134	321	100.0	18	100.0	303	100

Data on boat paths are available for the 180 movements observed from the cliff overlooking Missionary Bay. These paths are plotted in figure 14 and detailed in table 16. The most heavily used paths were between Cardwell and Goold/Garden Island (paths H and A; 26% of all movements), and between Cardwell and the Missionary Bay creeks (paths B and D; 25%). Paths between Cardwell and Macushla and Cape Richards (paths C, G, I and E) accounted for 17% of all traffic (figure 14, table 16).

Table 16. Boat movements in Missionary Bay. Paths of boats recorded from 430 m cliff near the northern end of Hinchinbrook Island. Path codes are illustrated in figure 14.

Movements between			Paths	*n*	%	Sub-total
Cardwell area	&	Garden Island/Goold Island	H	43	**23.9**	
Cardwell area	&	Garden Island/Goold Island	A	4	**2.2**	26.1
Cardwell area	&	Missionary Bay Creeks	B	23	**12.8**	
Cardwell area	&	Missionary Bay Creeks	D	22	**12.2**	25
Cape Richards	&	Macushla	P	15	**8.3**	
Macushla	&	Missionary Bay Creeks	Q	14	**7.8**	
Along southern side of Goold Island			M	13	**7.2**	
Garden Island/Goold Island	&	Missionary Bay Creeks	L	11	**6.1**	
Cardwell area	&	Macushla Missionary Bay	C	9	**5.0**	
Cardwell area	&	Macushla	G	9	**5.0**	10
Cardwell area	&	Cape Richards	I	9	**5.0**	
Cardwell area	&	Cape Richards	E	3	**1.7**	6.7
Garden Island/Goold Island	&	Cape Richards	N	3	**1.7**	
Garden Island/Goold Island	&	mid-Missionary Bay	F	2	**1.1**	
			Total	180	100	

DISCUSSION

The importance of the Hinchinbrook area as dugong habitat has been recognised since the 1970s (Heinsohn & Marsh 1980). The particular importance of the area for the conservation of dugongs along the populated coast of Queensland was recognised only when the decline in dugong numbers was quantified (Marsh et al. 1996). In 1987, dugongs in the Townsville-Hinchinbrook region represented approximately 19% of all dugongs in the Great Barrier Reef region south of Cooktown. Due to the decline of dugongs elsewhere, this had increased to 32% by 1992, and to 49% by 1994 (Marsh et al. 1996).

This study has provided the first detailed, year-round picture of dugong distribution and habitat use in the Townsville-Hinchinbrook area. The previous aerial surveys of the region lacked either temporal or spatial coverage. Marsh's transect surveys have all been conducted in the same month (Marsh et al. 1996), while Heinsohn's shoreline surveys did not cover significant areas of dugong habitat, especially in Missionary Bay. This study has combined year-round aerial surveys with long-term tracking, and has been supplemented by sightings from the public and Heinsohn's data from the 1970s.

The aerial surveys showed that the most important dugong habitat in the Townsville-Cardwell region occurs in Missionary/Shepherd Bay in the Hinchinbrook area and in eastern Cleveland Bay in the Townsville area (figures 6b, 6c). Areas of less intense use, based on the aerial surveys, are Hinchinbrook Channel and the area between Magnetic Island and Bluewater Creek (figures 6b, 6a, 6c). A different, and independent, measure of habitat use in the Townsville-Cardwell region was provided by the tracking. While confirming the broad results of the aerial surveys, the tracking identified substantial use of Hinchinbrook Channel by dugongs (figures 4b, 5a). It also highlighted the use of the Lucinda coast and Bowling Green Bay (figures 4b, 5b). The sightings reported by the public, although inevitably biased by the distribution of search effort, provided useful supplementary information on the distribution of marine mammals in areas of high visitation. The public sightings demonstrated the presence of dugongs in all areas of Hinchinbrook Channel, particularly the southern half (figure 12a, table 12), where few aerial survey or tracking records occurred. The public sightings, and the tracking, also highlighted the presence of dugongs along the Cardwell foreshore (figures 12a, 4b). The importance of this area as a dugong feeding area was confirmed by the survey of feeding trails (figure 13). The results of Heinsohn's shoreline surveys of the 1970s are consistent with the current distribution of dugongs, although dugongs appear to have been more common in Hinchinbrook Channel at the time of Heinsohn's surveys.

The relative abundance of dugongs in Hinchinbrook Channel was one of the main discrepancies between the aerial survey and tracking data. Dugongs in the channel were difficult to see from the air because of the often turbid water, the presence of shadows from clouds formed along the spine of Hinchinbrook Island, and because some of the dugongs used relatively deep water. On four aerial surveys we flew directly over a discrete area of the channel that was occupied, on each occasion, by one of the tagged dugongs, but he was never seen. Other areas where the tracking data highlighted a sightability bias in the aerial surveys were off Lucinda, and along the northern coast of Hinchinbrook Island in Missionary Bay. Few dugongs were seen in these areas (figure 6b) where the water was typically very turbid, yet the tracking data shows substantial use by dugongs (figure 4b). In areas of deep water, both the tracking and aerial survey data are biased. In such areas neither the dugongs, nor their transmitters spend much time near the surface. One such area is northern Missionary Bay, where boat based observations indicate greater use by dugongs than suggested by the tracking and survey data. Spot dives in the area identified a patchy cover of the seagrass *H. decipiens* to a depth of 11 m. Although recent seagrass maps of the area indicate no seagrass in this area, this particular area was not surveyed (Lee Long et al. 1998, map 1).

Missionary Bay and eastern Cleveland Bay have been confirmed as the most important areas for dugongs in this region, however, the tracking has shown that the effectiveness of dissecting out such areas for localised protection is questionable. In the Hinchinbrook area, greater Missionary Bay (including Shepherd Bay), is not divisible from the northern half of Hinchinbrook Channel (including the area off Cardwell), nor separable from the area off Lucinda. All are part of the one habitat from the dugongs' perspective and all are linked by regular movements of dugongs. In the Townsville area, Cleveland Bay and Bowling Green Bay form the one dugong habitat. At the regional scale, the Hinchinbrook and Townsville areas are also linked by the flux of dugongs between them.

The estimates of dugong numbers in the Hinchinbrook and Cleveland Bay survey blocks are similar to those resulting from the standard dugong surveys conducted in previous years (table 17). Although the coverage of each set of surveys was similar, a statistical comparison of these estimates is not possible as the survey designs were different. Marsh's survey of Hinchinbrook extended as far north as Dunk Island, but excluded Shepherd Bay, and the density of transects on the current study was substantially greater than on Marsh's surveys. Despite the variation in the estimates, these data suggest that there has been no decline in dugong numbers in this region since 1987.

Table 17. Estimates of dugong populations in the Cleveland Bay and Hinchinbrook survey blocks. The size and shape of survey blocks was not identical for the surveys by Marsh and those of the current study.

	Population estimate +/- se		
Survey Date	Cleveland Bay	Hinchinbrook	Reference
Nov. 1987	360 +/- 92	284 +/- 131	Marsh et al. 1996
Nov. 1992	106 +/- 56	227 +/- 114	Marsh et al. 1996
Nov. 1994	183 +/- 29	484 +/- 170	Marsh et al. 1996
1997/8	266 +/- 81[1]	523 +/- 230[2]	This study

[1] Average of seven surveys [2] Average of eight surveys

During the current study dugong numbers were estimated from seven surveys of Cleveland Bay and eight surveys of Hinchinbrook. Population estimates varied considerably. In Cleveland Bay, estimates ranged from 176 (se 60) to 400 (se 97), and in the Hinchinbrook block they ranged from 306 (se 108) to 1186 (se 458; table 6). The statistical comparison of surveys was complicated by the changes to some transects instigated about halfway through the surveys. However, most comparisons resulted in significant differences in population estimates (table 3, appendix 2). The significant variations in population estimates may be the result of:

- substantial movements of dugongs occurring within the survey area - hence population estimates of Cleveland Bay or Hinchinbrook vary because of movement of dugongs between these blocks
- substantial movement of dugongs between the survey blocks and adjoining areas to the north or south - hence the significant difference in population estimates when both survey blocks were surveyed together
- substantial variation in sightability of dugongs between surveys that was not adequately described by the environmental covariates.

It is likely that all three factors were occurring. The tracking demonstrated movement of a substantial proportion of tagged dugongs between survey blocks and between the survey areas and surrounding areas. Importantly, the tracking indicated that there was no large-scale movement or migration out of the survey area (only one of 13 dugongs left the region during the tracking period).

Comparison of the results of these surveys with the results of surveys from other areas using very similar methods suggests that the density of dugongs in Cleveland Bay and Hinchinbrook is quite high (table 18). Such a comparison must be done with caution as most other surveys covered much greater areas and included areas of good and poor dugong habitat. The most comparable surveys are those of Shoalwater Bay/Port Clinton and Exmouth Gulf. Both these surveys primarily covered a relatively small inshore area that was known to be important dugong and turtle habitat. The density of dugongs was substantially higher in Cleveland Bay/Hinchinbrook than in these other areas. In Ningaloo Reef the water was particularly clear, making dugongs much more easily sighted than most other areas. Hence the very high density of dugongs observed in this area.

Table 18. Density of dugongs estimated by aerial surveys of different areas.

Location	Date	Area (km^2)	Density dugongs/km^2 +/- se	Reference
Cleveland Bay & Hinchinbrook	1997/8	888	0.75 +/- 0.20*	This study
Shoalwater Bay/Port Clinton	1997	1185	0.40 +/- 0.08	Preen 1999
Exmouth Gulf	1989	3180	0.33 +/- 0.10	Preen et al. 1997
	1994	3180	0.32 +/- 0.16	Preen et al. 1997
Ningaloo Reef	1989	555	1.14 +/- 0.23	Preen et al. 1997
	1994	869	1.11 +/- 0.37	Preen et al. 1997
Qld Gulf of Carpentaria	1997	33 026	0.12 +/- 0.02	Marsh et al. 1998
GBR south of Cape Bedford	1986–7	39 183	0.09 +/- 0.01	Marsh et al. 1994
	1992	39 183	0.05 +/- 0.01	Marsh et al. 1994
GBR north of Cape Bedford	1985	31 288	0.26 +/- 0.0	Marsh & Saalfeld 1989a
	1990	31 288	0.33 +/- 0.0	Marsh et al. 1993
Torres Strait	1987	30 533	0.41 +/- 0.0	Marsh & Saalfeld 1991
	1991	30 560	0.79 +/- 0.1	Marsh et al. 1997
Shark Bay	1989	14 906	0.71 +/- 0.12	Marsh et al. 1994
	1994	14 906	0.71 +/-0.10	Preen et al. 1997

* Average of five surveys.

The distribution of dugongs, dolphins, turtles, manta rays and gill nets in the Townsville-Cardwell region was similar in the 1970s (when Heinsohn conducted 26 shoreline surveys of the area), and in 1997–98 (when I conducted nine surveys). The important difference between the two groups of surveys was the lower sighting rate of dugongs during the recent surveys. This difference is not easily dismissed as an artefact of different survey methods as they were similar for each set of surveys. Heinsohn's surveys were flown at a higher altitude and surveyed a wider strip. Heinsohn flew at mostly at 900' (274 m) and surveyed a strip estimated to be 800 m wide (Heinsohn et al. 1979), while we flew at 550' (167 m) and used a marked strip width of 250 m. The probability of detecting a dugong decreases the further the dugong is from the flight line (see Buckland et al. 1993), so it is very likely that Heinsohn's *effective* strip width was substantially narrower than 800 m. We used a narrower strip width to avoid the problem of missing animals at greater distances. However, we did scan beyond the marked outer edge of our transects in Hinchinbrook Channel, and recorded the dugongs and dolphins (but not turtles) seen as a separate category. Consequently, the effective strip width searched during Heinsohn's and our surveys was not as different as the nominal strip widths suggest. The sighting rates of most species and gill nets were higher during the recent surveys, than during the 1970s (table 11). Assuming that all these groups have not increased in abundance, these results suggest that the closer view afforded by the lower survey altitude of the recent surveys more than compensates for the wider view afforded by Heinsohn's higher surveys.

Although dolphins, turtles, manta rays and gill nets were seen more frequently during the 1997–98 surveys than during the surveys of the 1970s, dugongs showed the opposite trend. Dugongs were seen 4.15 times more frequently in Hinchinbrook Channel in the 1970s than during the recent surveys (table 11). Assuming that dolphins, turtles and manta rays have not all increased in abundance since the 1970s, the most plausible explanation for the different trend shown by dugongs is that the number of dugongs in the region has declined since the 1970s.

Strip-transect aerial surveys indicate that there has not been a decline in dugong numbers in the Townsville-Cardwell region since 1987 (table 17). In this regard, this region is unique to the southern Great Barrier Reef region (Marsh et al. 1996). Data on the decline in dugong deaths in shark nets, and other anecdotal information suggest that the decline in dugong numbers south of Cooktown (measured as 50% between 1987 and 1994) may have commenced in the 1960s (Marsh et al. 1996). Hence, it is plausible that there was a decline in dugong numbers in the Townsville-Cardwell region between Heinsohn's surveys and the first strip-transect survey in 1987.

The apparent decline in dugong numbers in Hinchinbrook Channel (table 11), like the decline of dugongs along most of the populated coast of Queensland, may have many causes (Marsh et al. 1996). Possible factors include gill net mortality, seagrass loss (especially around the Herbert River distributaries), and disturbance by boat traffic.

Mesh net mortality has been addressed by prohibiting the use of nets likely to catch dugongs within the Hinchinbrook Dugong Protection Area. Although this DPA would provide better protection for dugongs if its boundaries were adjusted to incorporate the Lucinda area used by dugongs (as originally proposed by Preen and Morissette 1997), mesh netting is now banned from most dugong habitat in the Hinchinbrook area. The extent of seagrass loss is unknown, although there was apparently no detected decline in seagrass abundance in the southern channel between 1987 and 1996 (Lee Long et al. 1998). Habitat deterioration due to upstream practices is a difficult issue to manage, but Landcare and Integrated Catchment Management are likely to have long-term benefits for coastal habitats. Boat traffic is an increasing problem.

The great majority of boats used in the Hinchinbrook area are powerboats. Data from the boat-paths study indicate that 80% of all boat movements in the northern Hinchinbrook area are made by small to large speedboats. The data from the aerial surveys, which included additional areas south of Hinchinbrook Island, where trawlers were common (figure 9b), suggest that 66% of boats used in the Hinchinbrook area are small to large speedboats (table 19).

Table 19. Percentage of different categories of boats recorded in the Hinchinbrook area.

	Percentage of boat types	
Boat type	Northern Hinchinbrook (from observation of boat paths)	Hinchinbrook (from aerial surveys)
Small to medium speedboat	65.2	61.5
Large speedboat	14.2	4.9
Sailing boat	11.1	13.9
Displacement hull/trawler	4.2	17.8
House boat	3.9	1.9
Cruise ship	1.4	0
n	431	309

The distribution of dugongs (based on tracking and aerial surveys) and the distribution of boats (based on aerial surveys) suggests that there may be a relationship between the two (figure 15). Within both Missionary Bay and Cleveland Bay, the greatest density of dugong sightings occurs within the area where there were few boat sightings. This inverse relationship is particularly strong in Cleveland Bay, where there is a lot of boat activity around the seagrass beds to the northeast and southwest of the area used by the dugongs. If this apparent relationship is evidence of displacement of dugongs by boat traffic, it may partly explain some of the differences between Heinsohn's surveys of the 1970s and the recent surveys. In particular, Heinsohn recorded dugongs over a much larger area of eastern Cleveland Bay (specifically on the areas of seagrass now little used by dugongs to the northeast and southwest; figure 11a) and in the southern and western areas of Hinchinbrook Channel (figure 11a).

Boat traffic in the Townsville-Hinchinbrook area has probably increased greatly since the 1970s, when George Heinsohn's surveys were flown. In the 11 years between 1984 and 1995, boat registrations in the Ingham district increased by 24% (Gilbert & Benzaken 1996). With recent developments in Hinchinbrook Channel, boat traffic in that area is likely to increase significantly. The two proposed marinas in the initial stages of being established at Oyster Point and Dungeness will attract more boats to the region. Anecdotal evidence indicates that the new boat ramp at Oyster Point has already increased boat traffic in the northern channel. Up to 70 boat trailers have been counted at this boat ramp on weekends (Whiteman 1998), which is approximately a four-fold increase compared with prior use of other tide-limited boat ramps at Cardwell (personal observation). One hundred and twenty boat trailers were counted at the Oyster Point boat ramp on Easter Saturday 1998 (Williams 1998). The greater boating activity is probably a result of the capacity to launch boats under rough and windy conditions. During such conditions it is likely that most boating will be restricted to the protected channel, thus increasing the use of this area.

The establishment of a marina-based resort at Oyster Point will also change the nature of boating activity in the northern channel. A study of boat use in southern Moreton Bay found that the use of recreational boats is very pulsed, with 83% of usage occurring on the weekend (Curgenven & Shanco 1982). As a result there is relatively little boat traffic for five days/week. The pattern of boat usage at a marina resort is likely to be very different. Fishing dinghy hire, jet ski hire, para sailing, water skiing, sight seeing cruises, ferry services to Hinchinbrook Island and fast-cat trips to the reef can be expected to occur with the same frequency seven days/week. Consequently, not only is overall boat activity likely to increase, but so too will the average daily intensity of boat traffic.

Boat strike of dugongs is known to occur in the northern Hinchinbrook area under the current intensity of boat traffic (Illidge 1996). In Florida there has been a tight correlation between the increase in boat traffic and the increase in manatee deaths caused by boat strike (Wright et al. 1995). The predicted increase in boat traffic in the Hinchinbrook area can be expected to result in an increase in boat strikes, and an increase in other effects of boat disturbance such as habitat alienation and restricted access to intertidal seagrasses. For these reasons it is important to establish control of boat traffic, by regulation and education, before the increase occurs. This will help prevent the gradual decline of the quality of the dugongs' habitat.

Dolphins

This report presents the first reliable data on the species composition of dolphins in the Townsville-Cardwell area, and indeed for most of the Queensland coast. Unfortunately, the number of each species seen on most surveys was inadequate to calculate meaningful population estimates.

The breakdown of dolphin species in Missionary Bay and Cleveland Bay, as determined by aerial survey, was broadly similar to the species composition of dolphins identified in the Hinchinbrook area by members of the public (table 20). In both cases Humpback dolphins were the most commonly seen species (based on number of groups, not number of individuals), while similar proportions of Irrawaddy and Bottlenose dolphins were seen.

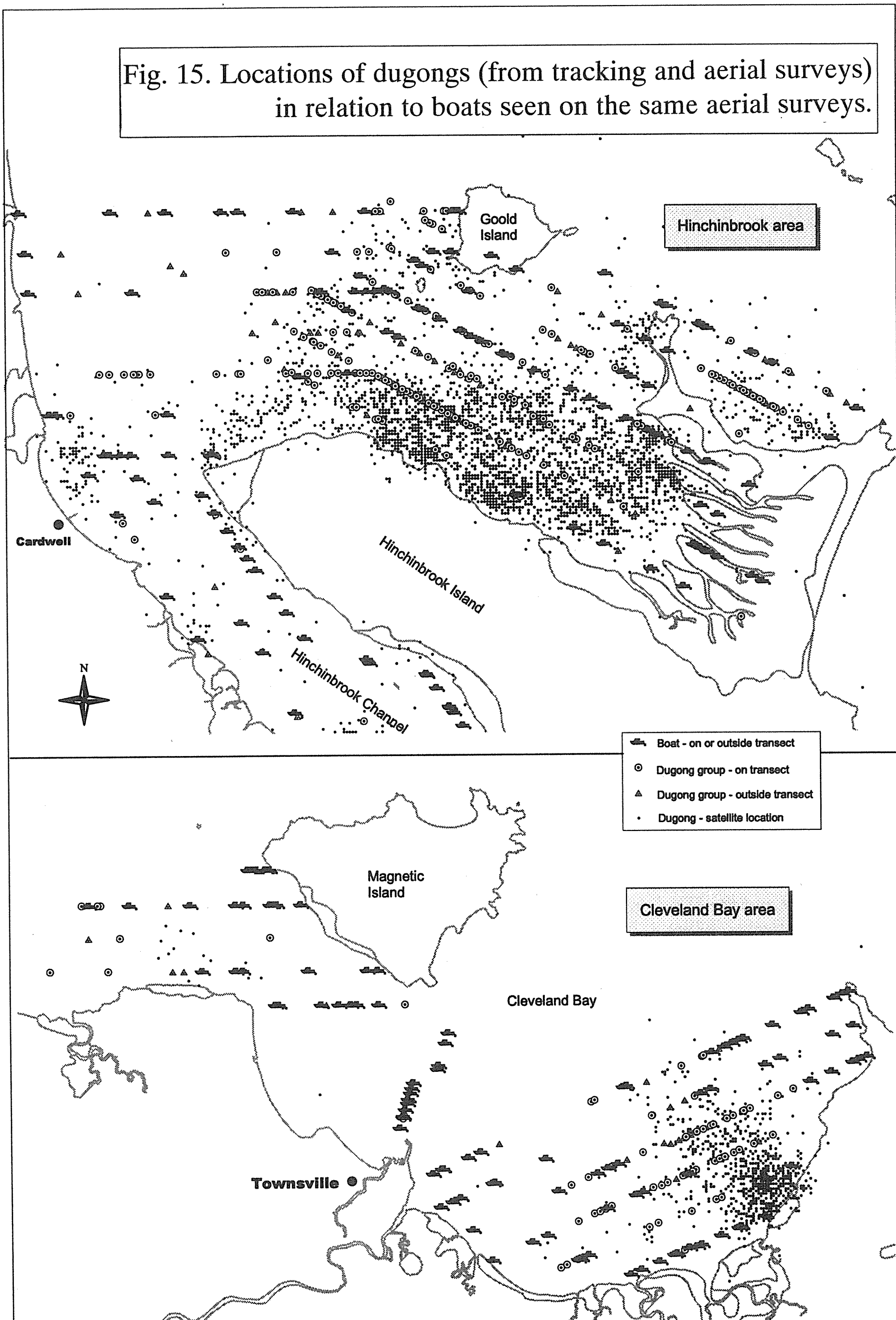


Fig. 15. Locations of dugongs (from tracking and aerial surveys) in relation to boats seen on the same aerial surveys.

Humpback dolphins were common at both ends of Hinchinbrook Channel, in Missionary Bay and in Cleveland Bay (figures 9a and 12b). Irrawaddy dolphins were most common in Hinchinbrook Channel and in the southern part of Halifax Bay (figure 9b). By contrast, Bottlenose dolphins were most common in offshore areas of Halifax Bay (table 10, figure 9c). The apparent preference of Humpback and Irrawaddy dolphins for protected, nearshore waters, and Bottlenose dolphins for offshore waters is consistent with what is known of these species (Corkeron et al. 1997; Klinowska 1991; Stacy & Leatherwood 1997). Humpback and Irrawaddy dolphins are listed as Rare under Queensland legislation (*Nature Conservation Act 1992*).

Table 20. Percentage of dolphin species recorded by the public, and on aerial surveys.

	Percentage of dolphin groups recorded	
	Public sightings - Hinchinbrook area	Aerial surveys - Hinchinbrook & Cleveland Bay
Humpback dolphin	40	51
Irrawaddy dolphin	35	18.4
Bottlenose dolphin	20	24.5
other	5	6.1
n	20	49

Turtles

The distribution of turtles in the Townsville-Cardwell region closely follows the known distribution of seagrasses in the area (Lee Long et al. 1998). Consequently, turtles were most frequently seen in greater Missionary Bay and in the eastern half of Cleveland Bay (figure 7). Estimates of turtle numbers varied significantly amongst surveys (table 3). These differences may reflect movement of turtles between survey blocks between surveys, or movements between survey blocks and adjacent areas that were not surveyed. They may also be due to variable sightability as a result of weather and water clarity differences amongst surveys, or to different diving and surfacing behaviour of turtles on different surveys.

Table 21 shows the density of turtles estimated in a variety of areas, in comparison to the Townsville and Hinchinbrook area. It is difficult, however, to compare the density of turtles in Cleveland Bay and the Hinchinbrook area with surveys of other areas, as most other surveys have covered much greater areas, including a greater diversity of habitats (e.g. nearshore embayments to offshore reefs). The surveys of Shoalwater Bay/Port Clinton and Exmouth Gulf are the most comparable surveys. The survey of Ningaloo reef is not strictly comparable because of the different habitat and the very clear water. The density of turtles in Cleveland Bay/Hinchinbrook is similar to that in Exmouth Gulf but only about half that of Shoalwater Bay/Port Clinton (table 21). The latter area, which experiences very low levels of visitation and boat traffic is known to support exceptionally high numbers of turtles.

Table 21. Density of turtles estimated by aerial surveys of different areas.

Location	Date	Area (km^2)	Density turtles/km^2 +/- se	Reference
Cleveland Bay & Hinchinbrook	1997–98	888	1.13 +/- 0.20*	This study
Shoalwater Bay/Port Clinton	1997	1185	2.03 +/- 0.31	Preen 1999
Exmouth Gulf	1989	3180	1.42 +/- 0.28	Preen et al. 1997
	1994	3180	1.02 +/- 0.22	Preen et al. 1997
Ningaloo Reef	1989	555	4.51 +/- 0.47	Preen et al. 1997
	1994	869	4.9 +/- 0.83	Preen et al. 1997
Qld Gulf of Carpentaria	1997	33 026	0.48 +/- 0.04	Marsh et al. 1998
GBR south of Cape Bedford	1986–87	39 183	0.64 +/- 0.04	Marsh et al. 1994
	1992	39 183	0.85 +/- 0.13	Marsh et al. 1994
GBR north of Cape Bedford	1985	31 288	1.03 +/- 0.08	Marsh & Saalfeld 1989b
	1990	31 288	1.46 +/- 0.11	Marsh et al. 1993
Torres Strait	1987	30 533	1.43 +/- 0.16	Marsh & Saalfeld 1991
Shark Bay	1989	14 906	0.43 +/- 0.05	Preen et al. 1997
	1994	14 906	0.57 +/-0.05	Preen et al. 1997

* Average of five surveys.

CONCLUSIONS

The Townsville-Cardwell section of the Queensland coast is a particularly important area for dugongs. In 1994, approximately 49% of dugongs in the Great Barrier Reef south of Cooktown occurred in this area (Marsh et al. 1996). Dugongs move throughout the whole Townsville-Cardwell region (and beyond), and division of the region into discrete sections is, at least partly, arbitrary. Nevertheless, the northern Hinchinbrook area, including Shepherd Bay, Missionary Bay and Hinchinbrook Channel supports the largest number of dugongs at any one time in this region, and is the core of the Hinchinbrook Dugong Protection Area.

Unfortunately, the Hinchinbrook DPA does not extend to the waters off Lucinda, which were used by the dugongs tagged in Missionary Bay area. Similarly, all the dugongs tagged in the Cleveland Bay DPA spent time in Bowling Green Bay. The waters of Lucinda, and the waters of Bowling Green Bay are Type 'B' DPAs and as such, the use of several types of net that pose threat of entanglement and drowning to dugongs is still permitted. These nets include foreshore nets (i.e. nets set in waters < 2 m deep) that can be set on seagrass meadows, drift nets up to 1.2km long (in waters > 20 m deep) and bottom set nets (nets anchored close to the sediment). These areas of the Lucinda coast and Bowling Green Bay that are regularly used by dugongs should be included in the adjoining Type 'A' DPAs (Hinchinbrook and Cleveland Bay, respectively).

Although the Hinchinbrook and Cleveland Bay DPAs prohibit the use of some mesh nets that pose a threat to dugongs, no other specific management has been implemented to protect the dugongs or their habitat in these special areas. Developments in Hinchinbrook Channel mean that increasing boat traffic is one potential impact that will require attention. To that end, I have proposed a series of recommendations for a Boat Traffic Management Plan for the Hinchinbrook DPA. These recommendations attempt to strike a balance between reasonable use and adequate protection of a unique and important habitat. The recommendations are integrated in that the protection of some areas is compromised for the better protection of other, more important areas. As a result the suggested plan should not be divided into its component parts or partially implemented without careful consideration of the consequences.

RECOMMENDATIONS FOR BOAT TRAFFIC MANAGEMENT IN THE HINCHINBROOK DUGONG PROTECTION AREA

Goal

To allow for reasonable recreational and commercial boating in the Hinchinbrook Dugong Protection Area (DPA) while maintaining the area as high quality dugong habitat.

Strategies

1. To increase awareness of boat users of the importance of maintaining the Hinchinbrook DPA as high quality dugong habitat.

2. To manage boating activities primarily within a framework of Boating Management Areas which are delineated on the basis of their existing use by boaters, their importance for dugongs, and localised factors (such as water depth) that may moderate or exacerbate the effects of boat traffic.

Recommendations

1. Develop an education and awareness program to:
(i) foster an appreciation by boaters of the significance of the Hinchinbrook Dugong Protection Area, 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.

Rationale: The management of boating activity in the Hinchinbrook area will depend to a large extent on voluntary compliance with regulations. Such compliance will require an appreciation of the need for the regulations, which will require an education and awareness program.

2. Establish five Boating Management Areas (BMAs) within the Hinchinbrook Dugong Protection Area for the regulation of boating activity.

It would be preferable not to superimpose another zoning scheme on top of the existing management regimes established by Great Barrier Reef and Queensland Marine Parks zones, Fish Habitat Areas and fisheries closures that operate in the Hinchinbrook area. However, the spatial scale of the patterns of dugong and boater use of this area means that it is necessary to implement a boating management regime that reflects the dugongs' usage of the area. The proposed Boating Management Areas are derived from the existing use of different areas by dugongs and boats, factors that affect the potential threat to dugongs from boats, and consideration of future patterns of boat use.

Boating Management Area 1

Location: Northern Missionary Bay (including Garden and Goold Islands) and Shepherd Bay (figure 16). Southern boundary marked by a line joining a point just west of Macushla (on Hinchinbrook Island) and two or more buoys in Missionary Bay (located at 18.20^0 S, 146.09^0 E, and 18.20^0 S, 146.19^0 E).

Suggested activities allowed: Small- to medium-sized (< 10 m) recreational and commercial craft (including current passenger ferry services) that travel at high speeds can use this BMA to access the Cape Richards resort, Macushla, Missionary Bay creeks and destinations east of Missionary Bay (Brook Islands, eastern Hinchinbrook, offshore reefs). Maximum speed limit of 20 kn. No restrictions on the use of sailing craft, houseboats or smaller displacement-hulled boats (< 10 m). Commercial passenger ferries allowed under permit.

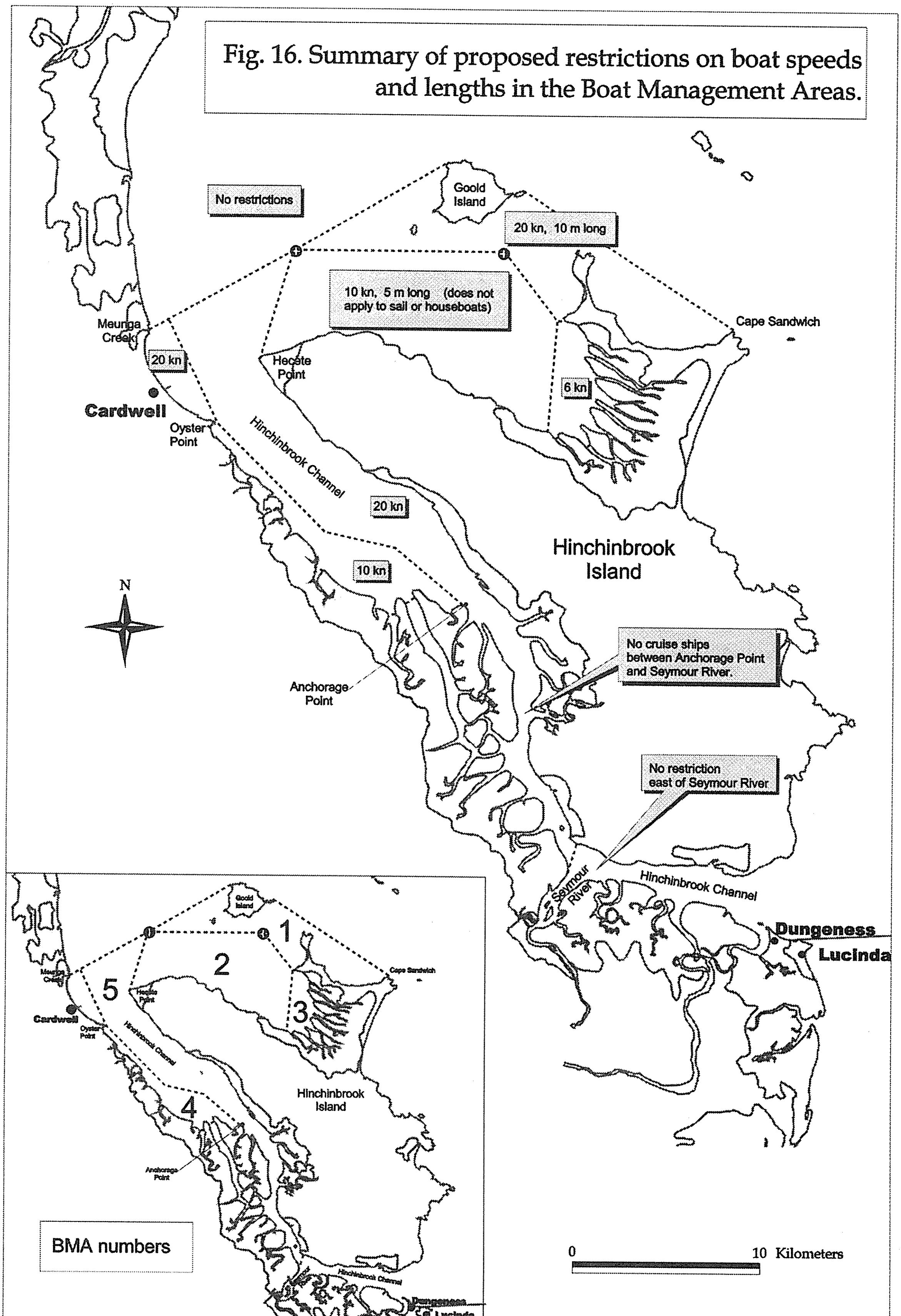


Fig. 16. Summary of proposed restrictions on boat speeds and lengths in the Boat Management Areas.

Suggested changes to existing use: Large (> 10 m) seagoing displacement-hulled vessels, such as trawlers, not permitted in this BMA, except for anchoring behind Cape Sandwich, Cape Richards and Goold Island, or for transit during exceptional weather events.

Suggested restrictions on possible future use: Large fast vessels, such as those used to take tourists to the reef (e.g. wave-piercers, fast cats) not permitted in this BMA. Such boats should be directed north of Goold Island.

Rationale:

Location: The proposed positions of the marker buoys, and hence the southern boundary to this BMA, is a balance between the perceived need for an acceptably direct path for boats to traverse Missionary Bay and the need to direct boat traffic away from important dugong habitat. The area of this BMA to the southwest of Goold Island, which is heavily used by dugongs (figure 4b), will be subjected to greater boat traffic in an effort to protect the areas of greatest dugong concentration to the south and southeast (in BMAs 2 and 3). The relatively northern location of the buoys ensures that the larger and faster craft that use BMA 1 will stay in relatively deep water, where dugongs will be better able to avoid approaching boats.

Speed and size restrictions: The 10 m and 20 kn restrictions are a balance between the reasonable use of the area and the risk of fatal boat strike and noise disturbance. The faster a boat travels, the less time is available for a dugong to take evasive action, and generally, the amount of underwater noise generated increases with speed (McCauley et al. 1996). These restrictions will have little impact on existing use because: (i) few boats that currently transit Missionary Bay would exceed 20 kn under most weather conditions, and (ii) the vast majority of recreational craft that use this area are < 10 m long. One of the three commercial ferries currently operating to northern Hinchinbrook Island is 12 m long, and an exception to the 10 m limit could be made, perhaps with a sunset clause ending with the disuse of this vessel.

Excluding reef cats: Large passenger ferries of the type used to access the reef are likely to represent a high risk to dugongs and turtles. These boats are very fast, have large, deep propellers and have a large footprint. Consequently, they have the characteristics of craft that are likely to represent a significant boat-strike threat (Wright et al. 1995). The faster the boat and the larger its potential area of impact, the smaller the chance that dugongs or other wildlife could make evasive movements. Furthermore, this type of boat generates high levels of underwater noise (McCauley et al. 1996), which may degrade the habitat in this area for acoustic species such as dugongs and cetaceans (Anderson and Barclay 1995; Richardson et al. 1995; Norris 1994). These boats are designed for use in open waters and can avoid Missionary Bay.

Restrictions on trawlers: Trawlers, and similar vessels should be allowed to anchor behind Cape Sandwich, Cape Richards and Goold Island, as they currently do. They would also be able to pass through BMA 1 for safety reasons during exceptional weather events. Under normal circumstances, however, trawlers have no need to pass though Missionary Bay because they are very seaworthy and because current GBRMP zoning prohibits trawling within Missionary Bay. Current GBRMPA zoning does allow trawling on the seagrass meadows of Shepherd Bay. The importance of Shepherd Bay for dugongs has only been discovered as a result of the current project. Hence, I suggest that Shepherd Bay should be rezoned to prohibit trawling. This would ensure the protection of the seagrass meadows as dugong, turtle, prawn and fish habitat

Boating Management Area 2

Location: The area of Missionary Bay south of a line joining Hecate Point, the permanent buoys (located at 18.20° S, 146.09° E, and 18.20° S, 146.19° E) and Macushla (figure 16).

Suggested activities allowed: All motor vessels < 5 m long permitted. All houseboats and sailing boats permitted. Speed restriction of 10 kn to apply to all vessels. Under adverse weather conditions motor boats < 10 m long could transit this BMA as long as they comply with the speed limit or maintain the minimum safe speed for control of the vessel (additional conditions should apply to some commercial vessels - see below).

Suggested changes to existing use: Motor vessels greater than 5 m long (excluding houseboats) prohibited from this area. These vessels should use BMA 1.

Rationale:

Speed and size restrictions: This BMA contains most of the habitat that is most heavily used by dugongs (figure 15). Seagrass covers nearly all of this BMA (and extends further to the north than indicated in recent maps by Lee Long et al. 1998; personal observation). Most of this BMA is less than 3 m deep. High-speed boats travelling over seagrass beds, especially in shallow areas, are likely to pose the greatest threat to dugongs. The suggested regime for BMA 2 allows the passage of most recreational and commercial fishing craft, but requires these vessels to travel at reduced speeds, for the protection of wildlife. Vessels larger than 5 m, or those wishing to travel at greater speeds can choose to travel through BMA 1.

Safety provision: Human safety is of paramount importance, so it is necessary to allow for the transit of BMA 2 under adverse weather conditions. However, observations suggest that dugongs' ability to detect an approaching powerboat decreases as wave height increases, presumably due to the increase in ambient noise levels. Consequently, I suggest that larger vessels that choose to transit this BMA for safety reasons must comply with the speed restrictions. To prevent abuse of this safety provision, I suggest that there should be a sunset clause on the transit of this area by commercial ferries. These vessels should be seaworthy enough not to need to transit BMA 2 (except under exceptional circumstances), and the sunset clause would allow for eventual upgrading of these vessels, if required.

Boating Management Area 3

Location: The area of Missionary Bay south and east of Macushla, including the mouths of the major creeks (figure 16).

Suggested activities allowed: This area is accessible to all sailing boats and all other boats < 15 m long. Larger displacement-hulled vessels, such as some commercial and research vessels should be allowed under permit. All boats restricted to a maximum speed of 6 kn. Boats restricted from BMA 2 would enter this area from BMA 1, near Macushla (figure 16).

Suggested changes to existing use: No current users would be prevented from accessing the Missionary Bay creeks.

Rationale: This BMA is designed to provide access to the Missionary Bay creeks by all users. Because of the shallowness of many areas in this BMA, the importance of this area to dugongs, and the access provided for large boats, the speed of craft should be kept < 6 kn.

Boating Management Area 4

Location: The nearshore waters of northern Hinchinbrook Channel between Meunga Creek and Anchorage Point, along the mainland coast (figure 16).

Suggested activities allowed: Virtually all current boat use would continue. North of Oyster Point the maximum boat speed should be 20 kn. South of Oyster Point the maximum boat speed should be 10 kn.

Suggested changes to existing or future use: The 10 kn speed restriction south of Oyster Point will affect commercial crab fishers that set their pots in this area, as they generally travel at higher speeds.

Restrictions on possible future use: Water skiing, parasailing and the use of jet skis should be prohibited between Meunga Creek and Oyster Point to preserve the habitat quality of this dugong grazing area.

Rationale:

Restrictions around Cardwell: The seagrass meadow off the Cardwell foreshore is the largest in the region outside Missionary and Shepherd Bays (Lee Long et al. 1998) and the species of seagrasses that make up this meadow are particularly favoured by dugongs. Dugongs are regularly seen in this area (I have seen herds of 12, 20 and approximately 100), and the extent of feeding trails indicates that it is an important feeding ground for dugongs. Due to the high public profile of dugongs, and the difficulty of seeing them in most areas, Cardwell has considerable potential to capitalise on the proximity of dugongs to its beach, jetty and boat ramps. To realise this potential, however, the nearshore seagrass meadow must be maintained as a favoured grazing area.

The current pattern and intensity of boat traffic around Cardwell does not appear to be having an adverse effect on the dugongs. This is probably because the nature of the traffic through this area. Most of the boat traffic passes through a limited number of corridors - predominantly from the boat ramp and jetty out towards Missionary Bay/Goold Island, or south into Hinchinbrook Channel. As a result, these movements pass at right angles to the north-south oriented feeding area. Most other boat movements are those of tender vessels moving between the jetty and moored vessels. These are small vessels, and many of them are rowed.

The apparent benign nature of current traffic does not mean that regulation of boating activity is not required. The future introduction of jet skis, water skiing, parasailing and other boating activities have the potential to make this area unsuitable dugong habitat. These types of boating activities are more likely to run parallel to the shore, and thus through the length of the feeding area. In the case of jet skis, they can also operate in the nearshore shallow waters that deter other boats.

Speed limit south of Oyster Point: The seagrass beds and adjacent waters between Oyster Point and Anchorage Point were used extensively by tracked dugongs. They were also the area of greatest dugong abundance during Heinsohn's aerial surveys between 1974 and 1981. Many of the seagrass beds in this area occur very close to the mangrove-lined shore (Lee Long et al. 1998). The boats of commercial crab fishers transit this narrow zone up to several times each day, on the high tide, and this disturbance may displace the dugongs from these grazing areas. The crab boats, which travel quickly between pots, also pose a threat to green turtles that graze these seagrass beds. The 10 kn speed limit over the seagrass meadows and adjacent habitat between Oyster Point and Anchorage Point will reduce the risk of boat strike and is likely to reduce the risk of habitat alienation. Crab fishers will be able to operate in the area, but they will have to travel at slower speeds along this section of the coast. There will be no restrictions on the activities of crab fishers in any other part of the channel.

Boating Management Area 5

Location: Hinchinbrook Channel north of the Seymour River (figure 16)

Suggested activities allowed: All current recreational boating, except boat and ski races, should be allowed. All current commercial boating will be permitted, although the access of cruise ships should be limited. A maximum boat speed of 20 kn should apply to all vessels (except reef fast cats).

Suggested changes to existing use: Cruise ships should not be allowed south of Anchorage Point, or north of the Seymour River. Boat and ski races should be restricted to the southern channel, east of the Seymour River. However, the Great Barrier Reef Marine Park Authority Ministerial Council has recommended to the State Government that no permits for ski boat races should be granted for ski races in this area.

Suggested restrictions on possible future use: Reef fast cats that may operate between 'Port Hinchinbrook' or Cardwell and the reef should be restricted to 15 kn through this BMA.

Rationale:

Speed limits: Dugongs (and dolphins and turtles) occur throughout all areas of the

Hinchinbrook Channel. The faster vessels travel, the less time available for wildlife to take evasive action. An appropriate balance between reasonable boat use and conservation requires some restriction on boat speeds. An upper limit of 20 kn would have no affect on the overwhelming majority of boat users.

Due to their large footprints and large deep propellers, fast cats and similar craft operating to the reef should be required to travel at 15 kn within this BMA, to minimise the risk of boat strike.

Speed boat races limited to the southern channel: Racing speedboats travel at very high speeds (up to 70 kn; Burnham 1993 in Gilbert and Benzaken 1996) and pose a threat to a variety of wildlife. The middle one-third of Hinchinbrook Channel, between the mouth of the Seymour River and Anchorage Point (figure 16) is particularly narrow. In some locations it is less than 500 m from bank to bank. In this 16 km long section of the channel, both wildlife and the racing boats are particularly constrained, and the likelihood of boat strike or disturbance due to noise levels is increased.

It has been reported that about nine boat races are currently conducted through the channel each year. The one race I witnessed involved 20 boats. As the races involve a return journey from the southern to the northern end of the channel, this race involved 40 high speed passes of the full length of the channel. In the US, episodic periods of high levels of boat traffic have been associated with propeller injuries to dolphins (Wells & Scott 1997). As dolphins are distinctly faster and more agile than dugongs, the risks from such concentrated and fast boat traffic would be expected to be significantly greater for dugongs. In Florida, fast small- to medium-sized speedboats, presumably like those used for races in Hinchinbrook Channel, account for most of the fatal manatee injuries caused by boats (Wright et al. 1995).

Although the largely single-file nature of racing boats limits their impact to a relatively narrow band, this does not necessarily reduce their potential threat to dugongs. The way dugongs respond to a passing speedboat may make them more vulnerable to being struck by a following boat. I have observed fast speedboats (travelling at approximately 20 kn) pass through groups of dugong in water 4–5 m deep. Typically, the dugongs dived as the boat approached and surfaced shortly afterwards in its wake. When Anderson (1981) drove a fast speedboat (27 kn) through a group of dugongs (probably in approximately 3 m water) the dugongs took no evasive action, but aggregated after the boat had passed. '*If a second boat had been following close behind, the response of the dugongs would have increased the risk of collision rather than reducing it*' (Anderson 1981, p. 643).

Prohibiting speed boat races from BMA 5 will limit this activity to that section of the Hinchinbrook Channel between Lucinda and the mouth of Seymour River. Dugongs' use of this section of the channel has been confirmed by numerous sightings reported by the public and the transit of this area by at least one tagged dugong. However, dugongs now appear to be less common here than they were in the 1970s, and compared with the rest of the channel, this area now has a relatively low abundance of dugongs. Consequently, if boat and ski races were to occur in the channel, this would be the most appropriate location. The area provides a loop circuit of 25 km length, has a relatively deep channel and includes the start/end location for the current boat races.

The alternatives to restricting boat races to the southern channel are either: (i) allowing boat races to continue at the current frequency and number of participants, or (ii) banning races in all of the channel. Given the status of Hinchinbrook Channel, as a Zone A Dugong Protection Area, and being aware of the very confined nature of the middle one third of the channel, it is difficult to mount a credible case for the support the first option. Accepting that the races are an existing (but controversial) use and constitute an important form of recreation for a segment of the local community, it may be unrealistic to expect the complete banning of the races in Hinchinbrook Channel. The compromise that has been suggested should maintain the integrity of that part of the channel that is most important to dugongs, while allowing races to continue throughout nearly one third of the channel's length.

Cruise ships not permitted to transit the narrow section of the channel between the Seymour River and Anchorage Point: Very large boats in the narrow channel pose a threat to wildlife. In Florida, most fatal propeller wounds to manatees are caused by medium sized and larger vessels because they have large propellers that cut deeply (Wright et al. 1995). In some areas slow-moving vessels, like tugs, have had to fit specially designed propeller guards. The central one third of the channel is unsuitable for the passage of cruise ships because of the threat posed by their very large propellers and because of the level of underwater noise that they would generate. In the narrow, shallow sections of the channel, this noise is likely to be amplified by reflection. Cruise ships would not be restricted from entering the northern and southern sections of the channel.

Additional Recommendations

3. Install channel markers in the northern end of Hinchinbrook Channel to encourage boaters to use a single corridor down the channel.

Rationale: Dugongs and dolphins occur throughout the northern channel and the level of boat disturbance could be reduced if boats were focussed within a narrower corridor. At present there is no marked channel in the northern area, so boat traffic is dispersed. Racing sailboats can reach moderate speeds (up to 15 kn) and many (especially catamarans) will use shallow waters when tacking. A marked channel could be used to restrict racing sailboats to deeper water.

4. Require boat-based commercial dugong watching to operate under a permit system.

Rationale: Commercial dugong watching is conducted in Missionary Bay. Current practice is unregulated and involves significant risk to dugongs due to the high speed approach to and departure from the dugongs, and due to the types of vessels used. Any commercial dugong watching should be regulated by permit, and guidelines should be developed for boat-based dugong watching, as has been done for whales.

5. Operators of commercial passenger craft should be required, as a condition of their permit, to report suspected boat strikes to the Queensland Environmental Protection Agency and GBRMPA. Passengers should also be actively encouraged to report suspected strikes.

Rationale: Ongoing management of boat traffic will benefit from a knowledge of boat strike incidents. The Author's experience to date indicates that few boaters report strikes of dugongs or turtles. Some boat strikes involving the commercial vessels in the Hinchinbrook area have been reported by passengers, although it is likely that most strikes have gone unreported. Commercial passenger craft could be required to display a poster providing information about dugongs in the area and requesting passengers to report suspected strikes. If passengers know to report boat-strike incidents, it is likely that most boat strikes by commercial passenger vessels will be reported. As two passenger ferry services account for 15% of all boat traffic in Missionary Bay, and these ferries are the type of craft most likely to cause fatal strikes, significant benefits may be achieved by having educated and vigilant passengers.

6. The boat traffic management plan should be reviewed at set intervals.

Rationale: The nature and intensity of boat traffic within the Hinchinbrook DPA will change through time. Not all these changes can be predicted. Consequently the boat traffic management plan should be reviewed at set intervals. Possible issues that have not been addressed in these recommendations, and that may require examination in the future include:

(1) The need to establish a cap on boat numbers operating in some areas.
(2) The effect of directing all the fast boat traffic through restricted area between BMA 2 and Garden Island. This area is not very deep (mostly < 4 m) and is often used by dugongs. A 'Go slow' zone may be required here.
(3) The impacts of jet ski and water ski activity around Garden Island and the western shore of Goold Island.

(4) The impacts of boat races on dolphins, turtles and dugongs in the southern channel.
(5) The possible need for propeller guards and additional speed limits on some commercial vessels, such as sightseeing cruises, that will transit the area regularly and may constitute a significant proportion of channel boat traffic.
(6) The possible need for some vessel-free areas.
(7) The need for additional resources to allow adequate enforcement of boating management regulations.
(8) Further restrictions in some areas if current use patterns changed significantly (e.g. if the boat ramp at Meunga Creek was upgraded and this area became a popular launching facility).

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APPENDIX 1.

SIGHTING AND INFORMATION SHEET DISTRIBUTED IN THE HINCHINBROOK AREA IN 1997 TO SOLICIT PUBLIC SIGHTINGS OF DUGONGS AND DOLPHINS.

The Hinchinbrook region is a particularly important habitat for endangered Dugong, and some rare inshore dolphins. James Cook University, in association with the Hinchinbrook Region Marine Resources Advisory Committee and the Department of Environment is assembling records of sightings of these species in the region. This information will assist with the development of management plans that will help ensure the protection of these inshore marine mammals.

If you see a marine mammal in the Hinchinbrook region could you please:

1. **Indicate the location of the sighting on the map** on the reverse side of this sheet
2. **Indicate the path taken by your boat on the day of the sighting** (if you were in a boat)
3. **Fill in the information** on the reverse side of this sheet
4. **Fold** and seal this sighting sheet so the **Reply Paid** address is on the outside and **post it**

Key features to note that will help with your identifications are:
back fin (shape and size, or absence); **body colour;** and **snout shape.** See attached sheet for illustrations and details

---

No stamp required
if posted in Australia

Reply Paid 18
Hinchinbrook Region Marine Mammal Survey
Dr Tony Preen
Department of Tropical Enviornment Studies and Geography
James Cook University
Townsville 4811

Fold

Sender:..
....
....

***PLEASE** do not disturb the animals by approaching too closely*
***PLEASE** be cautious in shallow waters – to avoid boat strike.*

Please circle appropriate options:

SPECIES: Dugong / Bottlenose dolphin / Humpback dolphin / Irrawaddy dolphin / other

CONFIDENCE OF IDENTIFICATION: Certain / Pretty sure / Not certain **DATE:** ....

SEEN FROM: Shore / Sailing Boat / Tinny or powerboat at anchor / Tinny or powerboat travelling

NUMBER IN GROUP: .... **NUMBER OF CALVES:** .... **PHOTOS:** Yes / No
(include a copy if possible)

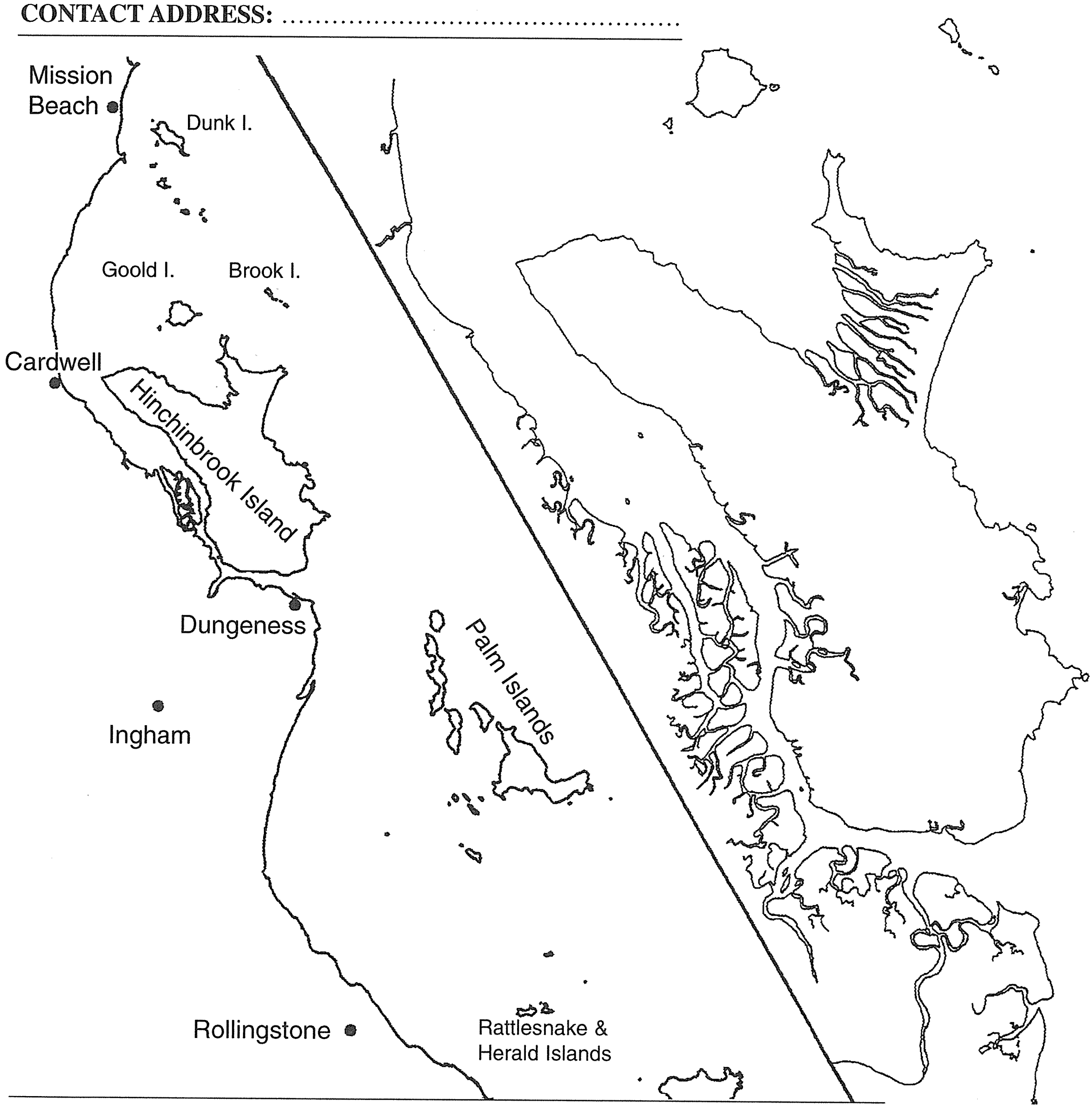
WEATHER (wind, waves, cloud etc.): ....

COMMENTS (activity etc.): ....

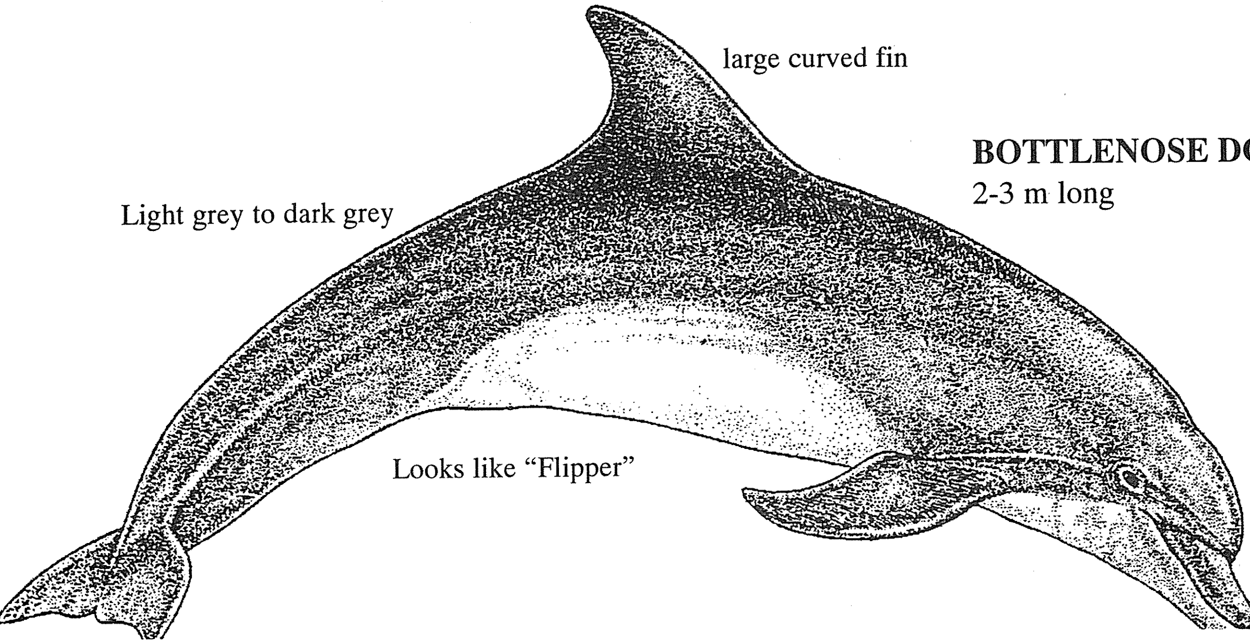
....

NAME OF OBSERVER:...**PHONE:** ....

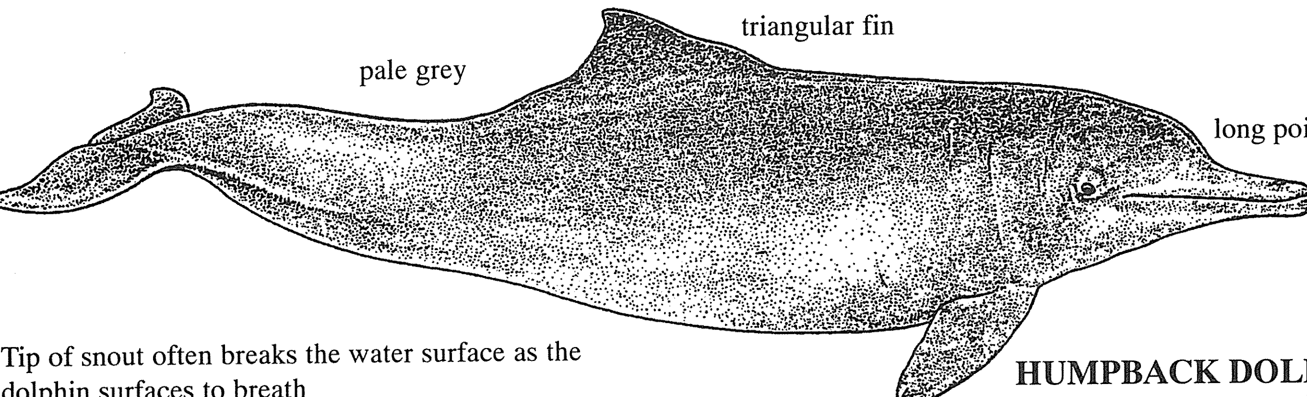
CONTACT ADDRESS: ....



SEE REVERSE SIDE FOR DIRECTIONS

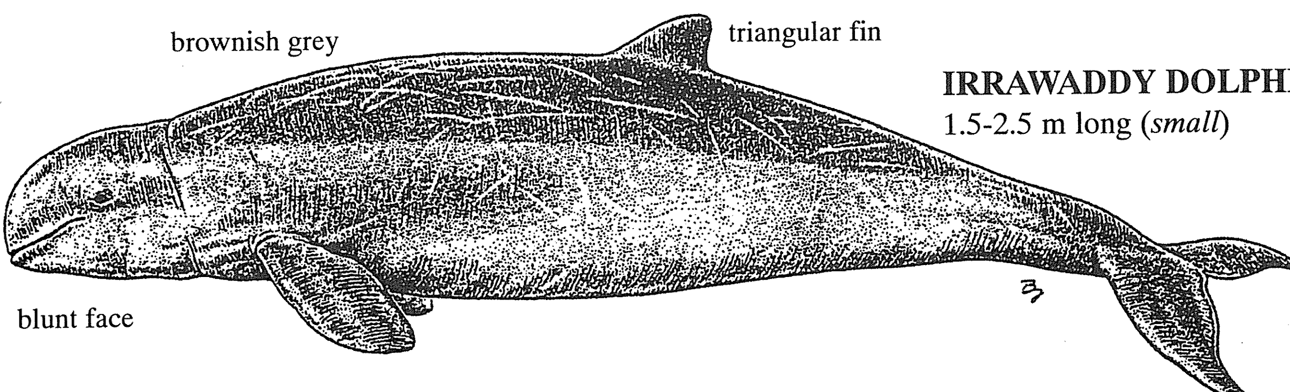


BOTTLENOSE DOLPHIN
2-3 m long

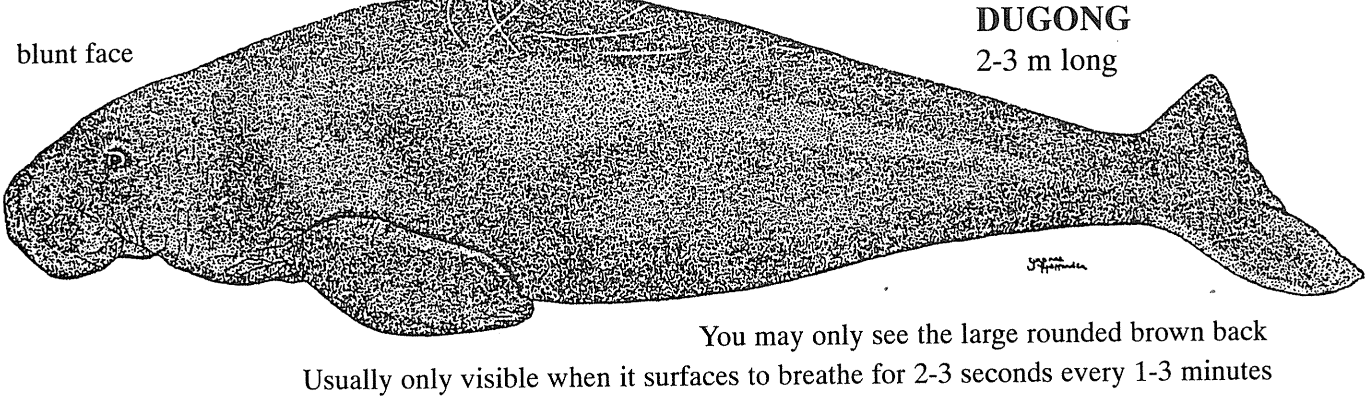


Tip of snout often breaks the water surface as the dolphin surfaces to breath

HUMPBACK DOLPHIN
2-3 m long



IRRAWADDY DOLPHIN
1.5-2.5 m long (*small*)



DUGONG
2-3 m long

You may only see the large rounded brown back

Usually only visible when it surfaces to breathe for 2-3 seconds every 1-3 minutes

Please send sightings to Dr Tony Preen, Dept. Tropical Environment Studies, James Cook University 4811

Dugongs and Dolphins

Although they often share the same habitat, dugongs and dolphins are very different. Dolphins are carnivores and feed on fish, squid and some other marine animals. Dugongs are herbivores and feed almost exclusively on seagrasses. In fact the dugong is the only strictly marine mammal that feeds on plants. Because dolphins have to be able to catch their food, they tend to be faster and more active than dugongs. Being more active, dolphins have to breathe frequently, and hence they tend to spend a lot of time near the water surface. Dugongs, by contrast, spend much of their time near the bottom feeding on seagrass and they only come to the surface for a quick breath every minute or two. For these reasons it is often easier to see dolphins than dugongs. Dolphins are also more conspicuous because they have a fin on their back. The shape of this fin is very important in identifying the type of dolphin. Dugongs do not have a back fin.

There are many other differences. For example, female dolphins have their mammary glands concealed behind slits on their belly. This keeps their body shape very streamlined. Dugongs, with less need for speed, have more conspicuous mammary glands that are located near the 'armpits' of their front flippers. When a female dugong is lactating, her nipples are 6-7 cm long. The location of prominent nipples in this position is probably one of the main reasons why dugongs are the origin of the mermaid legend.

Dugongs are long-lived, slow breeding animals. Although they live for up to 70 years, they do not become sexually mature until they are 10-15 years old and they only have one calf every 3-7 years. This is a very low rate of reproduction compared with most other animals, like kangaroos, cattle or fish. It is this very low rate of reproduction that makes dugongs especially vulnerable to over-harvesting, be that by incidental take in fishing nets, hunting or boat strike.

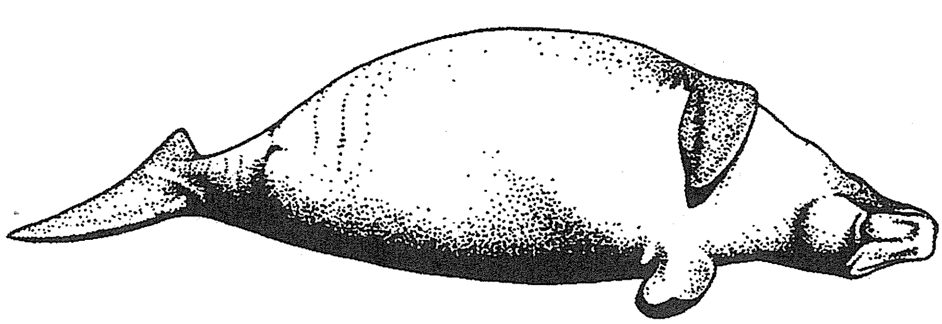
Much of what we know about dugongs has been learned by analysing the carcasses of dead dugongs. There is still much to be learned, and it is important that any dead dugong is examined.

IF YOU FIND AN INJURED OR DEAD DUGONG OR DOLPHIN:

1. If it is dead and in the water, tie it to a tree so that it does not float away.
2. Notify the Department of Environment as soon as possible.

Call one of these numbers:

Townsville:	(077) 225 313
Lucinda:	(077) 778 356
Cardwell:	(070) 668 115
Ingham:	(077) 761 700



APPENDIX 2. RESULTS OF ANALYSES OF VARIANCE TESTING FOR DIFFERENCES AMONGST DUGONG POPULATION ESTIMATES FROM DIFFERENT SURVEYS OF CLEVELAND BAY AND HINCHINBROOK SURVEY BLOCKS.

Results are presented without covariates (1) and with survey conditions included as a covariate.

1. Dugongs. Block 1 (Cleveland Bay) Seven surveys

Source of variation	d.f		*F*		*P*	
	1	2	1	2	1	2
Survey	6	6	2.67	2.21	0.020	0.049
Transect	15	15	9.34	9.01	0.000	0.000
Residual	90	88				
Regression		2		0.35		0.706

2. Dugongs. Block 2 (Hinchinbrook) version 1 transects - three surveys

Source of variation	d.f		*F*		*P*	
	1	2	1	2	1	2
Survey	2	2	3.60	0.130	0.034	0.879
Transect	26	26	3.14	2.60	0.000	0.002
Residual	52	50				
Regression		2		0.10		0.907

3. Dugongs. Block 2 (Hinchinbrook) ver. 2 transects - five surveys

Source of variation	d.f		*F*		*P*	
	1	2	1	2	1	2
Survey	4	4	1.11	3.84	0.356	0.006
Transect	23	23	14.29	15.32	0.000	0.000
Residual	92	90				
Regression		2		7.97		0.001

4. Dugongs. Blocks 1 and 2 (version 2 transects) four surveys

Source of variation	d.f		*F*		*P*	
	1	2	1	2	1	2
Transect nested in Block[1]	38	38	7.81	8.06	0.000	0.000
Block[2]	1	1	0.06	0.00	0.815	0.958
Survey[1]	3	3	3.17	5.38	0.027	0.002
Block by Survey[1]	3	3	1.83	0.23	0.146	0.879
Residual	114	112				
Regression[1]		2		3.65		0.029

[1] Tested against residual [2] Tested against Transect nested in Block

APPENDIX 3. RESULTS OF ANALYSES OF VARIANCE TESTING FOR DIFFERENCES AMONGST TURTLE POPULATION ESTIMATES FROM DIFFERENT SURVEYS OF CLEVELAND BAY AND HINCHINBROOK SURVEY BLOCKS.

Results are presented without covariates (1) and with survey conditions included as a covariate.

1. Turtles. Block 1 (Cleveland Bay) Seven surveys

Source of variation	d.f		*F*		*P*	
	1	2	1	2	1	2
Survey	6	6	3.50	2.77	0.004	0.016
Transect	15	15	9.53	9.26	0.000	0.000
Residual	90	88				
Regression		2		0.95		0.390

2. Turtles. Block 2 (Hinchinbrook) version 1 transects - three surveys

Source of variation	d.f		*F*		*P*	
	1	2	1	2	1	2
Survey	2	2	9.75	0.53	0.000	0.593
Transect	26	26	2.98	2.43	0.000	0.003
Residual	52	50				
Regression		2		1.23		0.301

3. Turtles. Block 2 (Hinchinbrook) ver. 2 transects - five surveys

Source of variation	d.f		*F*		*P*	
	1	2	1	2	1	2
Survey	4	4	12.63	11.17	0.000	0.000
Transect	23	23	7.63	7.26	0.000	0.000
Residual	92	90				
Regression		2		2.09		0.129

4. Turtles. Blocks 1 and 2 (version 2 transects) four surveys

Source of variation	d.f		*F*		*P*	
	1	2	1	2	1	2
Transect nested in Block[1]	38	38	6.16	6.37	0.000	0.000
Block[2]	1	1	1.49	2.17	0.229	0.149
Survey[1]	3	3	11.99	5.72	0.000	0.001
Block by Survey[1]	3	3	4.54	3.29	0.005	0.023
Residual	114	112				
Regression[1]		2		1.18		0.318

[1] Tested against residual   [2] Tested against Transect nested in Block