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	3	Missionary Bay	25	98	88.8	8
K2	F	3	Missionary Bay	94	572	92.8	15
Liz	F	5	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	3	Missionary Bay	156	263	92.4	0
MT	F	5	Missionary Bay	210	323	94.7	2
Shirley	F	5	Missionary Bay	222	690	94.9	0
MM	F	3	Missionary Bay	236	769	94.7	18
Arthur	M		Missionary Bay	287	310	96.1	12
Mudskipper	F	3	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

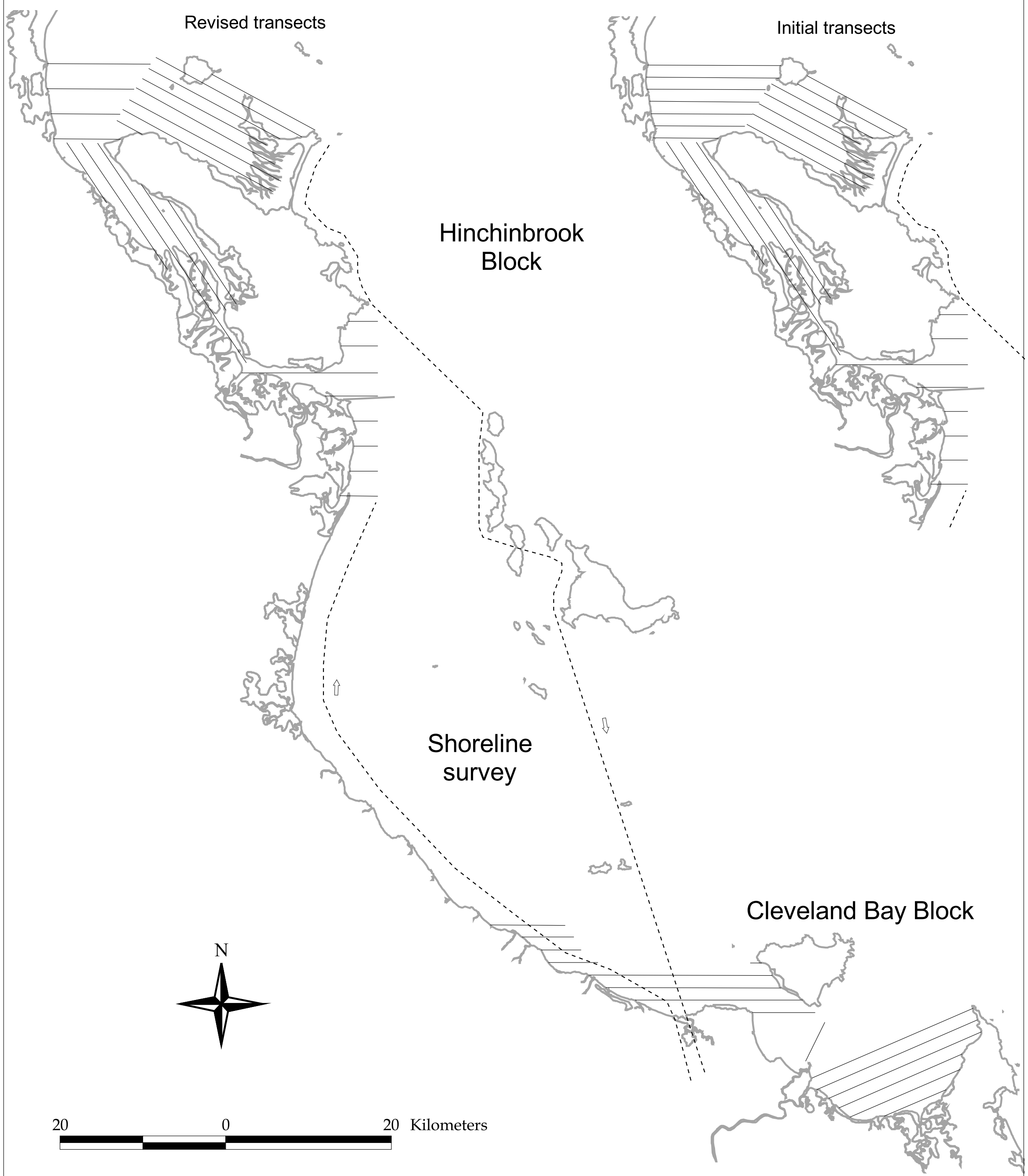
Service Argos, which operates the satellite location system, provides a quality rating for locations. Sixty-eight percent of location quality (LQ) 3 fixes are estimated to fall within 150 m of the true location. For LQ 2 the radius is 350 m, and for LQ 1 it is 1000 m (New Argos Location 1994). Independent 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	σ			σ			σ	σ	σ	σ	σ
Hinchinbrook	τ	5	τ		τ	τ	τ	τ	τ		τ

	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
5: 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.