Aust. Wildl. Res., 1990, **17**, 511-24

The Distribution and Abundance of Dugongs in the Great Barrier Reef Marine Park South of Cape Bedford

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Abstract

In 1986 and 1987, dugongs were counted from the air at an overall sampling intensity of 10·1% over a total area of 39 396 km^2 in the inshore waters of the Great Barrier Reef region south of Cape Bedford. The survey area included the southern portion of the Cairns Section, the Central Section, and the Mackay–Capricorn Section of the Great Barrier Reef Marine Park. We corrected sightings for perception bias (the proportion of animals visible in the transect which are missed by observers), and standardised them for availability bias (the proportion of animals that are invisible due to water turbidity) with survey-specific correction factors. The resultant population estimate (±SE) was 3479±459 dugongs at an overall density of 0·088±0·012 km^{-2}, a precision of 13%. There were no significant differences between population and density estimates obtained from repeat surveys of the northern half of the Central Section. Highest densities were observed on inshore seagrass beds and in waters less than 5 m deep. Maps of density and distribution are given and recommendations made on the timing of future surveys.

Introduction

As part of a program to determine the distribution and abundance of the dugong, *Dugong dugon*, in the Great Barrier Reef Marine Park (GBRMP), we present the results of a series of aerial surveys of the inshore waters between Cape Bedford (15°14'S.,145°21'E.) and the southern boundary of the GBRMP in 1986 and 1987. Marsh and Saalfeld (1989*a*) detail the results of similar surveys of the region north of Cape Bedford.

Methods

Transects ran east–west (except near Hinchinbrook I. where the mountains made this dangerous), and usually extended 21·6 km from the coast and/or inshore islands. (The latter is the distance flown in 7 min at 185 km h^{-1} [100 kn].) Between Dunk I. and Cape Bedford, where the continental shelf runs closer to the coast, most transects were flown to the outer barrier reefs.

The Mackay–Capricorn Section of the GBRMP (a coastal zone area of 16 090 km^2) was surveyed between 18 and 25 November 1986 at an overall sampling intensity of 10·0%; the Central Section (11 778 km^2) between 29 September and 21 October 1987 at a sampling intensity of 11·8%; and the Cairns Section south of Cape Bedford (11 528 km^2) between 12 and 16 October 1987 at a sampling intensity of 8·7%. In addition, the northern half of the Central Section between Cape Cleveland and Dunk I. (5480 km^2) was surveyed with the same design between 22 and 24 September 1986 at an overall sampling intensity of 10·9%. The overall sampling intensity for the entire region surveyed was 10·4%. Inshore areas in the region which have been excluded from the GBRMP were also surveyed.

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As in the other surveys (Marsh and Saalfeld 1989*a*), the transect lines were usually spaced at intervals of 5′ latitude except in areas of known seagrass beds where the sampling intensity was increased (Figs 1–6). For estimation of regional densities of dugongs, the survey areas were divided into blocks (Figs 1–6).

All surveys were held during periods of neap tides to minimize water turbidity. Daily schedules were arranged to avoid severe glare associated with a low or mid-day sun. Repeatability was also increased by surveying only when weather conditions were consistently good; the conditions encountered are summarised in Table 1.

Table 1. Weather conditions encountered on each survey

Glare measured on the worse side of the aircraft; 0, none; 1, <25% of field of view affected; 2, 25≤50%; 3, >50%

Blocks	Wind speed (km^{-1})	Cloud cover (oktas)	Cloud minimum height (m)	Beaufort sea state (mode and range)	Glare (mode and range)	Visibility (km)
			Northern Central Section, September 1986			
8–11	≤20	0–2	300	1·0 (0·0–3·0)	1·0–2·0 (0·0–3·0)	10–20
			Central Section, September–October 1987			
1–7, 8–11	0–<10	0–2	450	1·0 (0·0–3·0)	1·0–2·0 (0·0–3·0)	>20
			Mackay–Capricorn Section, November 1986			
1–8	0–20	0–4	600	1·0 (0·0–3·0)	1·0–2·0 (0·0–2·0)	>20
			Cairns Section, October 1987			
	5–15	0–4	450	1·0 (0·0–3·0)	0·0–1·0 (0·0–2·0)	<20

Survey methodology, data handling and analysis techniques were similar to those used in previous surveys, as outlined by Marsh and Saalfeld (1989*a*, 1989*b*) and Marsh and Sinclair (1989*a*, 1989*b*). The artificial wing strut on either side of the aircraft was marked in three colours between the transect markers so that each transect was effectively divided horizontally into three portions of equal width. Each sighting was recorded as being made in the upper, middle or bottom third of the transect. This arrangement not only made it easier to determine whether simultaneous sightings by members of a tandem team were of different groups of dugongs, but allowed us to test whether there were differences in the sighting rate across the width of the transect.

Correction factors (Table 2) for perception bias (groups of dugongs visible in the transect that were missed by observers) and availability bias (groups of dugongs that were unavailable to observers because of water turbidity), and their associated coefficients to variation were calculated as outlined in Marsh and Sinclair (1989*a*). The population and density estimates and the distribution maps were based on corrected densities. The standard errors of the population and density estimates were adjusted to incorporate the errors associated with the appropriate estimates of the perception and availability correction factors and the mean group size (as outlined in Marsh and Sinclair 1989*a*).

The significance of the difference in density between the 1986 and 1987 surveys of the northern part of the Central Section was tested by means of a two-factor randomised block design with transect as the blocking factor. The analysis was carried out with and without measures of cloud cover (oktas) and/or sea state (Beaufort scale) as covariates. Input data for the analysis were corrected densities per square kilometre based on mean group sizes and the estimates of the correction factors for perception and availability bias, each transect contributing one density per survey based on the combined corrected counts of both tandem teams. The densities were log transformed for analysis to equalise the error variances.

Results and Discussion

Effective Transect Width

There were no significant differences in the proportion of dugongs sighted in the upper middle and bottom thirds of the transect for any survey (χ^2 goodness of fit: $\chi^2=0{\cdot}341$, $n=41$, 2 d.f., $P=0{\cdot}843$, 1986 northern Central Section survey; $\chi^2=1{\cdot}077$, $n=39$, 2 d.f., $P=0{\cdot}586$, 1987 Central Section survey; $\chi^2=5{\cdot}831$, $n=59$, 2 d.f., $P=0{\cdot}0542$, 1986 Mackay–

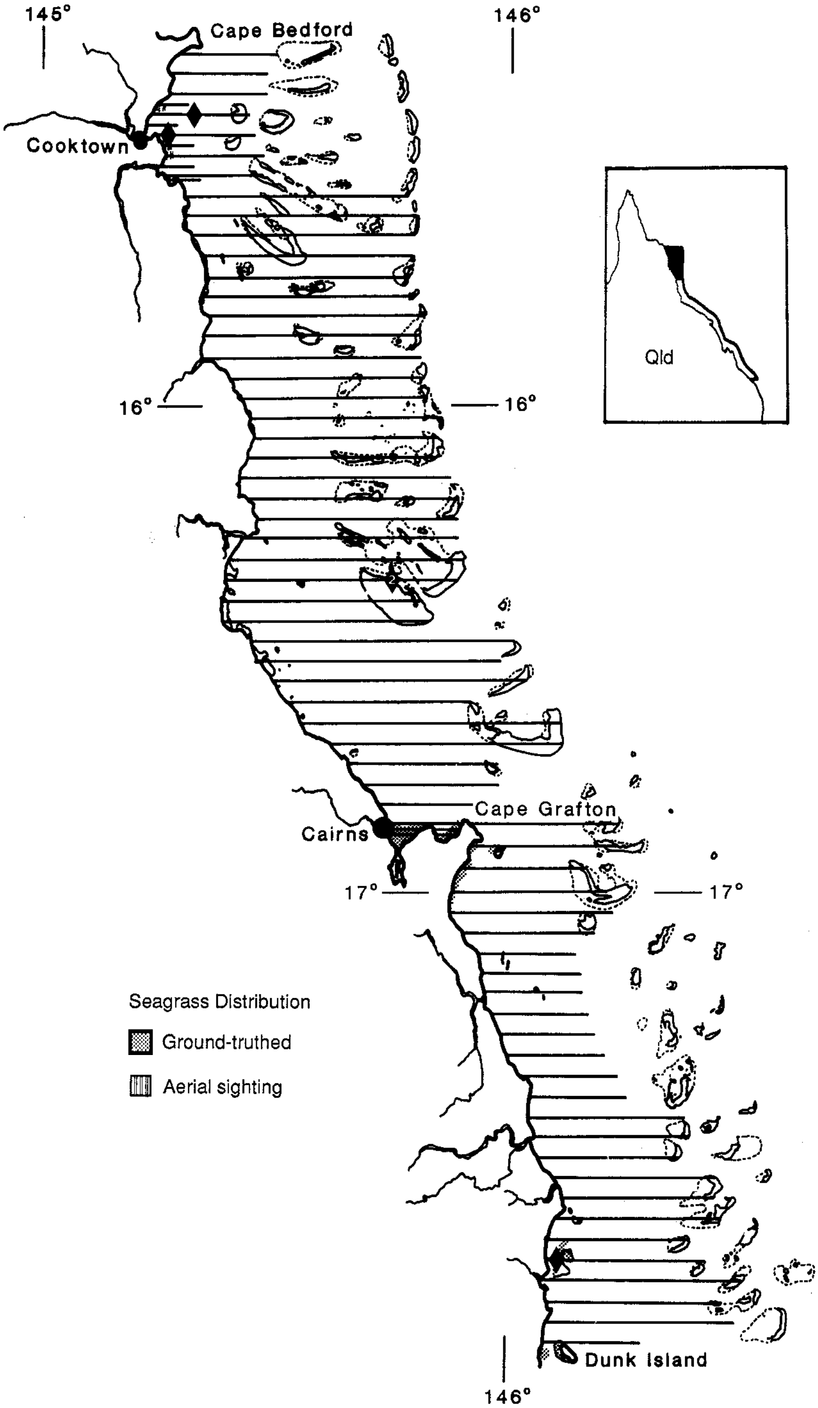

Fig. 1. Survey area from Cape Bedford to Dunk I., showing the transect lines for the October 1987 survey. Dugong sightings (◆) made during the survey are shown, as the sighting rate for this survey was too low to allow the determination of dugong density in the survey area. The distribution of inshore seagrass beds is also shown. The ground-truthed seagrass data are from Coles *et al.* (1987*b*). Inset, locality map.

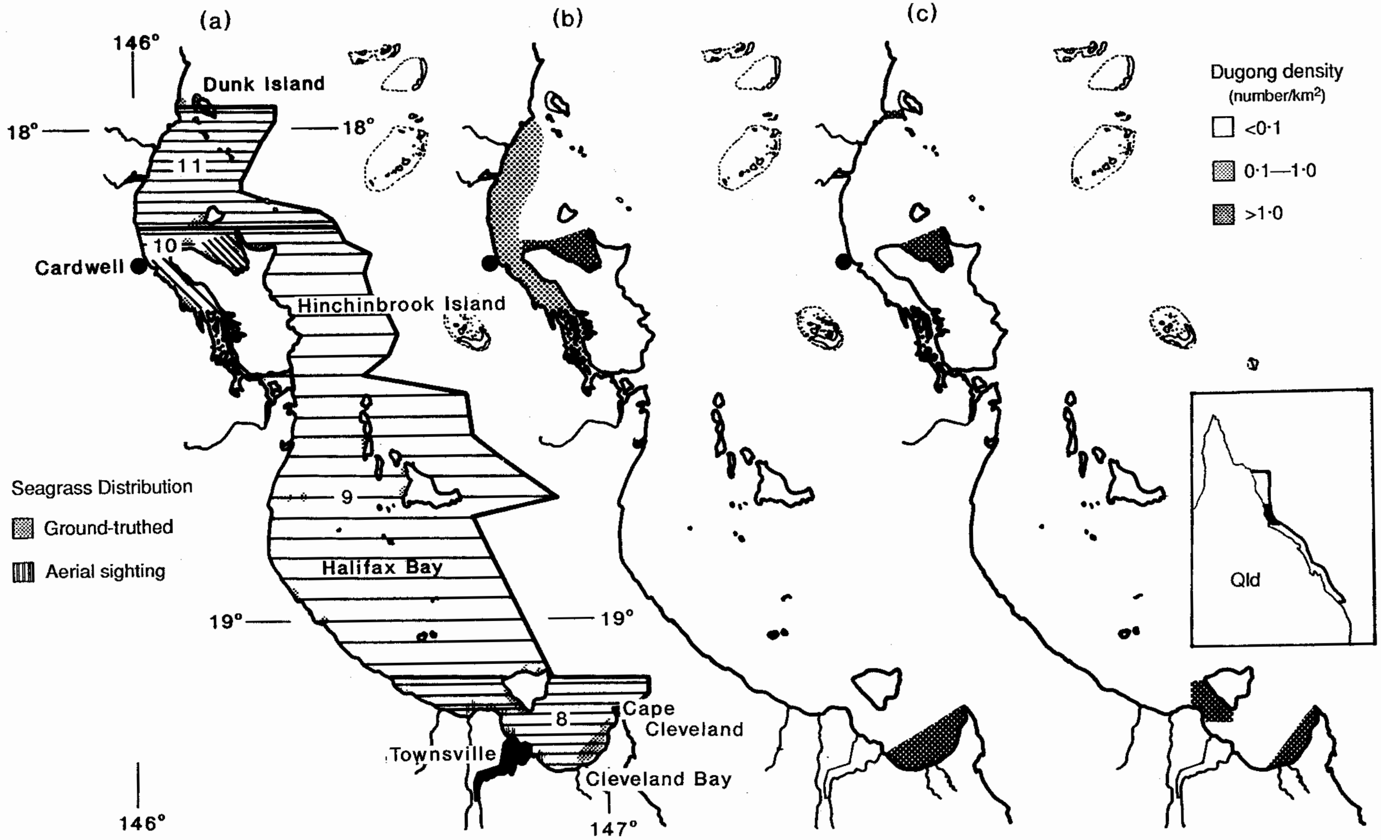

Fig. 2. Survey area from Dunk I. to Cape Cleveland (northern Central Section) showing: (*a*) transect lines for the September 1986 and October 1987 surveys and the distribution of inshore seagrass beds (ground-truthed seagrass data from Coles *et al.* 1987*b*); (*b*) dugong density distribution in September 1986; (*c*) dugong density distribution in October 1987.

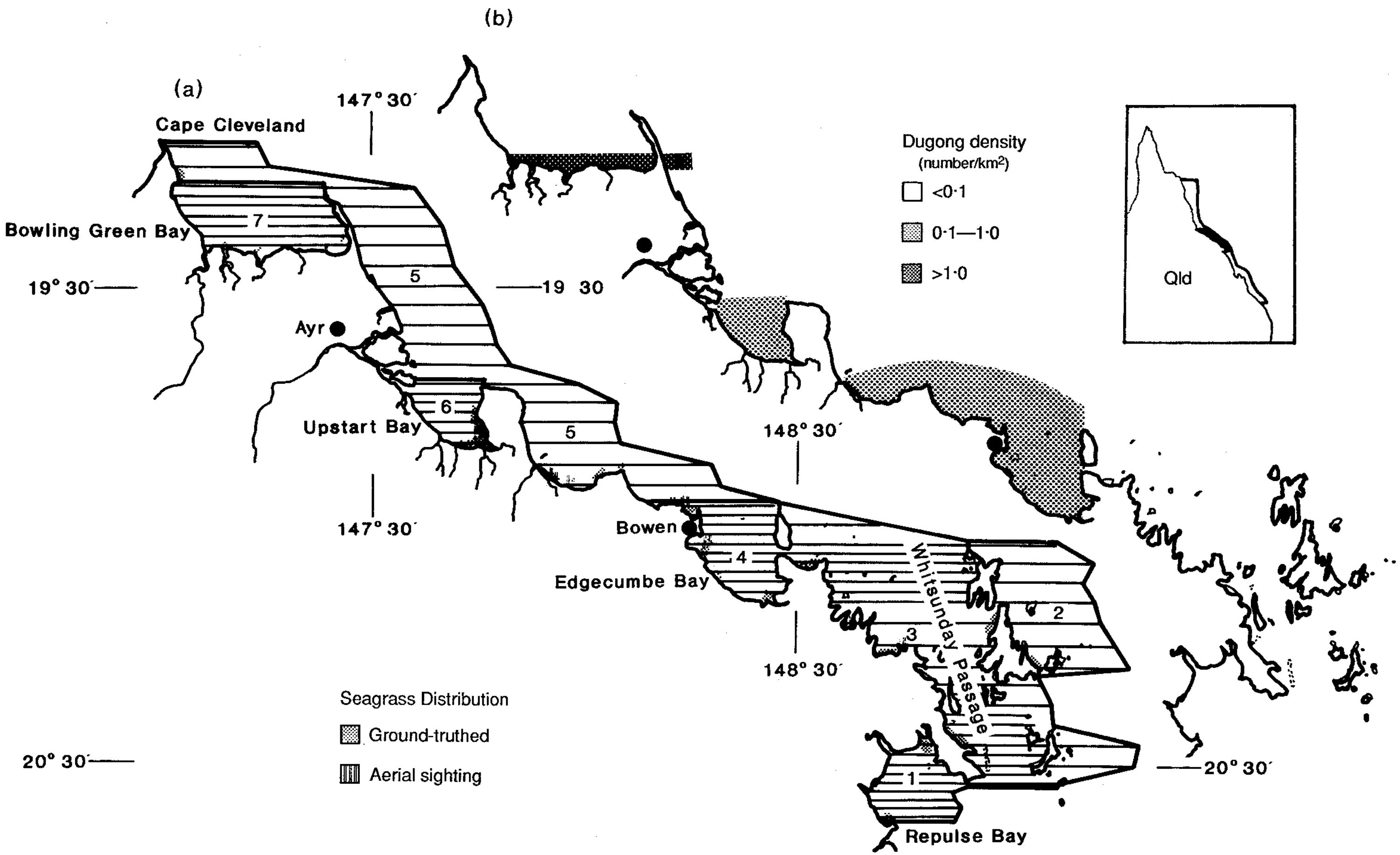

Fig. 3. Survey area from Cape Cleveland to Repulse Bay (southern Central Section) showing: (*a*) transect lines for the September–October 1987 survey and the distribution of inshore seagrass beds (ground-truthed seagrass data from Coles *et al.* 1987*b*); (*b*) dugong density distribution in September–October 1987.

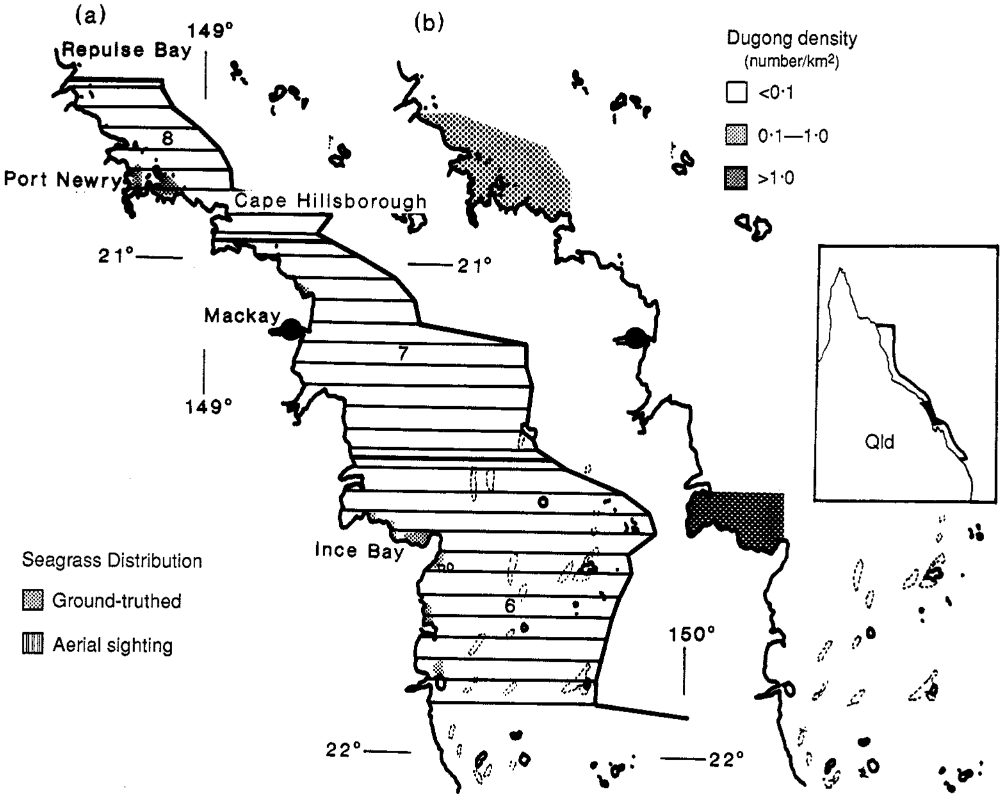

Fig. 4. Surveys area from Repulse Bay to Clairview (northern Mackay–Capricorn Section) showing: (*a*) transect lines for the November 1986 survey and the distribution of inshore seagrass beds (ground-truthed seagrass data from Coles *et al.* 1987*b*); (*b*) dugong density distribution in November 1986.

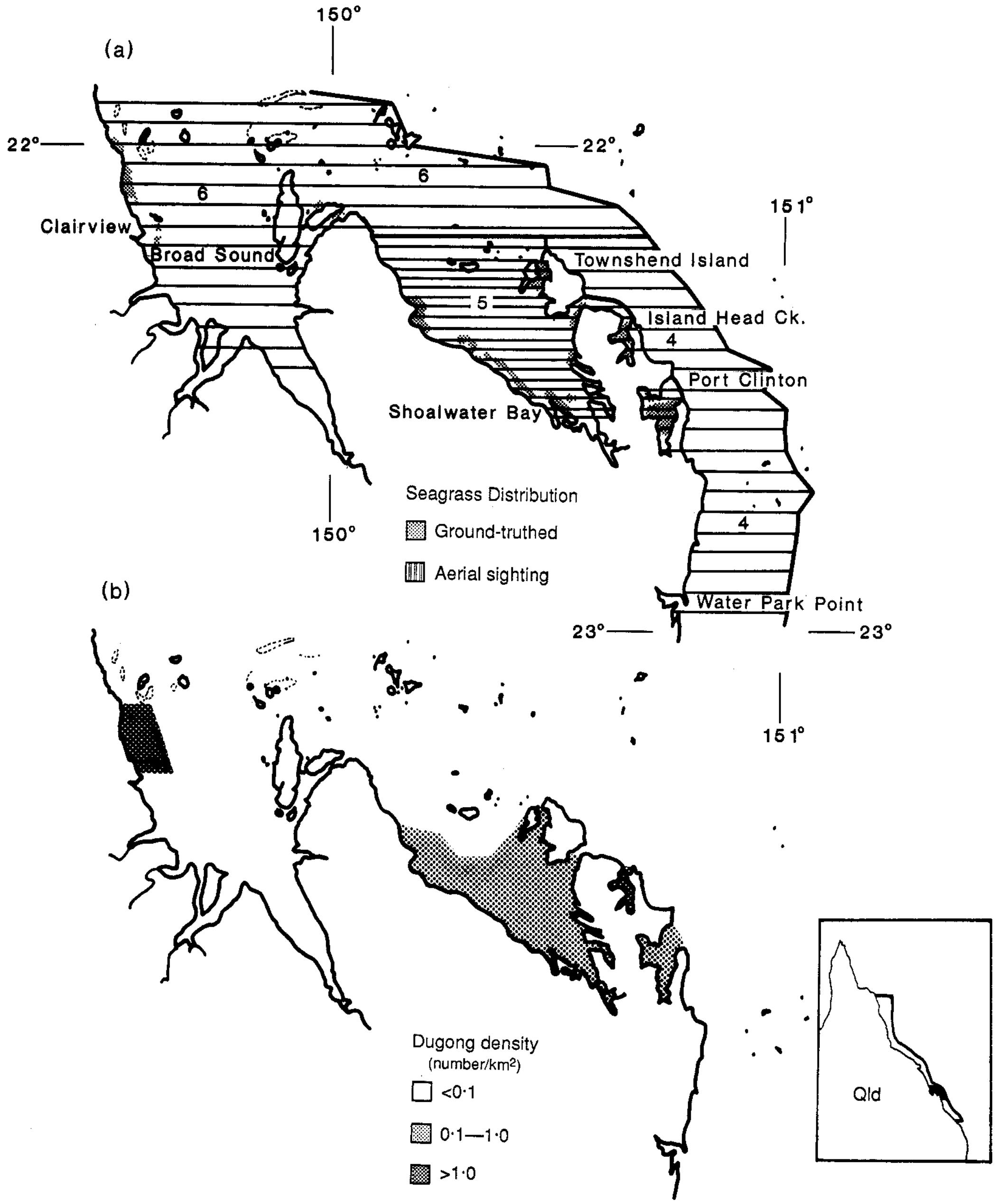

Fig. 5. Survey area from Clairview to Water Park Point (central Mackay–Capricorn Section) showing: (*a*) transect lines for the November 1986 survey and the distribution of inshore seagrass beds (ground-truthed seagrass data from Coles *et al.* 1987*b*); (*b*) dugong density distribution in November 1986.

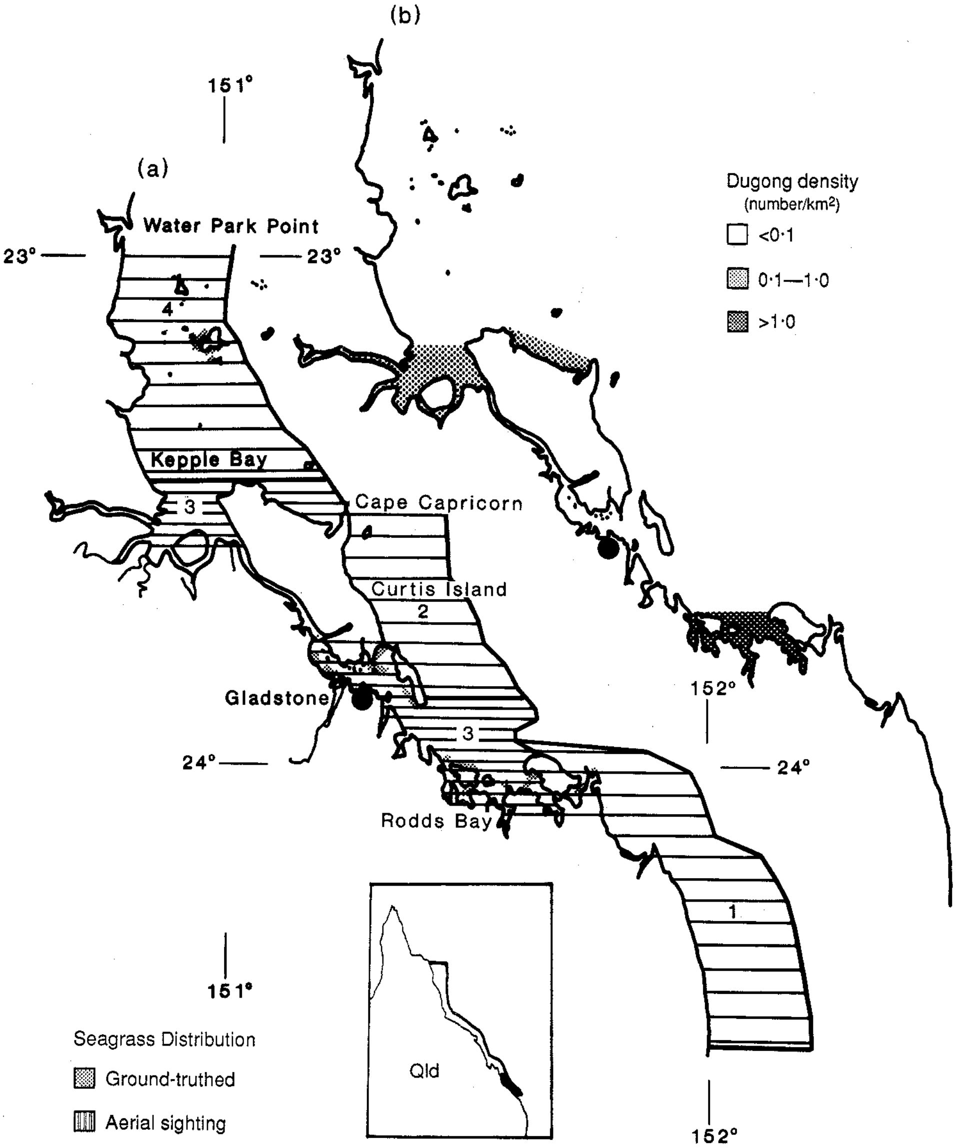

Fig. 6. Survey area from Water Park Point to Rodds Bay (southern Mackay–Capricorn Section) showing: (*a*) transect lines for the November 1986 survey and the distribution of inshore seagrass beds (ground-truthed seagrass data from Coles, unpublished); (*b*) dugong density distribution in November 1986.

Table 2. Details of group size estimates and correction factors used in the population estimates

Values in parentheses are coefficients of variation. Blocks indicated by bold type

Blocks: lines	Group size mean	Number of observers Port	Number of observers Stbd	Perception correction factor estimate Port	Perception correction factor estimate Stbd	Availability correction factor estimate
	Northern Central Section, Sept. 1986					
9: 16, 31–38; **10:** 38; **11**	1·2857 (0·1038)	1[A]	2	1·7273 (0·0651)	1·1020 (0·0575)	3·0000 (0·1701)
8; **9:** 11–15, 17–30; **10:** 51–58, 61, 64	1·2857 (0·1038)	2	2	1·1745 (0·0651)	1·1020 (0·0575)	3·0000 (0·1701)
	Central Section, Sept.–Oct. 1987					
All blocks and lines	1·6667 (0·1336)	2	2	1·0556 (0·0092)	1·0549 (0·0079)	3·5143 (0·1433)
	Mackay–Capricorn Section, Nov. 1986					
5: 64–74; **6:** 89	1·3559 (0·1274)	2	1[B]	1·0862 (0·0316)	1·2778 (0·0183)	3·0750 (0·1494)
1–4; **5:** 50–63, 75, 138–144; **6:** 76, 81–8, 90–106; **7**; **8**	1·3559 (0·1274)	2	2	1·0862 (0·0316)	1·0496 (0·0183)	3·0750 (0·1494)

[A] Training transects for port mid-seat observer. Port correction factor based on correction factor of the port rear-seat observer for the remainder of this survey.

[B] Training transects for starboard mid-seat observer. Starboard correction factor based on correction factor of the starboard rear-seat observer for the remainder of this survey.

Capricorn Section survey), indicating that the transect width is sufficiently narrow for there to be no decrease in sightability for groups further from the aircraft. In the Mackay-Capricorn Section, where the probability of there being a difference approached significance at the 0·05 level, the proportion of animals sighted was lowest in the middle of the transect (19%) suggesting that any variation was caused by the observers having difficulty deciding in which third of the transect each group was sighted, rather than by any reduction in sightability *per se.*

Group Size and Composition

Only six dugongs, including one cow–calf pair, were sighted in the Cairns Section between Dunk I. and Cape Bedford. The size and composition of the groups sighted on the other surveys are summarised in Fig. 7 and Table 2. The largest group sighted was 10 in the Port Newry area. Of all animals sighted, 62% were single dugongs or cow–calf pairs. The proportion of calves was 14·8% in the northern Central Section survey in September 1986; 13·4% in the Central Section survey in 1987; 7·7% in the Mackay–Capricorn Section survey in 1987. Differences between surveys were not significant ($\chi^2 = 2{\cdot}071$, 2 d.f., $P = 0{\cdot}3551$). The proportions of calves sighted in these surveys are not significantly different ($\chi^2 = 5{\cdot}058$, 9 d.f., $P = 0{\cdot}8292$) from those recorded during similar surveys of the northern Great Barrier Reef (Marsh and Saalfeld 1989*b*), and Torres Strait (Marsh and Saalfeld 1988). Two very small calves, probably newborn, were sighted separately in Shoalwater Bay on 18 November. This is consistent with other information on the timing of calving on the east coast of tropical Queensland (Marsh *et al.* 1984).

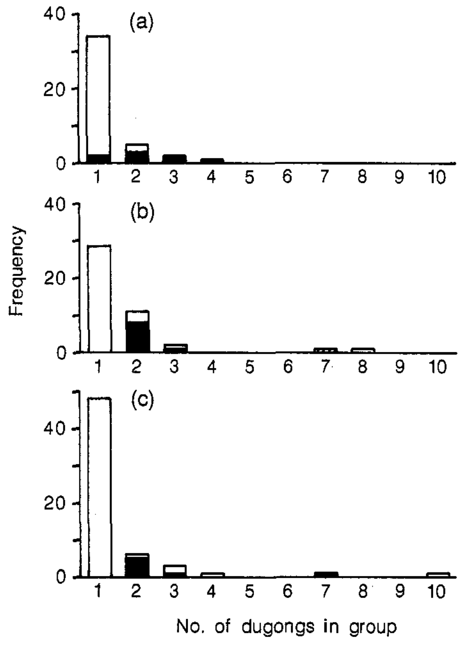

Fig. 7. Frequency histograms showing details of dugong group size and composition for: (*a*) the northern Central Section in September 1986; (*b*) the Central Section in September–October 1987; (*c*) the Mackay–Capricorn Section in November 1986. Open bars, no calves; solid bars, one calf per group; hatched, two calves per group.

Population and Density Estimates

The values of the mean group sizes and correction factors used in obtaining these estimates are summarised in Table 2. The raw data and positions of actual sightings have been listed in Marsh (1989). Table 3 gives estimates of the density and numbers of dugongs per block on the various surveys, together with the standard errors of these estimates. We consider that these are likely to be underestimates, because the standard used to correct for the number of dugongs which were not available to observers due to water turbidity is likely to be conservative (see Marsh and Sinclair 1989*a*).

Table 3. Estimated densities and numbers of dugongs for the surveys

Values are ±standard error incorporating the errors resulting from sampling and in estimating mean group size and correction factors

Section and subsection	Date	Block No.	Density per km²	Numbers
Central				
Northern half	Sept. 1986	8	0·61±0·19	375±118
		9	0·04±0·02	158±68
		10	1·10±0·24	340±74
		11	0·21±0·10	151±70
Total			0·19±0·03	1024±170
Precision				0·17
Northern half	Oct. 1987	8	0·59±0·15	360±92
		9	0	0
		10	0·59±0·35	184±110
		11	0·14±0·10	100±71
Total			0·12±0·03	644±160
Precision				0·25
Southern half	Sept.-Oct. 1987	1	0·10±0·12	31±35
		2	0·10±0·11	65±69
		3	0	0
		4	0·39±0·17	173±77
		5	0·14±0·05	312±122
		6	0·79±0·40	171±87
		7	0·24±0·21	136±120
Total			0·14±0·04	888±221
Precision				0·25
Total Central	Sept.-Oct. 1987	All	0·13±0·02	1532±273
Precision				0·18
Mackay-Capricorn	Nov. 1986	1	0·03±0·03	48±46
		2	0	0
		3	0·29±0·09	301±95
		4	0·02±0·01	51±48
		5	0·69±0·15	765±161
		6	0·09±0·05	542±293
		7	0	0
		8	0·31±0·13	240±104
Total			0·12±0·02	1947±369
Precision				0·19

(i) *Cairns Section*

Too few dugongs (Fig. 1) were sighted for the dugong population of this area to be estimated. This is not surprising, because the total area of inshore seagrass in this Section was subsequently estimated to be only about 34 km² (Fig. 1; R. G. Coles *et al.* 1987*b*; unpublished data). All but two animals were sighted close to inshore seagrass beds (Fig. 1). A cow-calf pair was seen at Bat Reef, 40 km from the mainland.

(ii) *Central Section*

There is an estimated 358 km² of inshore seagrass in the Central Section (Figs 2*a*, 3*a*; R. G. Coles *et al.* 1987*b*; unpublished data). The dugong population (±s.e.) of the whole region in September–October 1987 was estimated to be 1532±273 at an overall density of 0·13±0·02 per square kilometre surveyed, a precision of 18% (Table 3).

The results of the analysis of variance used to investigate the differences between the surveys of the northern half of the Central Section carried out in 1986 and 1987 (Table 4) indicated that there was no significant difference between observed densities between years ($P=0{\cdot}177$), even though the estimated population was 1024±170 in 1986 and 644±160 in 1987. This failure to detect a significant difference between years is not surprising. A power analysis along the lines outlined by Gerrodette (1987) indicates that, at the comparatively low level of precision obtained, the population estimates obtained by the two surveys would have to differ by about 70% for a difference significant at the 5% level to be detected. The addition of Beaufort sea state and/or cloud cover for each transect as covariates made little difference to the probability of a significant difference in density between surveys (Table 4).

Table 4. Summary of the analysis of variance comparing dugong density in the northern Central Section in September 1986 and October 1987 using a randomised block design with transect line as the blocking factor

Analysis performed with and without Beaufort sea state and cloud cover as covariates

Covariate	Factors			
	Lines (39 d.f.)		Years (1 d.f.)	
	F	*P*	*F*	*P*
None	0·39210	0·987	1·93470	0·177
Beaufort sea state	0·40860	0·983	2·14330	0·157
Cloud cover	0·36777	0·991	1·68580	0·207
Beaufort sea state+cloud cover	0·37668	0·989	2·00706	0·171

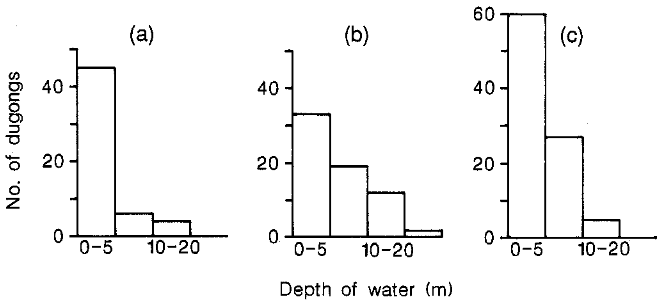

Fig. 8. Frequency histograms showing the depths of water in which dugongs were sighted in: (*a*) the northern Central Section in September 1986; (*b*) the Central Section in September–October 1987; (*c*) the Mackay–Capricorn Section in November 1986. These depths were obtained from marine charts and have not been corrected for tidal levels at the times of the surveys.

Figs 2*b*, 2*c* and 3*b* contain smoothed density distribution maps based on the results of the surveys. More detailed maps are provided in Marsh (1989). Of all animals seen, 79% were close to inshore seagrass beds, 64% in depths of 5 m or less (Fig. 8).

(iii) *Mackay–Capricorn Section*

R. G. Coles *et al.* (1987*b*; unpublished data; see Figs 4*a*, 5*a*, 6*a*) estimate that there are 220 km^2 of seagrass in the inshore waters of this Section. The dugong population estimates sum to 1947±369 for the region surveyed in November 1986.

Figs 4*b*, 5*b* and 6*b* contain smoothed density distribution maps based on the results of this survey. Of all sightings, 85% were in the vicinity of known seagrass beds; 67% of animals were sighted in depths of 5 m or less.

Evaluation of the Areas Surveyed

The estimated dugong population (±s.e.) of the inshore waters of the Great Barrier Reef region south of Cape Bedford, an area of 39 396 km^2, is 3479±459 at an overall density of 0·088±0·012 km^{-2}. This is substantially less than the population (8110±1073 at an overall density of 0·26±0·03 km^{-2}) in the northern reef waters between Cape Bedford and Hunter Point (11°30′S.,142°50′E.), an area of 31 288 km^2 (Marsh and Saalfeld 1989*a*). The difference is probably attributable to the availability of seagrass: approximately 2300 km^2 in the inshore waters of the Great Barrier Reef between Cape Bedford and Hunter Point, as against 610 km^2 in the inshore southern region (R. G. Coles *et al.* 1985, 1987*a*, 1987*b*; Lee Long *et al.* 1990). The estimate of the seagrass available to dugongs in the northern Great Barrier Reef does not include the large areas on the northern reefs, especially those in the Princess Charlotte Bay area (Hopley 1982) which support a significant proportion of the dugongs in this region (Marsh and Saalfeld 1989*a*). In contrast, anecdotal evidence and the results of a previous survey of the reefs in the Whitsunday area (Marsh 1986) suggest that dugongs are rarely sighted on reefs in the southern Great Barrier Reef region, which tend to be a greater distance from the coast than those further north. We do, however, have records of sightings of single dugongs at Lady Elliott I. (24°07′S.,152°43′E.; 80 km from the coast) in July 1985, and at North-West I. (23°18′S.,151°42′E.; 55 km from the coast) in 1988.

Very significant numbers of dugongs are present in the sheltered bays of the Central and Mackay–Capricorn Sections of the GBRMP (Figs 2–5). Of particular interest is the high density in eastern Cleveland Bay, in view of the proximity of this area to the Townsville–Magnetic I. beaches, where significant numbers of dugongs have been killed in shark and mackerel gill-nets since 1968 (Marsh 1988).

Future Surveys

Despite a relatively high sampling fraction of about 10%, the coefficients of variation for the population estimates of the Central and Mackay–Capricorn Sections were high (18% and 19% respectively). The precision was improved (13%) when both Sections were considered together. In future, we suggest that both Sections should be surveyed in a single season in order to increase the precision, and hence the capacity of the surveys to detect long-term trends. On the basis of a power analysis using the precision of the surveys carried out to date and the estimated rate of change of an unharvested dugong population, Marsh and Saalfeld (1989*a*) recommended that the northern half of the Great Barrier Reef region be surveyed every 5 years, in order to monitor trends in dugong numbers. We suggest that this pattern should also be followed in the inshore waters of the Central and Mackay–Capricorn Sections of the GBRMP. In view of the small area of seagrass in the Cairns Section south of Cape Bedford, it is doubtful whether an aerial survey of this area along the lines illustrated in Fig. 1 can be justified for dugongs *per se*. However, such a survey may nonetheless prove cost-effective in view of the concomitant information obtained on sea turtles (Marsh and Saalfeld 1989*b*) and cetaceans.

Acknowledgments

We thank the Great Barrier Reef Marine Park Authority for funding this research; the observers: B. Barker-Hudson, D. Devine, N. Hedgecock, R. Hughes, A. Smith and P. Slaughter; the pilots: G. Jacklin, W. Liddell, A. Serenc and R. Videtta; the Queensland National Parks and Wildlife Service for logistical support; Dr R. G. Coles for access to his seagrass data; Headquarters First Military District Support Unit Rockhampton for permission to survey in the Military Training Area in Shoalwater Bay, and Peter Spencer for assistance with data processing.

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Manuscript received 11 July 1989; accepted 11 May 1990