Dr H Marsh

Zoology Department

James Cook University

TOWNSVILLE QLD 4811

The distribution and abundance of dugongs in the southern Great Barrier Reef Marine Park

H Marsh and W K Saalfeld

Zoology Department, James Cook University of North Queensland, Townsville, Qld 4811

Running Head: Dugong aerial surveys

Key words: Dugongs, aerial survey, Great Barrier Reef Marine Park.

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 standardized them for availability bias (the proportion of animals that are invisible due to water turbidity) with survey-specific correction factors. The resultant population estimate was 3,479 $\pm$ S.E. 459 dugongs at an overall density of 0.088 $\pm$ S.E. 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 5m deep. Maps of density and distribution are given, and recommendations made on the timing of future surveys.

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 conducted a series of aerial surveys in the inshore waters of the entire Great Barrier Reef region south of Cape Bedford (15°14'S., 145°21'E.) in 1986 and 1987. The results of these surveys are presented in this paper. Marsh and Saalfeld (1988 and manuscript) present the results of similar surveys of the region north of Cape Bedford including Torres Strait.

Methods

All surveys were limited to the inshore waters. Transects ran east-west (except near Hinchinbrook Island area where the mountains made this dangerous), and usually extended 21.6 km from the coast and/or offshore islands. (The latter is the distance flown in seven minutes at 185 km h^{-1} [100 kn.]). Between Dunk Island 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 was surveyed between October 18 and 25 1986; the Central Section between September 29 and October 21 1987; and the Cairns Section south of Cape Bedford between October 12 and 16 1987. In addition, the northern half of the Central Section between Cape Cleveland and Dunk Island was surveyed using the same design between September 22 and 24 1986. Inshore areas in the region which have been excluded from the GBRMP were also surveyed.

As in the other surveys (Marsh and Saalfeld, 1988, and manuscript), the transect lines were usually spaced at intervals of 5° latitude except in areas of known seagrass beds where the sampling intensity was increased (Figures 1-5). For estimation of

regional densities of dugongs, the survey areas were divided into blocks (Figures 1-5). The area and sampling intensity of each block is summarized in Table 1. The overall sampling intensity was 10.2%.

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 good; the conditions encountered are summarized in Table 2.

Survey methodology, data handling and analysis techniques were similar to those used in previous surveys as outlined by Marsh and Saalfeld (1988 and manuscript) and Marsh and Sinclair (manuscripts a and b).

Correction factors 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 of variation were calculated as outlined in Marsh and Sinclair (manuscript 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, manuscript a).

The significance of the difference in density between surveys for the northern part of the Central Section, which was surveyed in both 1986 and 1987, was tested using a two factor randomized 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 equalize 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 either survey (X^2 Goodness of Fit: X^2=0.341, n=41, 2 d.f., p=0.843, 1986 northern Central Section Survey; X^2=1.077, n=39, 2 d.f., p=0.586, 1987 Central Section Survey; X^2=5.831, n=59, 2 d.f., p=0.0542 1986 Mackay/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 Island and Cape Bedford. The size and composition of the groups sighted on the other surveys are

summarized in Figure 6 and Table 3. The largest group sighted was 10 in the Port Newry area (Figure 4b). Sixty-two percent of animals sighted 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 (X^2=2.071; d.f.=2; p= 0.3551). The proportions of calves sighted in these surveys of the southern Great Barrier Reef Region are not significantly different (X^2=5.058; d.f.=9; p= 0.8292) from those recorded during similar surveys of the northern Great Barrier Reef (Marsh and Saalfeld, manuscript), and Torres Strait (Marsh and Saalfeld, 1988). Two very small calves, probably newborn, were sighted separately in Shoalwater Bay (Figure 5b) on November 18. This is consistent with the other information on the timing of calving on the east coast of tropical Queensland (Marsh *et al.*, 1984).

Population and Density Estimates

The values of the mean group sizes and correction factors used in obtaining these estimates are summarized in Table 3. The raw data and positions of actual sightings have been listed in Marsh (1989). Table 4 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, manuscript a).

a) Cairns Section

Too few dugongs (Figure 1a) were sighted to estimate the dugong population for this area. This is not surprising as the total area of inshore seagrass in this section has been subsequently estimated to be only about 34 km^2 (Figure 1b; R G Coles, unpublished data). All but two animals were sighted close to inshore seagrass beds (Figure 1). A cow calf pair was seen at Bat Reef, 40 km from the mainland.

b) Central Section

There is an estimated 358 km^2 of inshore seagrass in the Central Section (Figures 2d and 3c, R G Coles, unpublished data). The dugong population of the whole region in November 1987 was estimated to be 1532 $\pm$ 273 dugongs at an overall density of 0.13 $\pm$ S.E. 0.02 dugongs per km^2 surveyed, a precision of 18% (Table 4).

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 5) indicated that there was no significant difference between observed densities between years ($p=0.177$), even though the population estimate was (1024 $\pm$ S.E. 170 in 1986, 644 $\pm$ S.E. 160 in 1987). The addition of Beaufort sea state and/or cloud cover for each transect as covariates made little difference to the probability their being a significant difference in density between surveys (Table 5).

Figures 2b,c and 3b contain smoothed density distribution maps based on the results of the surveys. More detailed maps are provided in Marsh (1989). Seventy-nine percent of animals were seen close to inshore seagrass beds, 64% in depths of 5m or less (Figure 7).

c) Mackay/Capricorn Section

R G Coles (unpublished see Figures 4c and 5c) estimates that there are 186 km^2 of inshore seagrass in the inshore waters of this section, north of Water Park Point. The dugong population estimates sum to 1947 ± S.E. 369 for the region surveyed in November 1986.

Figures 4b and 5b contain smoothed density distribution maps based on the results of this survey. Seventy-seven percent of sightings from Port Clinton north were in the vicinity of known seagrass beds; 67% of animals were sighted in depths of 5m or less.

Evaluation of the areas surveyed

The estimated dugong population of the inshore waters of the Great Barrier Reef region south of Cape Bedford, an area of 39,396 km^2 is 3,479 ± S.E. 459 dugongs at an overall density of 0.088 ± S.E. 0.012 km^{-2}. This is substantially less than the dugong population (8110 ± S.E. 1073 at an overall density of 0.26 ± S.E.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, manuscript)· The difference is probably attributable to the availability of seagrass: approximately 860 km^2 in the inshore waters of the Great Barrier Reef between Cape Bedford and Hunter Point as against 580 km^2 in the inshore southern region (R G Coles, unpublished data). 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 the northern Great Barrier Reef region (Marsh and Saalfeld, manuscript). 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 Island (24°07'S, 152o43'E; 80 km from the coast) in July, 1985, and at North-West Island (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 (Figures 2 to 5). Of particular interest is the high density in eastern Cleveland Bay, in view of the proximity of this area to the Townsville/Magnetic Island beaches where there have been significant numbers of dugongs killed in shark and mackerel gill-nets since 1968 (Marsh, in press).

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 Section were high (18 % and 19% respectively). In contrast, the precision was much better (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 a harvested dugong population, Marsh and Saalfeld (manuscript) recommended that the northern half of the Great Barrier Reef region be surveyed every five 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 Figure 1 can be justified for dugongs *per se*. However, such a survey may prove cost-effective in view of the concomitant information obtained on sea turtles (Marsh and Saalfeld, in press) and cetaceans.

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Marsh, H., and Sinclair, D.F., manuscript b. An experimental evaluation of dugong and sea turtle aerial survey techniques. Submitted to *Aust. Wildl. Res.*

LEGEND TO FIGURES

Fig. 1a Cairns survey area, showing the transect lines for the October 1987 survey. Dugong sightings (♦) made during the survey are also shown as the sighting rate for this survey was too low to allow the determination of dugong density in the survey area.

Fig. 1b The distribution and density of inshore seagrass beds in the Cairns Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript).

Fig. 2a Northern Central Section survey area, showing the survey blocks (8-11) and transect lines for the September 1986 and October 1987 surveys.

Fig. 2b The distribution of dugong density in the northern Central Section survey area in September 1986.

♦ = individual sightings.

Fig. 2c The distribution of dugong density in the northern Central Section survey area in September - October 1987.

Fig. 2d The distribution and density of inshore seagrass beds in the northern Central Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript).

Fig. 3a Southern Central Section survey area, showing the survey blocks (1-7) and transect lines for the September - October 1987 survey. The uneven sampling intensity in Block 3 was the result of logistical problems; no dugongs were seen in this block.

Fig. 3b The distribution of dugong density in the southern Central Section survey area in September - October 1987.

Fig. 3c The distribution and density of inshore seagrass beds in the southern Central Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript) for the area north of Bowen and Coles *et al.*, (1987) for the area south of Bowen.

Fig. 4a Northern Mackay/Capricorn Section survey area, showing the survey blocks (6-8) and transect lines for the September 1986 survey.

Fig. 4b The distribution of dugong density in the northern Mackay/Capricorn Section survey area in September 1986.

Fig. 4c The distribution and density of inshore seagrass beds in the northern Mackay/Capricorn Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (1987).

Fig. 5a Southern Mackay/Capricorn Section survey area, showing the survey blocks (1-5) and transect lines for the September 1986 survey.

Fig. 5b The distribution of dugong density in the southern Mackay/Capricorn Section survey area in September 1986.

Fig. 5c The distribution and density of inshore seagrass beds in the southern Mackay/Capricorn Section survey area north of Water Park Point. The ground-truthed seagrass data are from Coles *et al.*, (1987).

Fig. 6 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 and (c) the Mackay/Capricorn Section in September 1986.

Fig. 7 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 and (c) the Mackay/Capricorn Section in September 1986. These depths were obtained from marine charts and have not been corrected for tidal levels at the times of the surveys.

TABLE 1: Areas of survey blocks and sampling intensities.

(a) Northern Central Section

Block	Area (km^2)	Sampling %	
		Sept. 1986	Oct. 1987
8	611.8	16.6	17.2[a]
9	3845.3	8.4	8.5[a]
10	309.6	18.3	20.1[a]
11	713.6	16.1	18.5[a]
	5480.2	10.9	11.4[a]

[a] differences in sampling fraction between surveys due to differences in the actual height at which transects flown on each survey.

(b) Southern Central Section, September - October, 1987

Block	Area (km^2)	Sampling %
1	297.0	20.0
2	644.0	9.6
3	1901.0	13.1
4	448.0	17.8
5	2230.0	7.9
6	218.0	18.1
7	560.0	18.2
	6298.0	12.2

TABLE 1: continued.

(c) Mackay/Capricorn Section, November, 1986

Block	Area (km^2)	Sampling %
1	1391.0	9.0
2	895.0	9.1
3	1022.0	16.2
4	3274.0	8.5
5	1105.0	17.9
6	6016.0	9.0
7	1612.0	8.8
8	775.0	9.3
	16090.0	10.0

(d) Cairns Section, October 1987

Block	Area (km^2)	Sampling %
All lines	11528.0	8.7

TABLE 2: Weather conditions encountered on each survey.

Survey	Blocks	Wind Speed (km/hr)	Cloud Cover (oktas)	Cloud Minimum height (m)	Beaufort Sea State mode (range)	Glare[a,b] mode (range)	Visibility (km)
(a) Northern Central Section, September 1986							
	1-4	≤20	0-2	300	1.0(0.0-3.0)	1.0-2.0(0.0-3.0)	10-20
(b) Central Section, September - October 1987							
	1-11	0-<10	0-2	450	1.0(0.0-3.0)	1.0-2.0(0.0-3.0)	>20
(c) 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
(d) Cairns Section, October 1987							
		5-15	0-4	450	1.0(0.0-3.0)	0.0-1.0(0.0-2.0)	<20

[a] worse side of aircraft

[b] Scale: 0 = none, 1 = < 25% of field of view affected by glare, 2 = 25 ≤ 50%, 3 = > 50%

TABLE 3: Details of group size estimates and correction factors used in the population estimates.

Blocks : lines	Group size mean (C.V.)	Number of observers Port	Starboard	Perception Correction Factor estimate (C.V.) Port	Starboard	Availability Correction Factor estimate (C.V.)
(a) Northern Central Section, September 1986						
1; 2: 38; 4: 16, 31-38	1.2857(0.1038)	1[a]	2	1.7273(0.0651)	1.1020(0.0575)	3.0000(0.1701)
2: 51-58, 61, 64; 3; 4: 1-5, 17-30, 59, 60, 62, 65-67	1.2857(0.1038)	2	2	1.1745(0.0651)	1.1020(0.0575)	3.0000(0.1701)
(b) Central Section, September - October 1987						
All blocks and lines	1.6667(0.1336)	2	2	1.0556(0.0092)	1.0549(0.0079)	3.5143(0.1433)
(c) Mackay/Capricorn Section, November 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; 2; 3; 4; 5: 50-63, 75 & 138-144; 6: 76, 81-88 & 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.

TABLE 4: Estimated densities and numbers of dugongs for the surveys. The values are ± standard error incorporating the errors resulting from sampling and in estimating mean group size and correction factors.

(a) Central Section

Block	Density per km^2	Numbers
(a) Northern Central Section, September 1986		
8[b]	0.61 ± 0.19	375 ± 118
9	0.04 ± 0.02	158 ± 68
10[a]	1.10 ± 0.24	340 ± 74
11	0.21 ± 0.10	151 ± 70
Total	0.19 ± 0.03	1024 ± 170
precision		0.17
(b) Northern Central Section, October 1987		
8	0.59 ± 0.15	360 ± 92
9	0.00 ± 0.00	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
(c) Southern Central Section, September - October 1987		
1	0.10 ± 0.12	31 ± 35
2	0.10 ± 0.11	65 ± 69
3	0.00 ± 0.00	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
Central Section, September - October 1987		
Total	0.13 ± 0.02	1532 ± 273
precision		0.18

TABLE 4: continued

(b) Mackay/Capricorn Section, November 1986

Block	Density per km^2	Numbers
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

TABLE 5: Summary of the analysis of variance comparing dugong density in the northern Central Section in September 1986 and October 1987 using a randomized block design with transect line as the blocking factor. The analysis has been performed with and without Beaufort sea state and cloud cover as covariates.

Covariate	Factors			
	Lines (d.f. = 39)		Years (d.f. = 1)	
	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

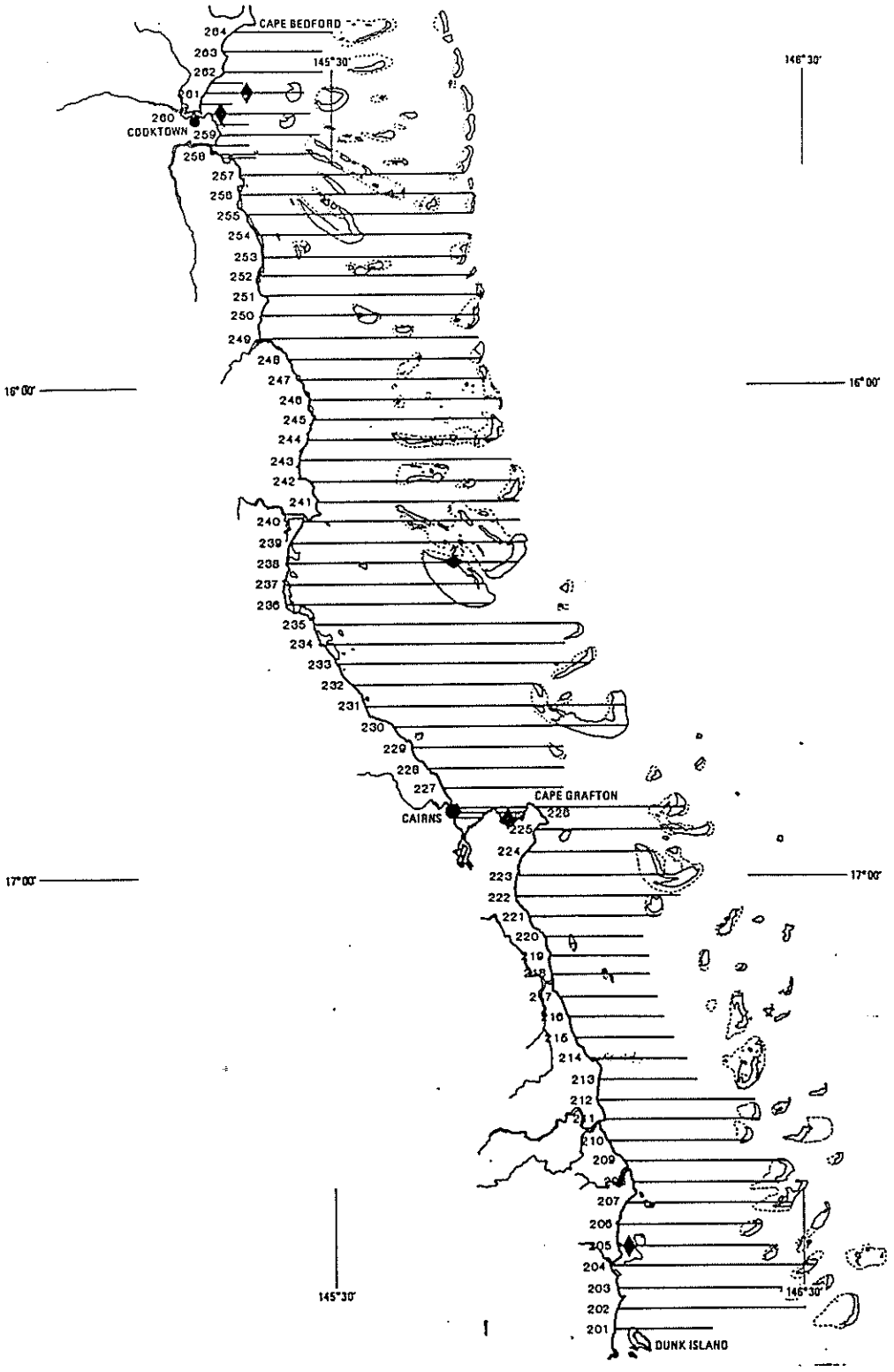

Fig. 1a Cairns survey area, showing the transect lines for the October 1987 survey. Dugong sightings (♦) made during the survey are also shown as the sighting rate for this survey was too low to allow the determination of dugong density in the survey area.

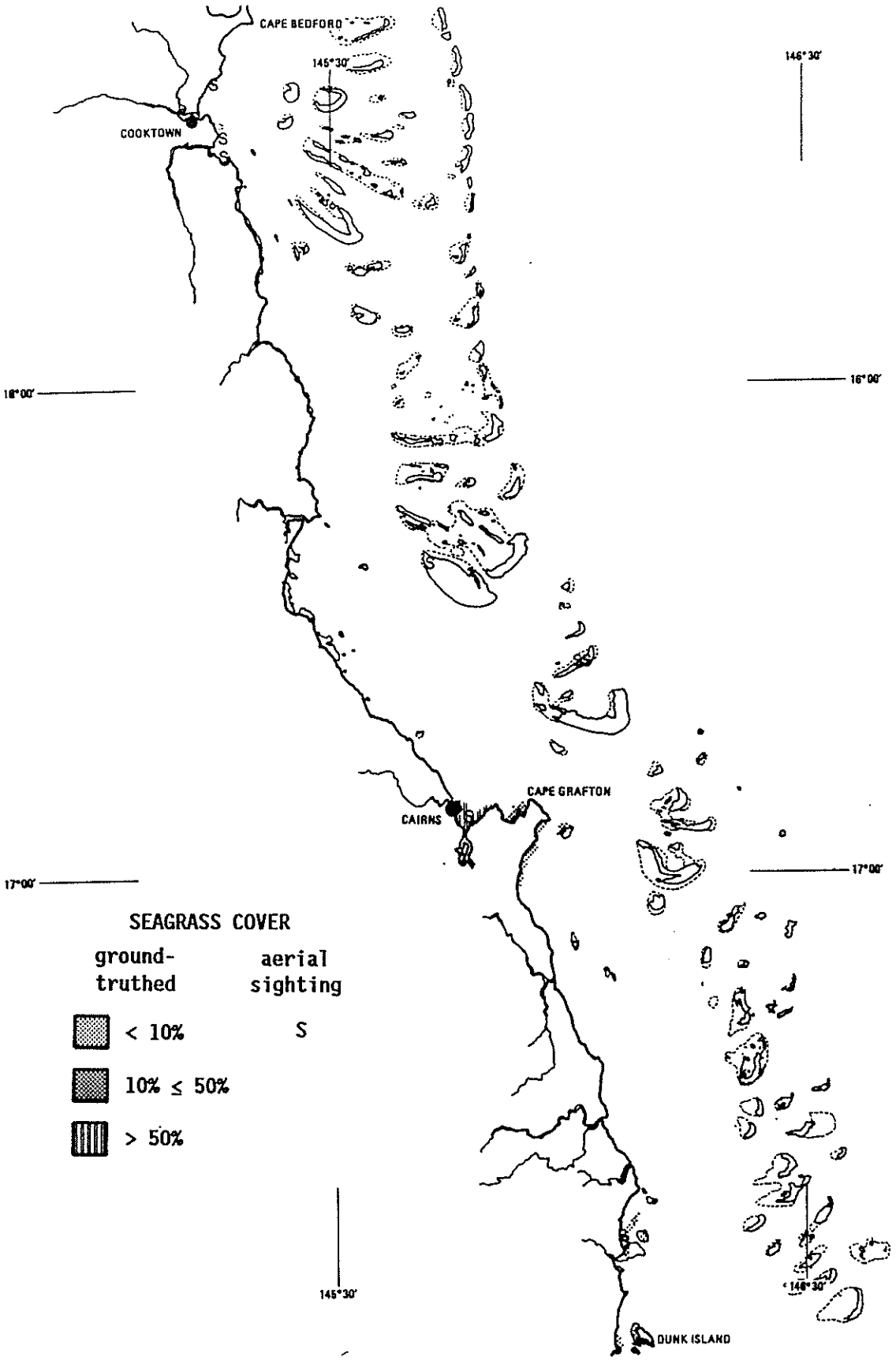

Fig. 1b The distribution and density of inshore seagrass beds in the Cairns Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript).

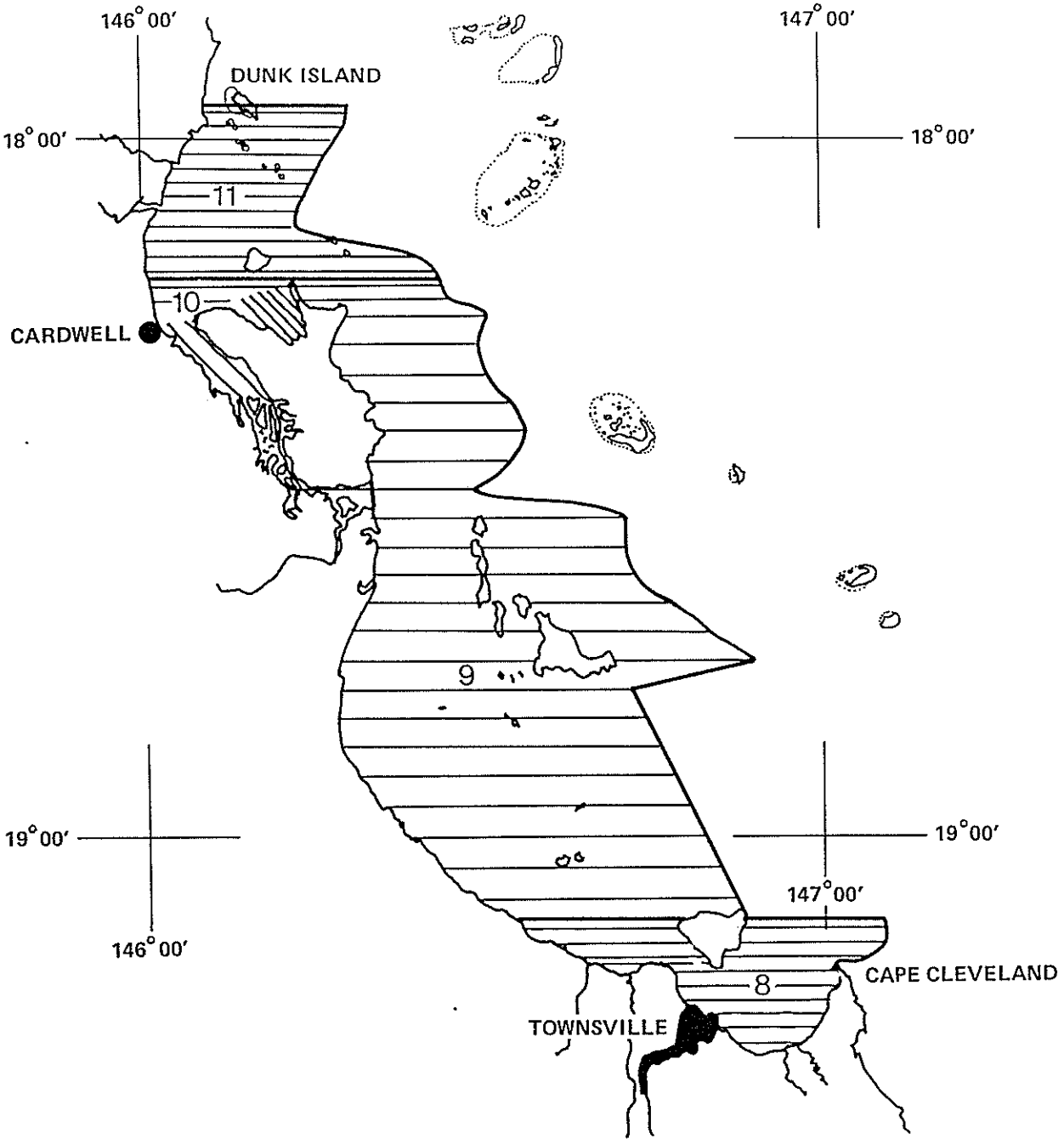

Fig. 2a Northern Central Section survey area, showing the survey blocks (8-11) and transect lines for the September 1986 and October 1987 surveys.

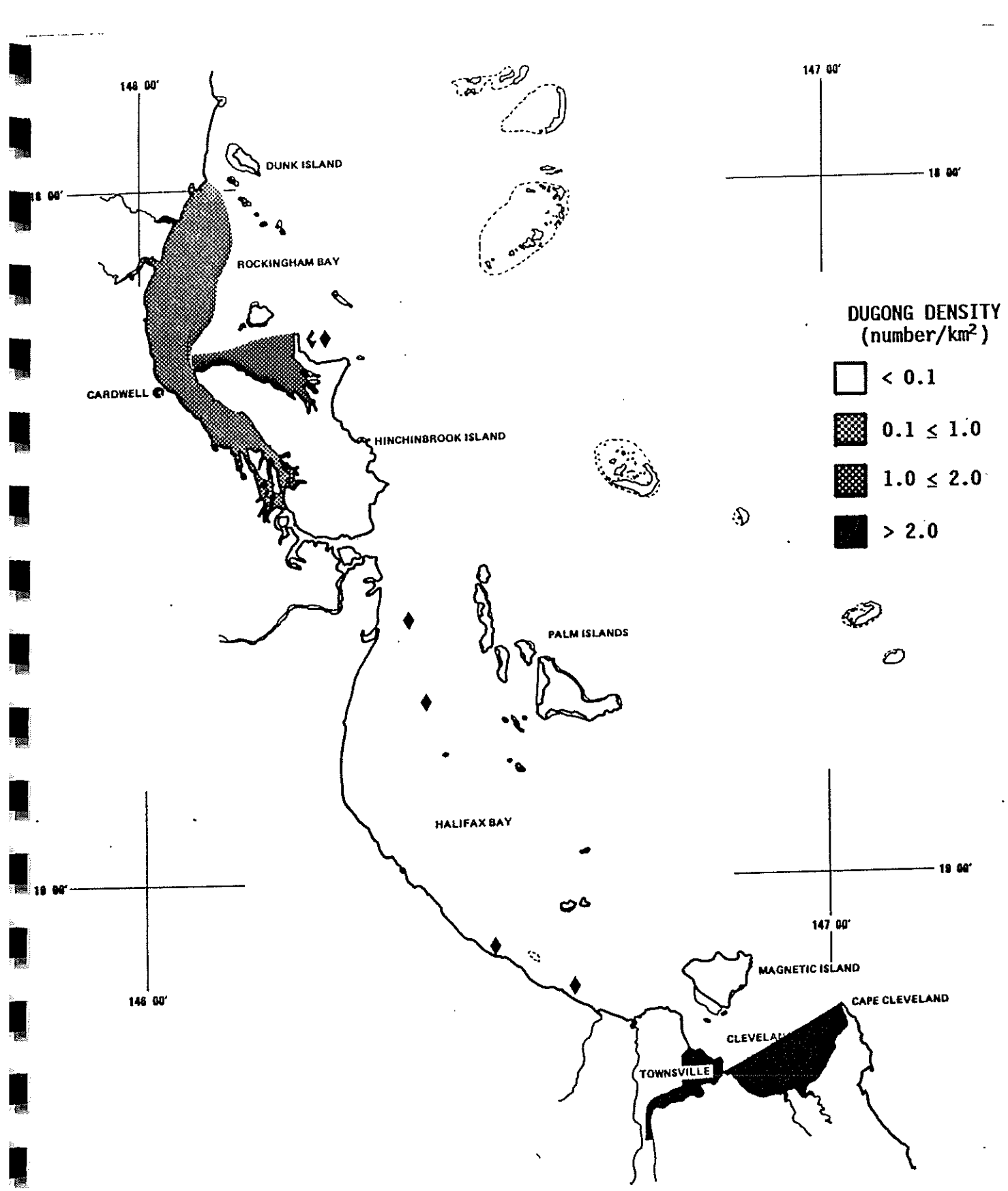

Fig. 2b The distribution of dugong density in the northern Central Section survey area in September 1986.

♦ = individual sightings.

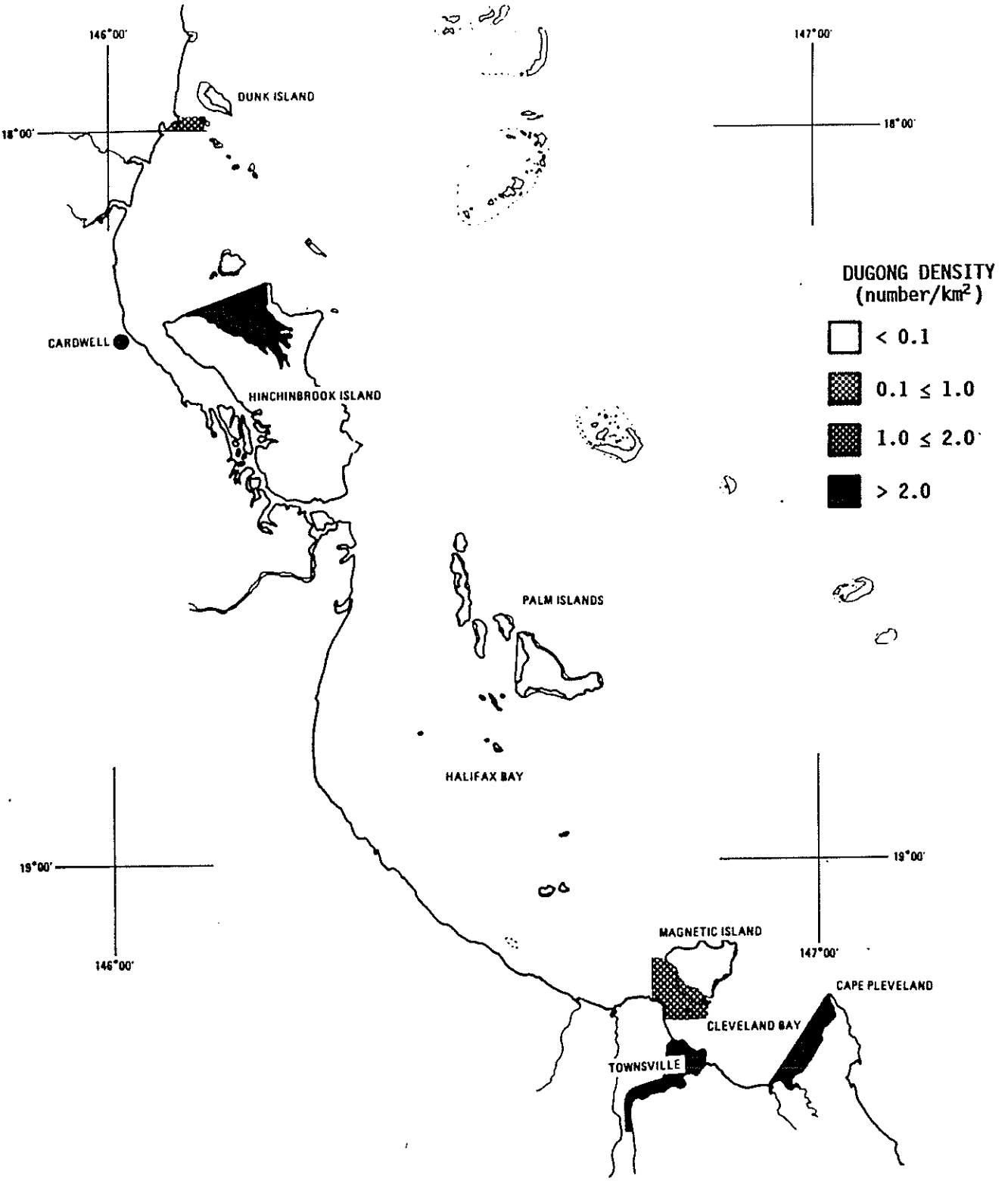

Fig. 2c The distribution of dugong density in the northern Central Section survey area in September - October 1987.

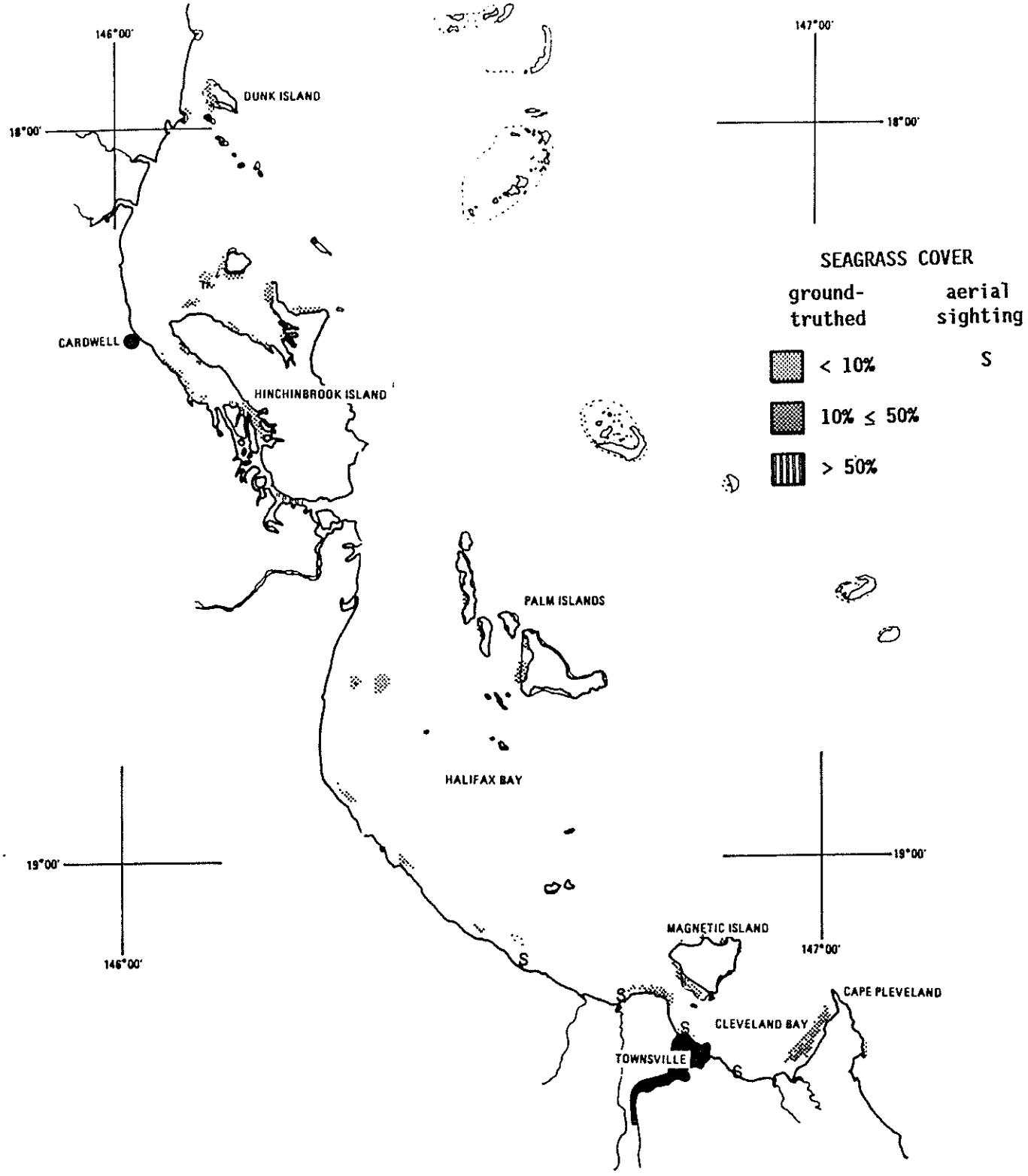

Fig. 2d The distribution and density of inshore seagrass beds in the northern Central Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript).

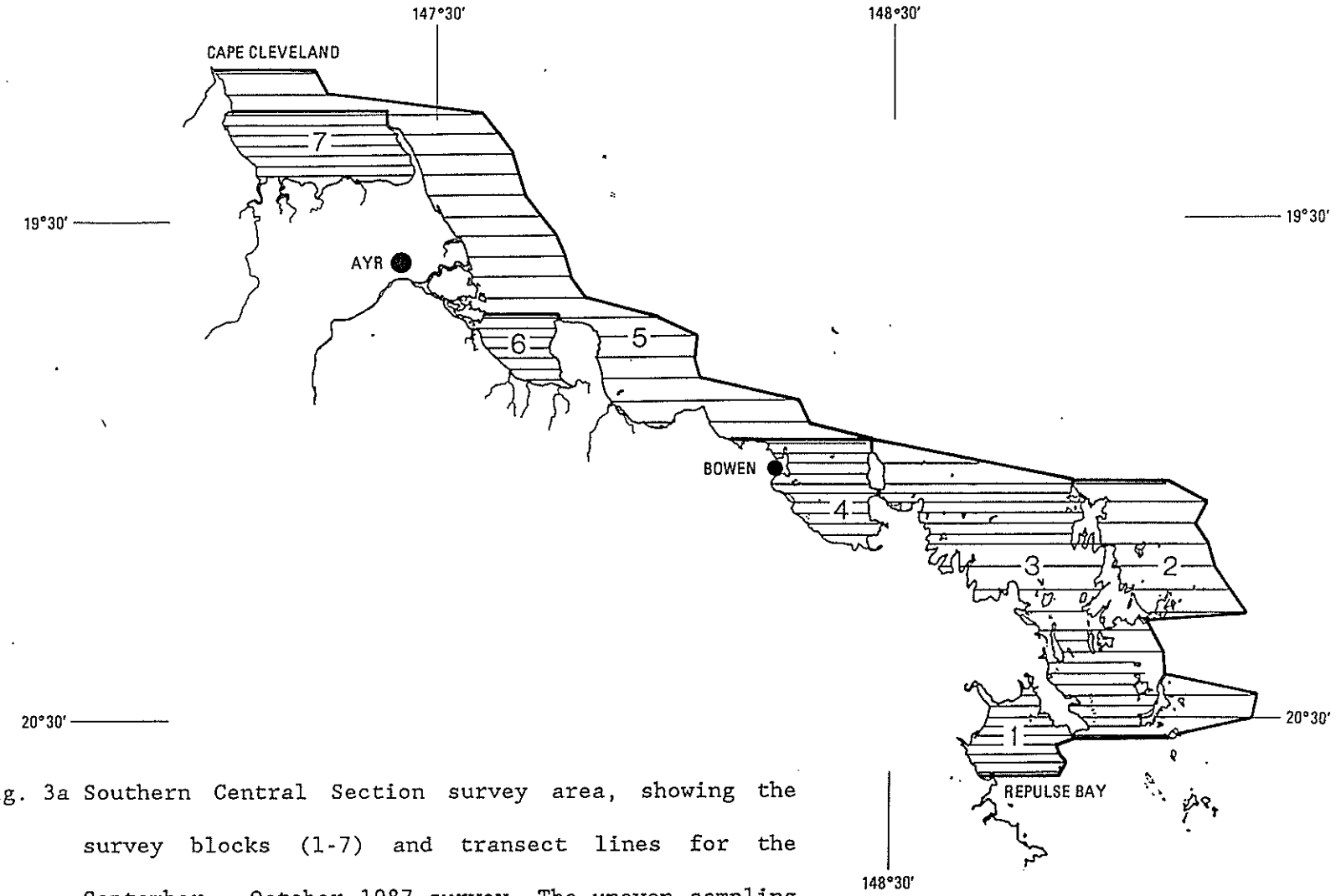

Fig. 3a Southern Central Section survey area, showing the survey blocks (1-7) and transect lines for the September - October 1987 survey. The uneven sampling intensity in Block 3 was the result of logistical problems; no dugongs were seen in this block.

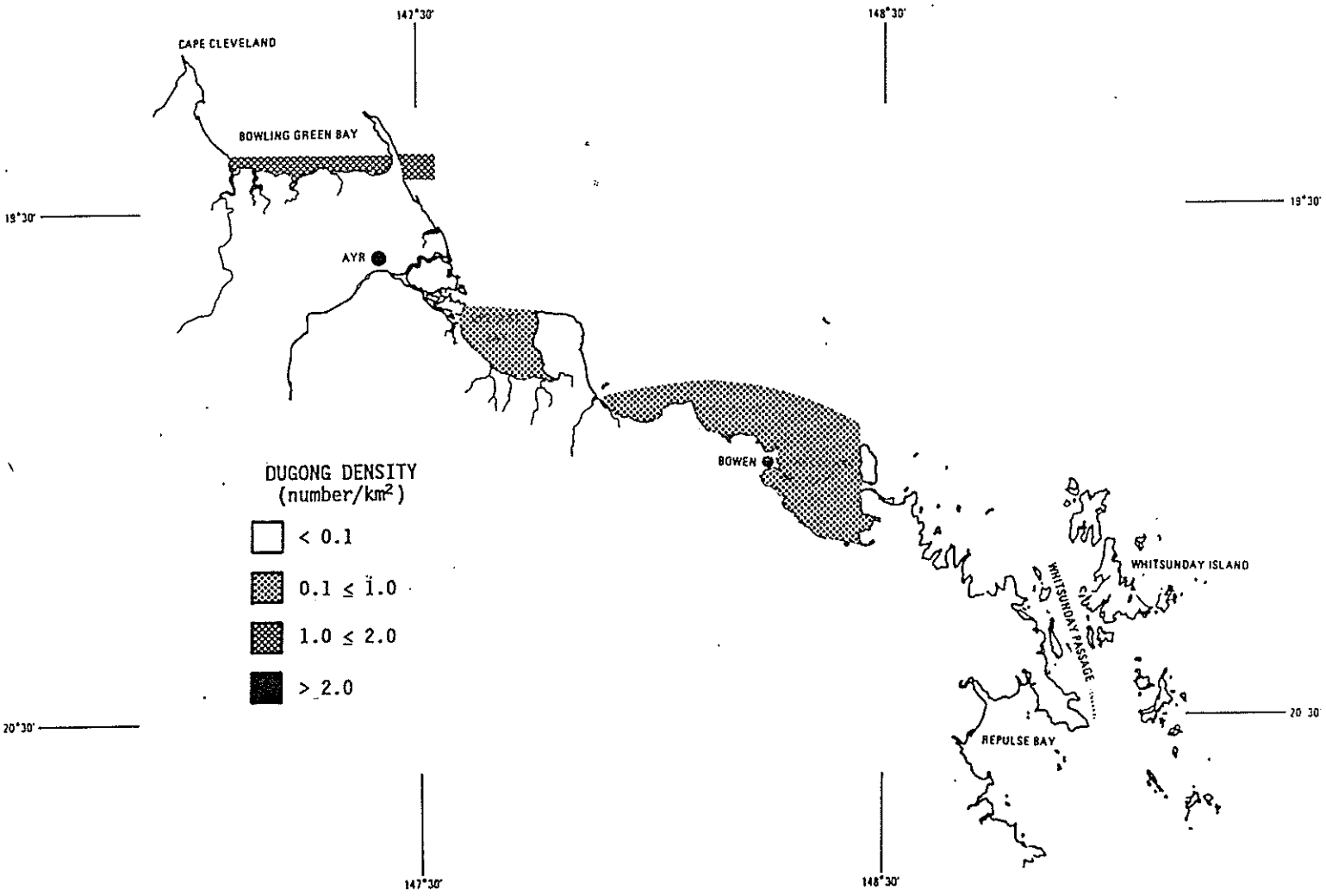

Fig. 3b The distribution of dugong density in the southern Central Section survey area in September - October 1987.

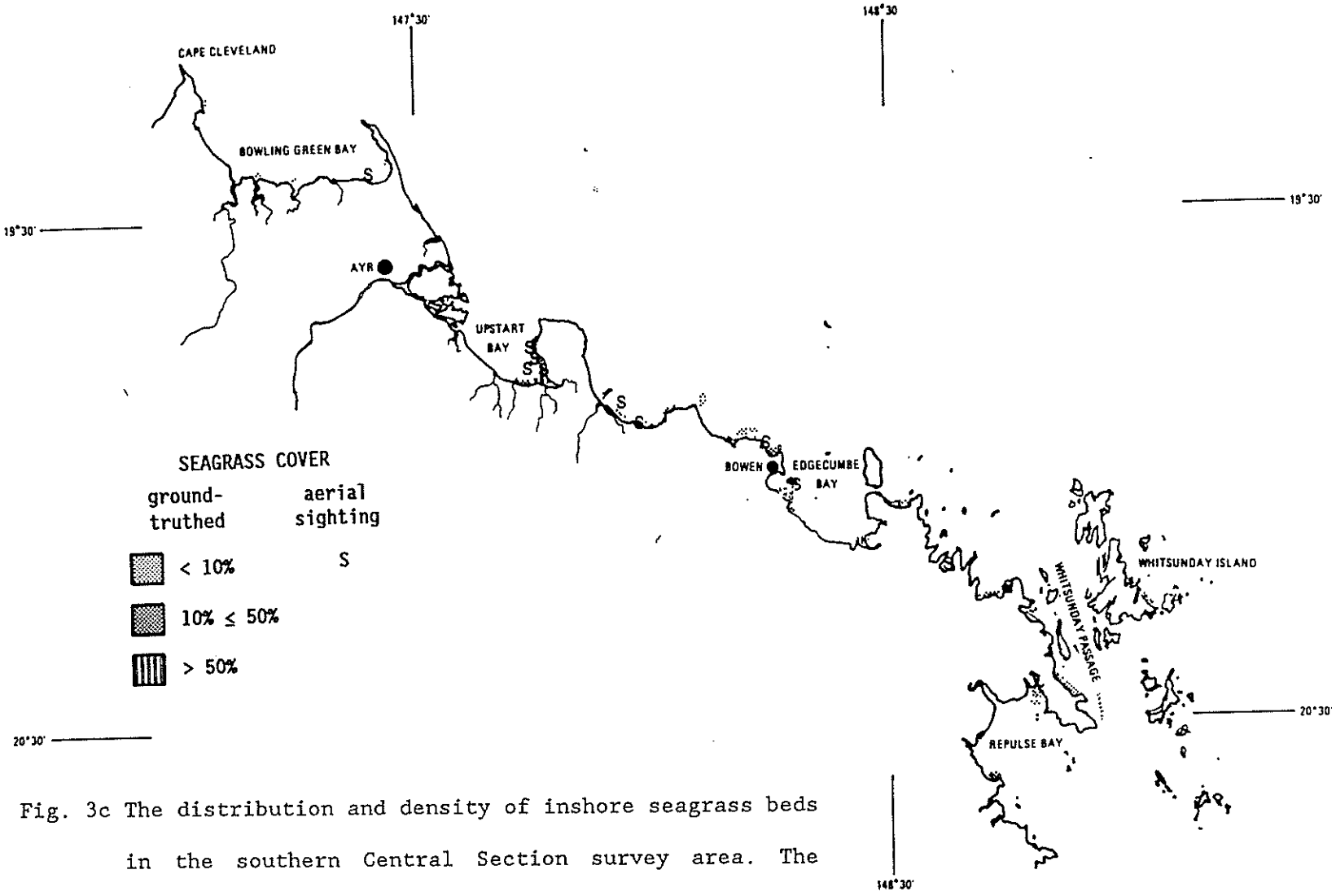

Fig. 3c The distribution and density of inshore seagrass beds in the southern Central Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript) for the area north of Bowen and Coles *et al.*, (1987) for the area south of Bowen.

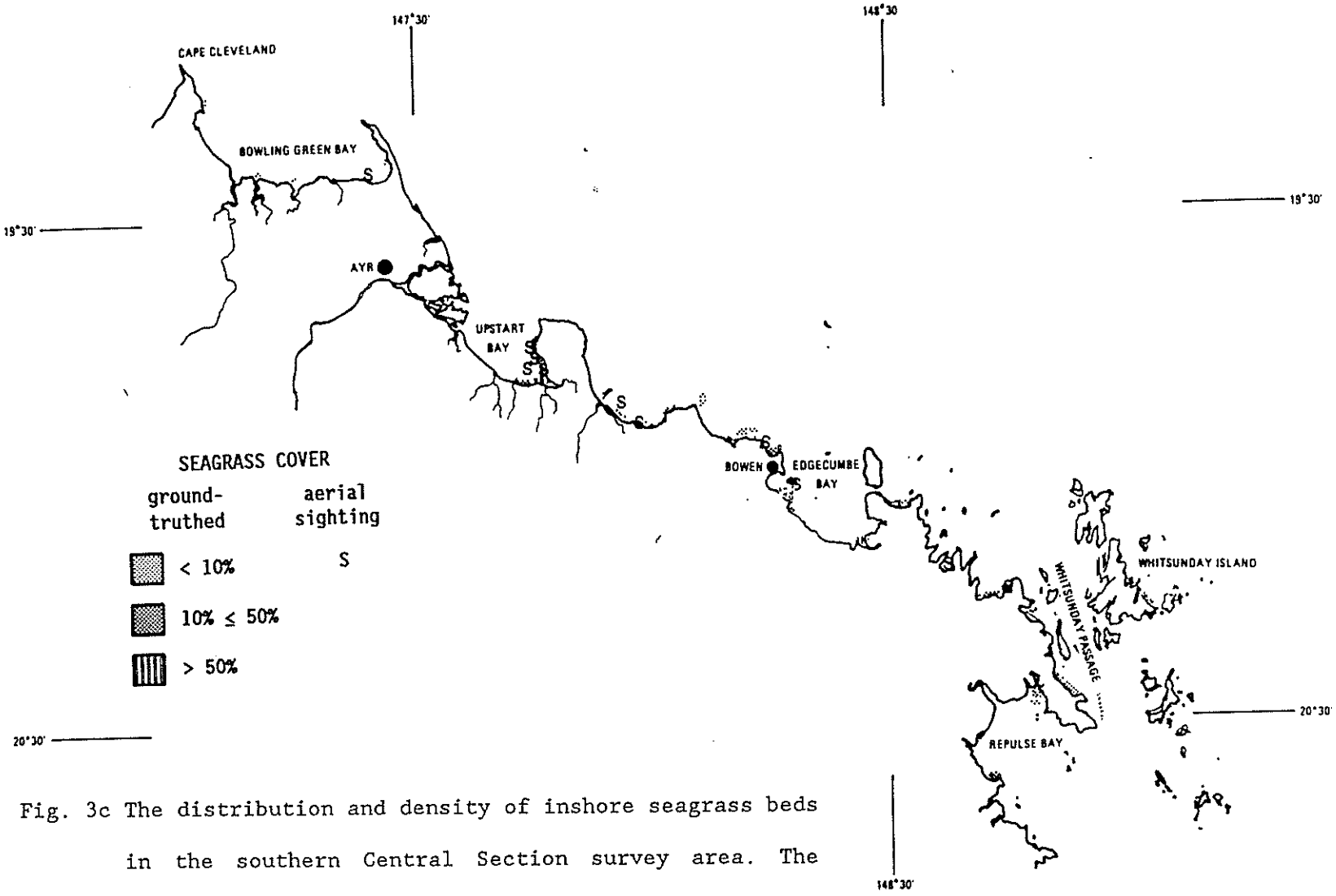

Fig. 3c The distribution and density of inshore seagrass beds in the southern Central Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript) for the area north of Bowen and Coles *et al.*, (1987) for the area south of Bowen.

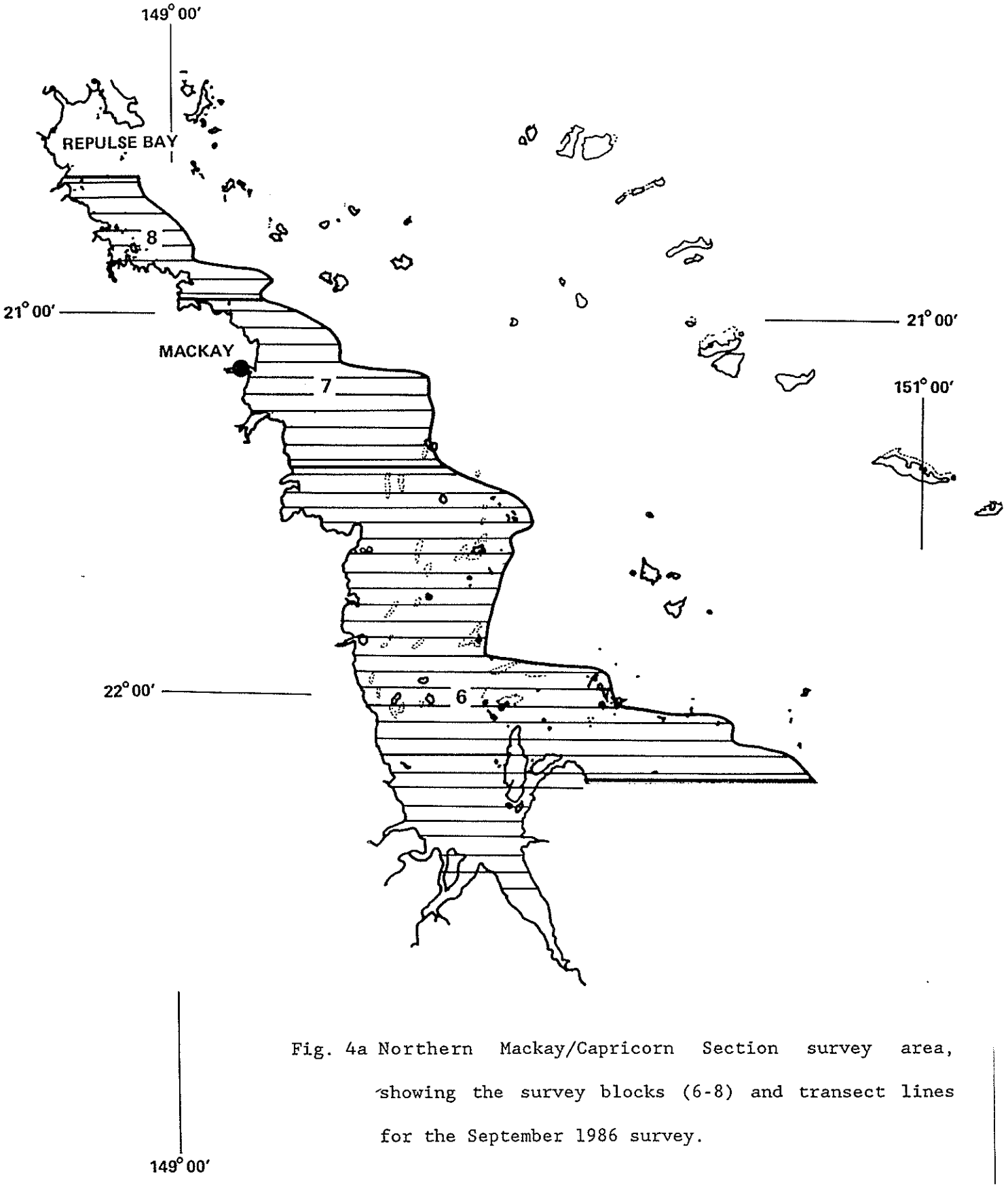

Fig. 4a Northern Mackay/Capricorn Section survey area, showing the survey blocks (6-8) and transect lines for the September 1986 survey.

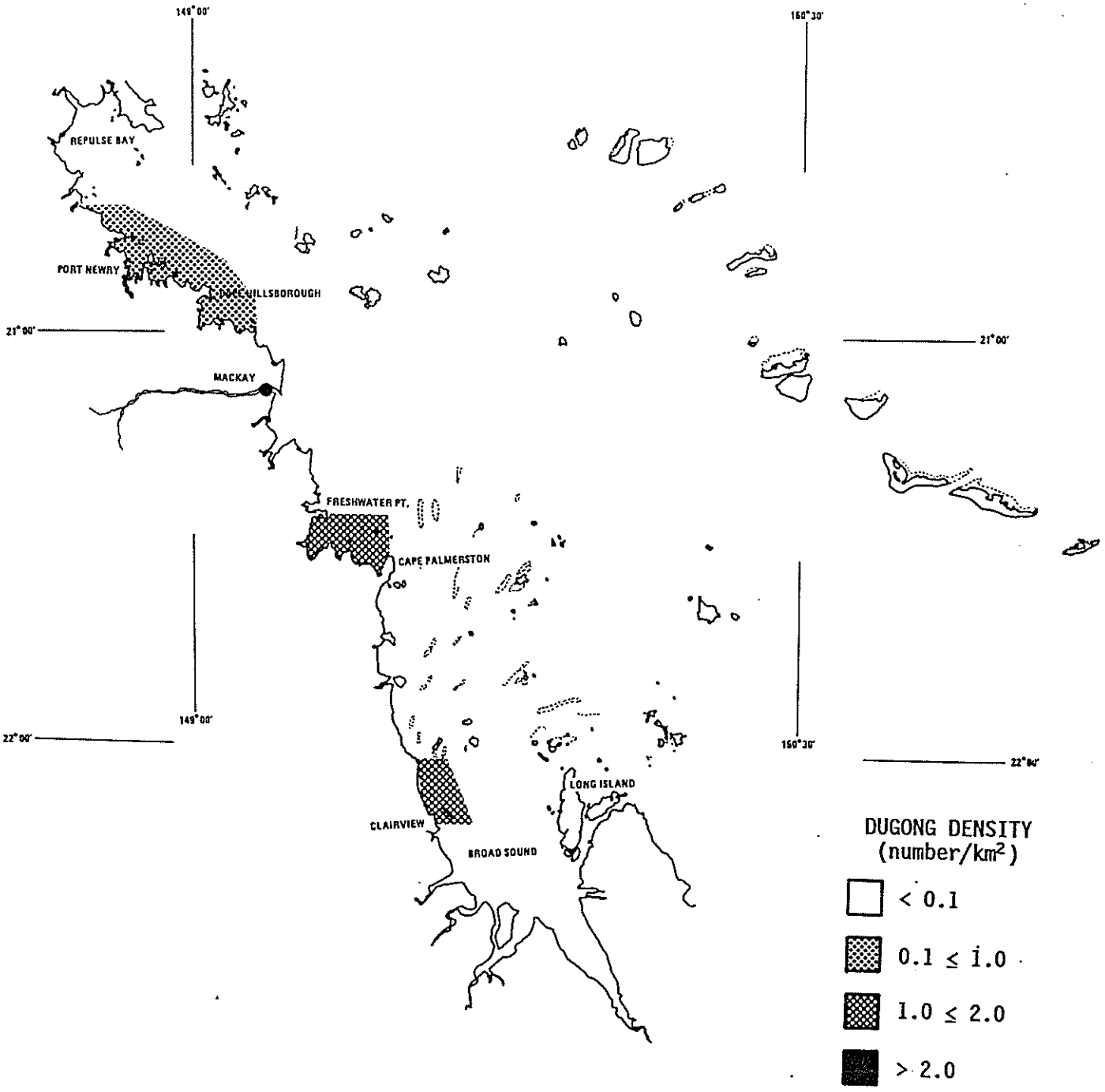

Fig. 4b The distribution of dugong density in the northern Mackay/Capricorn Section survey area in September 1986.

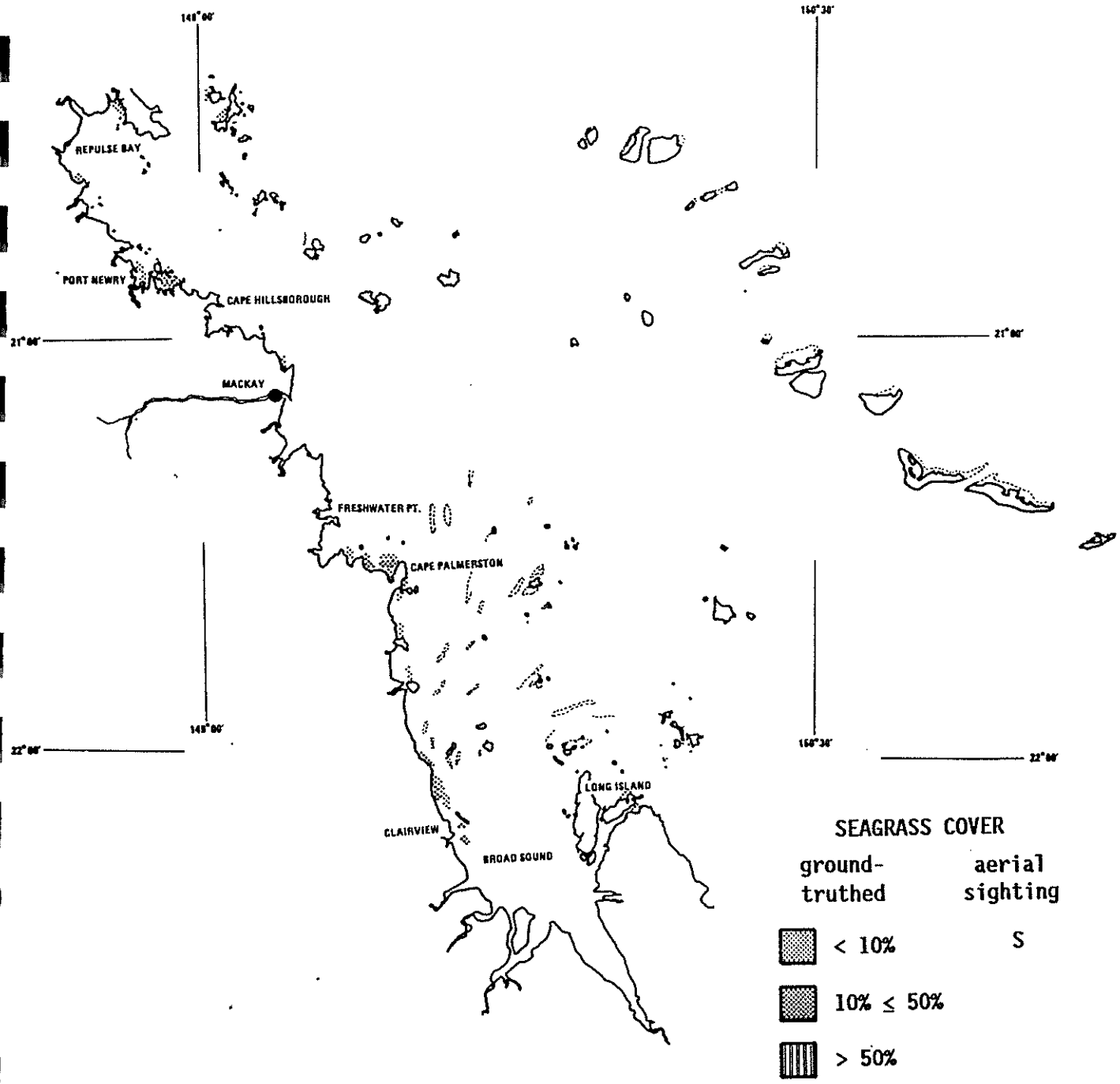

Fig. 4c The distribution and density of inshore seagrass beds in the northern Mackay/Capricorn Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (1987).

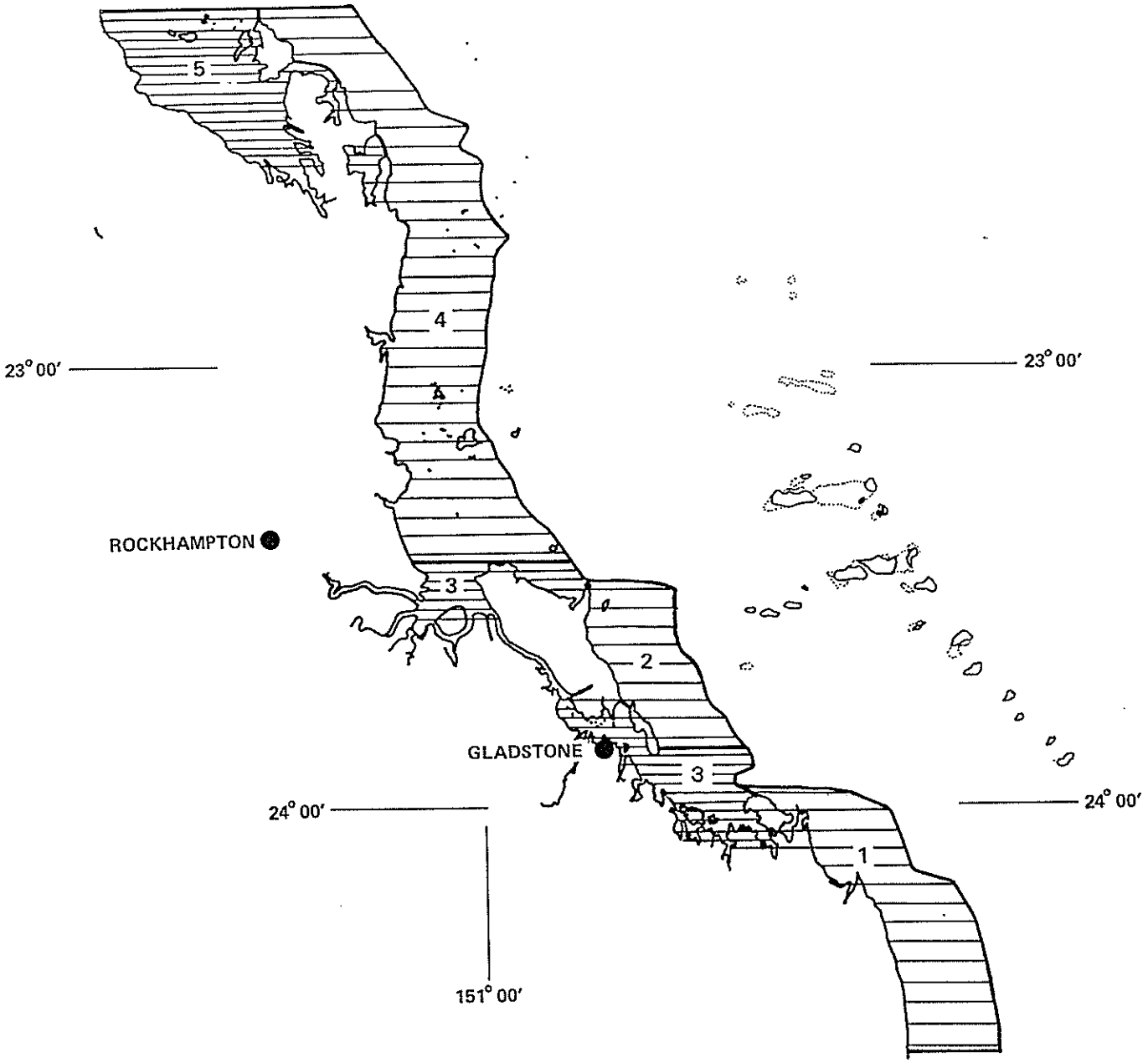

Fig. 5a Southern Mackay/Capricorn Section survey area, showing the survey blocks (1-5) and transect lines for the September 1986 survey.

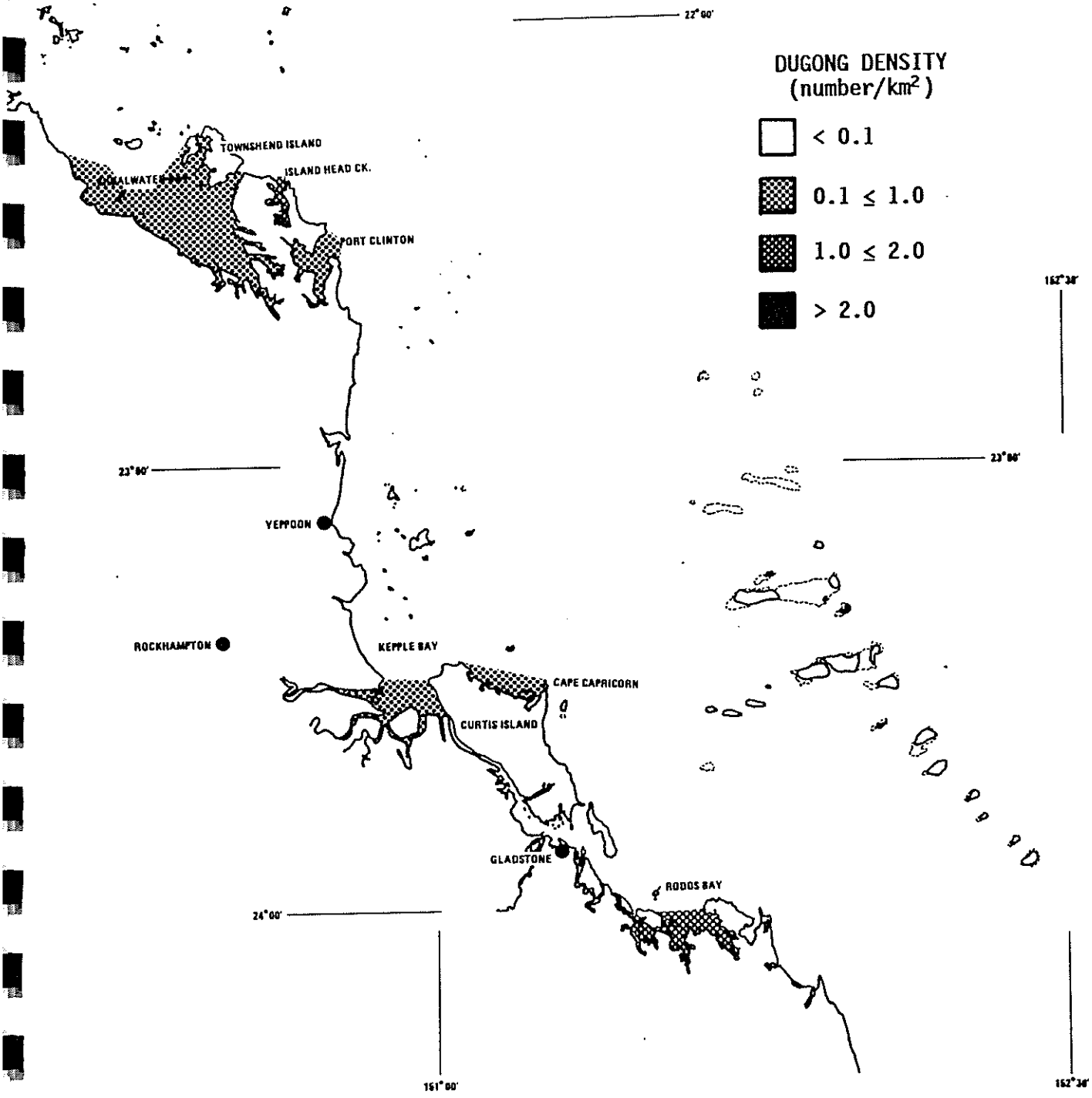

Fig. 5b The distribution of dugong density in the southern Mackay/Capricorn Section survey area in September 1986.

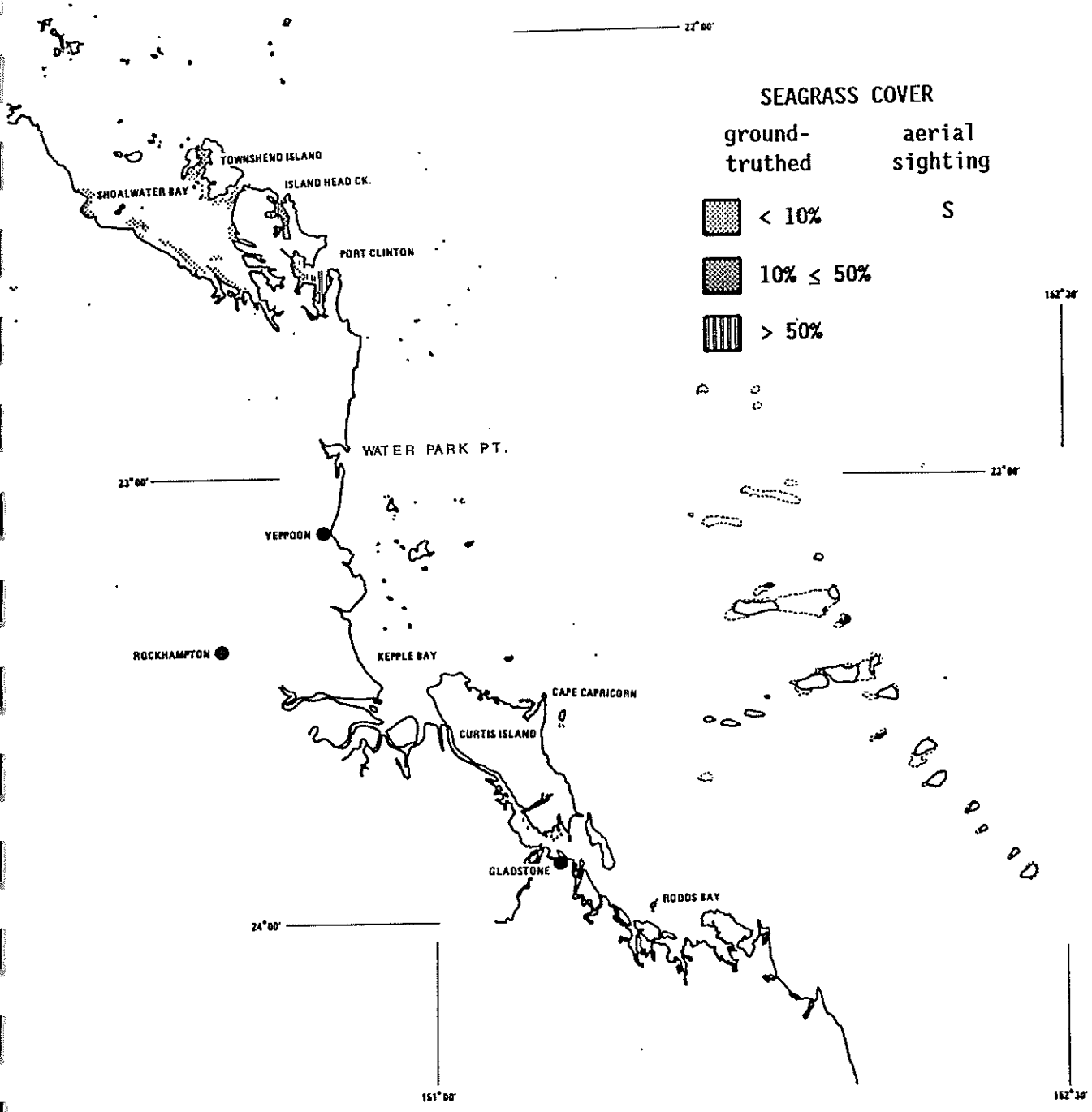

Fig. 5c The distribution and density of inshore seagrass beds in the southern Mackay/Capricorn Section survey area north of Water Park Point. The ground-truthed seagrass data are from Coles *et al.*, (1987).

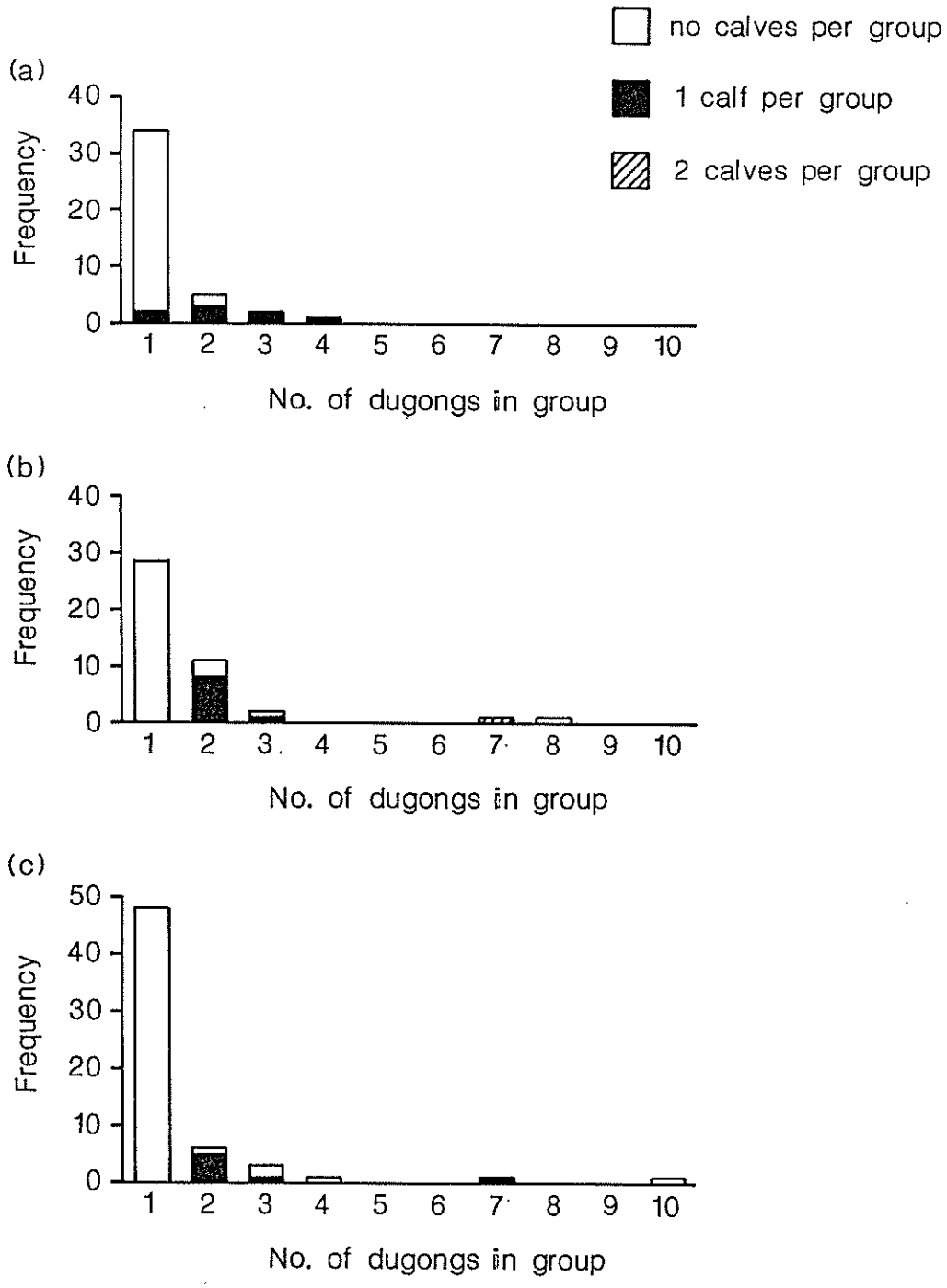

Fig. 6 Frequency histograms showing details of dugong group size and composition for (a) the Northern Central Section in September 1986, (b) the Central Section in September - October 1987 and (c) the Mackay/Capricorn Section in September 1986.

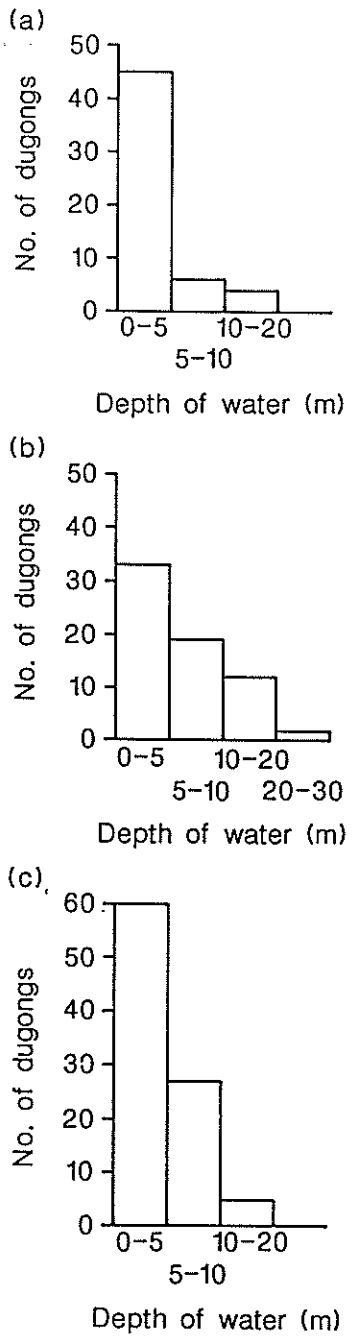

Fig. 7 Frequency histograms showing the depths of water in which dugongs were sighted in (a) the Northern Central Section in September 1986, (b) the Central Section in September - October 1987 and (c) the Mackay/Capricorn Section in September 1986. These depths were obtained from marine charts and have not been corrected for tidal levels at the times of the surveys.