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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

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Part 1

Synthesis

STRUCTURE OF THE REPORT

This report outlines the results of a research program conducted between 1984 and 1988. The program aimed to investigate the biology of dugongs and other large vertebrates within the GBR region, as a basis for the development of effective management strategies.

The report consists of five parts of which this is the first. This part is a synthesis of the results of the project in the context of our knowledge of dugong biology. It evaluates the current status of the dugong in the GBRMP, and makes recommendations for future research, monitoring, and management.

Parts 2 and 3 are collections of the papers and reports that have resulted from the project. Most of the papers are either in press or in review. Part 2 comprises the results of the dedicated aerial surveys. There are two papers on aerial survey methodology (Marsh and Sinclair, manuscripts a and b); two papers and a report on the distribution and abundance of dugongs in the northern and southern regions of the GBR region (Marsh and Saalfeld, manuscripts a and b), and adjacent Torres Strait (Marsh and Saalfeld, 1988); and a paper on the distribution and relative abundance of sea turtles in the northern GBR (Marsh and Saalfeld, in press).

The remaining papers and report are in Part 3: a paper on dugong movements and habitat usage based on conventional and satellite telemetry (Marsh and Rathbun, manuscript), a paper on the management of traditional dugong hunting in the Park (Smith and Marsh, in press), and a report on the incidental sightings of dugongs in the Great Barrier Reef region (Spencer, manuscript).

Part 4 is a collection of maps illustrating the distribution of dugongs and seagrasses within the GBR region, and the distribution of sea turtles in the northern GBR. Part 5 contains the raw data from the aerial surveys, and the computer programs used in the aerial survey data collection, processing and analysis. A copy of the raw data has also been included on a floppy disk in Word Perfect 4.2 format.

The aerial surveys yielded data additional to the material covered in this report. Sightings of sea turtles, cetaceans and sea snakes were recorded on all surveys. I have obtained funding from James Cook University to process the remaining sea turtle data, and have additional funding from the GBRMPA to process the valuable baseline information on cetacean distribution and abundance.

SYNTHESIS: CURRENT PERCEPTIONS ON THE STATUS OF THE DUGONG IN THE GREAT BARRIER REEF MARINE PARK IN THE CONTEXT OF ITS BIOLOGY WITH RECOMMENDATIONS FOR FUTURE RESEARCH, MONITORING AND MANAGEMENT.

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Executive summary

A four-year study has been carried out to establish a sound biological basis for managing dugongs in the Great Barrier Reef Marine Park. Procedures were developed for studying the distribution, and estimating the abundance of dugongs from dedicated aerial surveys. These surveys were carried out over the inshore waters of the entire Great Barrier Reef region to at least 20km offshore. The surveys were extended to the outer barrier reefs between Dunk Island (17°59'S., 146°14'E.) and Hunter Point (11°30'S., 142°50'E.). Incidental sightings of dugongs made by observers from aircraft, boats and the shore were collated to obtain additional information on dugong distribution. The movements of six male dugongs were also monitored for from one to 16 months using satellite and conventional tracking techniques.

The results of both the aerial surveys and the tracking studies indicated that dugongs spend most of their time in the vicinity of inshore and reefal seagrass beds. Dugong numbers in the Great Barrier Reef region are much higher than previously thought; there are an estimated 11,600 $\pm$ 1,170 animals in the region. This is likely to be an underestimate because of the conservative correction factors used to compensate for animals which are not sighted due to water turbidity.

The number of dugongs in an area is highly correlated with the area of seagrass. With the highest area of inshore seagrass in the GBR region plus significant seagrasses on some mid-shelf reefs, the Far Northern Section is the most important Section of the Park for dugongs with more than half the population of the region. The Starcke River area is outstanding with about 20% of the dugongs in the GBR. The general level of protection afforded the important dugong areas in the Far Northern Section is good with five areas zoned Marine National Park B or higher (no fishing allowed) and six zoned General Use B (no trawling allowed).

South of Cape Bedford, the Cairns Section has little seagrass and no important dugong areas. Many of the sheltered bays of both the Central and Mackay/ Capricorn Sections support significant numbers of dugongs although none of these areas has been given Marine National Park or higher zoning. Dugong areas in the Central and Mackay/Capricorn Sections of the Park tend to have a lower density of dugongs than seagrass areas of comparable size in the Far Northern Section. The areas with the lowest dugong density per area of seagrass tend to have high boat traffic.

Population simulations (Marsh, 1986) indicate that even with the most optimistic combination of life history parameters, low natural mortality, and no man-induced mortality a dugong population is unlikely to increase at more than about 5% per year. Within the GBR region, dugongs are legally hunted under permit by Aboriginal hunters from several Trust areas north of Cairns. They are also killed incidentally in commercial gill nets, and in shark nets set for bather protection near major population centres. There are no figures for the number of dugongs drowned in commercial gill nets. The present level of Aboriginal hunting is apparently within the sustainable yield of the dugong population, and the number of dugongs killed in shark nets is now very low. Overall, the level of man-induced mortality to dugongs in the GBRMP is probably relatively low, so that the expected rate of population change is likely to be slow (< 5% per annum). Because of this expected slow rate of population change and the difficulties of obtaining precise population estimates, it will probably be about a decade before it can be confirmed whether dugong numbers are increasing, decreasing or stable in the GBR region. This means that if the population were decreasing at say 5% per year, numbers would be reduced to about 60% of their present level before the trend is detected. A conservative management policy for dugongs centred on the protection of their seagrass habitats is therefore recommended in order to minimize the risk of population decline.

Recommendations

1. Zoning

The main strategy for managing dugong populations in the GBRMP should be through protection of seagrass habitats, particularly those which support substantial numbers of dugongs.

At least one such area in both the Central and Mackay/Capricorn Sections of the GBRMP should be zoned Marine National Park 'A' or higher, so that all commercial fishing including gill-netting is banned from a representative sample of outstanding dugong habitats throughout the GBRMP. I suggest that eastern Cleveland Bay in the Central Section and the Port Newry area in the Mackay Capricorn Section would be sites suitable for such zoning.

When areas are zoned to protect dugongs, the zonal boundaries should include the whole seagrass bed. The extent of some seagrass beds should be checked, particularly those in the Starcke River and Port Newry areas.

As dugong concentrations are often highest in intertidal areas, there should be complementary zoning of the coastal areas of Queensland adjacent to areas zoned to protect dugongs in the GBRMP. Such complementary zoning will be necessary if eastern Cleveland Bay and the Port Newry area are rezoned as suggested above. In addition, the zoning status of the estuaries adjacent to the Scientific Research Zone in the Starcke River area which are presently zoned General Use B (which means that gill-netting is allowed there but not in the adjacent fore-shores) should be changed to Marine National Park 'A' to remove this anomaly.

In the light of the correlative evidence that boat traffic *per se* seriously degrades the value of an area as dugong habitat, boat traffic should be discouraged in some of the important dugong areas in the Far Northern Section. The Preservation Zone between Dead Dog Creek and Barrow Point is particularly valuable in this regard and should be maintained.

2. Permit and Licence Conditions

Another major strategy for managing dugong populations should be through continuing support of existing conditions to minimize human mortality of dugongs.

The GBRMPA should take the following steps to monitor human-induced dugong mortality in the GBRMP:

- Request the Queensland Department of Harbours and Marine to require that shark meshing contractors collect information on (a) the size and sex of dugongs caught, and (2) the location of the net, as part of their contract. The Townsville shark netting contractor should be required to make dugong carcasses available to scientists at James Cook University for continuing life history studies. If the meat of these carcasses is edible, an arrangement should be made with the local Aboriginal and Islander community so that it can be made available to them.
- Continue to require the collection of dugong catch statistics from Aboriginal communities as a condition of dugong hunting permits. Hunters should also be encouraged to continue collecting dugong tusks for Q.NPWS to send to James Cook University so that the age/sex composition of the catch can be verified.
- Ask the fishing industry to make available log-book statistics so that the extent of commercial gill-netting in important dugong areas can be monitored.
- When there is seen to be a need for new shark nets within or adjacent to major dugong habitats within the GBRMP, the GBRMPA should encourage the Queensland Government to introduce drum lines rather than nets in view of the usually high dugong mortality in shark nets in the five years or so after they are first introduced. e.g. 81 dugongs were killed in Townsville shark nets in the first year of netting (Paterson, 1979).

3. Public Education

The dugong public education program should be expanded to target (1) Aboriginal and Islander hunters living on Trust Areas in the GBR region, (2) Aborigines and Islanders living away from Trust areas who frequently resent not being able to hunt dugongs legally, and (3) commercial gill-netters operating in high density dugong areas. The program should emphasize the vulnerability of the dugong to over-harvesting, the illegality of selling dugong meat, and the current restrictions on dugong hunting in the GBRMP. Gill-netters should be supplied with maps illustrating the high density dugong areas and encouraged to avoid fishing in such areas to minimize the risk of damaging their nets.

4. Monitoring of dugong numbers

The success of the dugong management program should be evaluated by monitoring the distribution and abundance of dugongs in the GBR region by conducting dedicated aerial surveys using the procedures and designs developed in this project. (Areas where no dugongs have been sighted and which contain no suitable habitat need not be surveyed). The surveys should be carried out at five-yearly intervals. The area north of Cape Bedford should be surveyed in one year; the remainder the following year. The surveys should be carried out in October/November when favorable weather conditions are most likely. The first survey of the area north of Cape Bedford should be carried out in 1990, five years after the last such survey.

Information on dugong sightings obtained from the Q.NPWS monitoring program should be collated in a data base to provide additional information on dugong habitat usage. However, these data will not be suitable for documenting population trends.

5. Research

The GBRMPA should encourage research using an expanded program of satellite and conventional telemetry to monitor the movements of individual adult dugongs to determine whether they use specialized mating and calving areas. The initial phase of this research should be carried out in a clear water area such as Moreton Bay near Brisbane. The research should then be extended to key areas in the Far Northern Section of the Park. It would be particularly useful if time-depth recorders could be attached to the radio-tracked animals to document the proportion of time individual dugongs spend at the surface, so that the proportion of animals which are unavailable to observers due to water turbidity can be estimated more accurately.

The GBRMPA should fund research to maximize the information obtained form the dedicated surveys carried out to date. In particular, the valuable baseline information on the distribution and abundance of cetaceans and sea snakes should be analyzed and synthesized.

The GBRMPA should fund research to check the extent of the seagrass beds in important dugong habitats, particularly those in the Starcke River and Port Newry areas.

Introduction

The dugong, the only herbivorous mammal which is strictly marine is listed as vulnerable to extinction in the IUCN Red List of Threatened Species (1986). Trade in dugong products is regulated or banned (depending on the dugong population involved) by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

The range of the dugong extends throughout the tropical and subtropical coastal and island waters of the Indo-West Pacific from East Africa to the Solomon Islands and Vanuatu, and between about 26-27° north and south of the equator (Nishiwaki and Marsh, 1985). Over much of this range which spans the waters of 43 countries, dugongs are now believed to be represented by relict populations separated by large areas where they are close to extinction or extinct. This assessment is, however, almost entirely based on anecdotal information and the actual extent to which their range has contracted is unknown.

A significant proportion of dugong stocks is believed to occur in northern Australian waters between Moreton Bay (near Brisbane) in the east, and Shark Bay in the west. The seagrass beds in the Great Barrier Reef region have been identified as major dugong habitats since the early 1970's, especially the Starcke River area (Nishiwaki and Marsh, 1985).

The Great Barrier Reef Marine Park Authority (GBRMPA) is concerned about the status of the dugong within the Park for two reasons. Firstly, the GBRMP Act (Australia, 1975) gives the Authority specific responsibility for endangered species and secondly, the large numbers of dugongs in the Park were listed as a reason for the region's being given World Heritage Listing.

Life history and reproductive ecology

Almost all information has been obtained from the analysis of specimens from dugongs accidentally drowned in shark nets or killed by native hunters in northern Australia and Papua New Guinea (Marsh, 1980, 1986 and unpublished; Marsh *et al* 1984 a,b,c). Age has been estimated by counting the dentinal growth layers in the tusks, the deposition rate being deduced from the seasonal pattern of growth layer deposition. The maximum age estimated is 73 years, and the minimum pre-reproductive period nine or 10 years for both sexes. The pre-reproductive period is very variable and ranges up to 15-17 years for some females.

Females may undergo a number of sterile cycles before becoming pregnant. Mating is promiscuous. Mating has not been observed in the GBRMP by scientists (although it has been described to me by Aboriginal hunters), and it is not known whether it occurs only in specific areas. A single calf is usually born after a gestation period estimated to be about 13-14 months (H Marsh and B E T Hudson, unpublished). The few reports available (see Marsh *et al.*, 1984c) suggest that calving occurs in shallow, specialized areas which are not associated with seagrass beds. Calving in the Great Barrier Reef Park is diffusely seasonal; most calves are born between September and November inclusive. The cow/calf bond is close. Calves can suckle for at least 18 months (Marsh *et al.*, 1984c).

There are no reliable data on age-specific fecundity or mortality, but there is evidence that some males may become post-reproductive (Marsh *et al.*, 1984b). Estimates of mean calving interval based on apparent pregnancy rates, placental scar counts, or calf counts range from three to seven years for various Australian/Torres Strait populations (Marsh, 1986; Marsh *et al.*, 1984c). Population simulations (Marsh, 1986) indicate that even with the most optimistic combination of life history parameters, low natural mortality, and no man-induced mortality, a dugong population is unlikely to increase at more than about 5% per year.

Natural mortality

Population models indicate that natural mortality must be low for a dugong population to be sustained (Marsh, 1986). There is little information available on causes of natural mortality and no information as to their relative importance. Dugongs bearing scars indicating that they have experienced and survived attacks by large sharks are occasionally sighted (Anderson, 1979; personal observation), and fatal shark (Patterson, 1939; Bradley in Marsh *et al.*, 1984c) and crocodile (unpublished data, 1988) attacks on dugongs have been observed in northern Australia. Storm surges associated with cyclones, such as that which devastated Bathurst Bay in 1899, can strand large numbers of dugongs (Marsh *et al.*, 1986); fortunately such events are probably rare.

Food and Feeding

Dugong food and feeding ecology have been reviewed by Lanyon *et al.*, (in press). Analyses of stomach and mouth contents indicate that seagrasses (families Potamogetonacae and Hydrocharitaceae) are their staple food and that they consume a wide variety of tropical and sub-tropical species. The genera eaten by dugongs in the GBRMP include *Halodule*, *Halophila*, *Cymodocea*, *Thalassia*, *Enhalus*, *Syringodium* and *Zostera* (Marsh *et al.*, 1982). *Thalassodendron*, the other genus which occurs in the Park, is eaten by dugongs in Torres Strait (Nietschmann, 1984) and probably in the GBR Region as well.

It is not known how selective dugongs are in choosing food. Marsh *et al.* (1982) found that *Halodule* (95% of stomachs), *Halophila* (89% of stomachs), and *Cymodocea* (61% of stomachs) are the genera most commonly found in dugong stomachs in north Queensland. These are also the most common seagrasses found in the shallow inshore waters of the GBR (Coles *et al.*, 1987) where most dugongs have been sighted during aerial surveys (Marsh and Saalfeld, manuscript a and b). When seagrasses are abundant, dugongs eat algae often but only in small amounts (% of food volume) and probably incidentally.

When feeding on soft and delicate seagrasses such as *Halodule* and *Halophila*, dugongs dig up the whole plant including the rhizomes leaving a distinctive feeding trail on the seagrass bed and causing a silty plume to form in the water (Heinsohn, *et al.*, 1977; Anderson and Birtles, 1978).

Diving behaviour

As bottom feeders, dugongs spend little time at or near the surface, although most animals surface to breathe at frequent intervals. Anderson and Birtles (1978) timed dives in Shoalwater Bay where dugongs were digging up whole seagrass plants. The mean time for each dive was 73.3 sec with a maximum of 400 sec. Marsh and Rathbun (manuscript) obtained similar dive times for a dugong tagged with a conventional radio-transmitter; on average this dugong spent 3.2% of its time at the surface during their (daytime) observations. The radio-tracking studies indicate that dugongs spend much more time at the surface at night (Marsh and Rathbun, manuscript).

Given their essentially coastal distribution and dependence on seagrass for food, it is doubtful that dugongs dive to any considerable depth. The deepest dive that I know of is an anecdotal account of a diver meeting a dugong in 20m of water in a bed of *Halophila spinulosa* in western Torres Strait (T. Skewes in Marsh, 1988). *Halophila decipens* is the only seagrass recorded at depths of greater than 11m in the GBR lagoon (Coles *et al.*, 1987) where it has been recorded at depths of 68m (P.K. Arnold in Lanyon, 1986). During aerial surveys in the GBR region, I have observed dugongs near the surface in water up to 37 m deep (Marsh and Saalfeld, manuscript a).

Movements

As detailed by Marsh and Rathbun (manuscript), techniques were developed during this project for tracking individual dugongs using buoyant, tethered, conventional and satellite radio transmitters, and subsequently applied to six dugongs caught in the GBR region. The dugongs (one immature, one pubertal and four mature males) were caught by bull-dogging or hoop-netting and tracked for between one and 16 months.

All spent most of their time in the vicinity of inshore seagrass beds using overlapping home ranges of 4 to 23 km^2. The only dugong to undertake long-distance movements was the pubertal male which journeyed between core areas in two bays about 140 km apart three times in nine weeks, completing the journey in as little as two days. One of the adult animals made several journeys about 10 km up the tidal reaches of a creek. The results of the two dedicated aerial surveys of the region between Cape Bedford and Cape Melville also indicate that dugongs undergo local movements (Marsh and Saalfeld, manuscript a).

These results support the GBRMPA's policy of conserving dugongs by giving a high level of protection to some inshore seagrass beds that support large numbers of animals. However, the results also indicate that it is important that such areas extend to both the seaward and landward margins of the seagrass beds. For example, the movements of dugongs monitored by satellite in the Starcke River region showed that the Scientific Zone is too close to the coast to give adequate protection to the dugongs (Figure 1). One animal made several journeys 10 km up the tidal sections of an adjacent creek, indicating the need for complementary zoning of the coastal areas in Queensland adjacent to areas zoned to protect dugongs in the GBRMP.

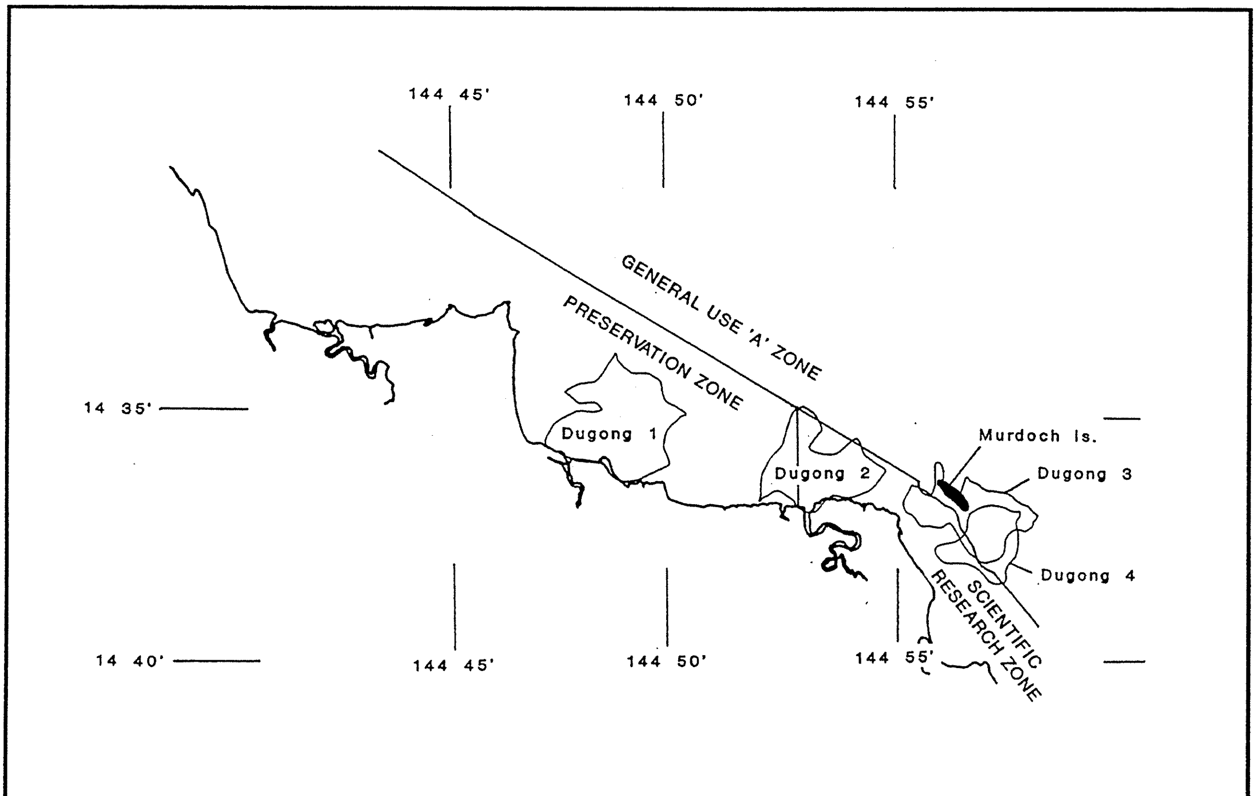

Figure 1. The seaward boundaries of the Scientific Research Zone and the Preservation Zone in the Starcke River area are too close to the coast to protect dugongs as shown by the home ranges of four mature males whose locations were monitored by satellite in the summer of 1987-88.

Abundance

During this project, procedures were developed for the large scale aerial census of dugongs (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 resultant population estimates are probably 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).

As summarized in Table 1, surveys were conducted between the coast and the outer barrier reefs from Dunk Island (17°59'S., 146°14'E.) at the boundary of the Cairns and Central Sections of the GBRMP to Hunter Point (11°30'S., 142°50'E.) in the Far Northern Section, and over the inshore waters to about 20 km offshore in the remainder of the GBR region (Marsh and Saalfeld 1988, manuscripts a and b).

Table 1. Details of dedicated aerial surveys for dugongs conducted in the Great Barrier Reef region 1984-87.

Survey	Date	Area km^2
Cape Melville to Cape Bedford	November 1984	7952
Hunter Point to Campbell Point	April 1985	15497
Hunter Point to Cape Bedford	November 1985	31288
Cape Bedford-Dunk Is	October 1987	11528
Dunk Is -Cape Cleveland	September 1986 October 1987	5480
Cape Cleveland- Repulse Bay	December 1985 October 1987	6298
Repulse Bay - southern boundary of the GBRMP	November 1986	16090
TOTAL		94133

These surveys were conducted at sampling intensities ranging from 7.9 to 12.2% and represent more than 250 hours of flying.

When the results of the surveys are summed (Table 2), the dugong population estimate for the GBR Region is about 11,600 $\pm$ 1170 animals, more than two thirds of which occur from Cape Bedford (near Cooktown) north.

Distribution and Habitat Usage

Consistent with the results of the tracking studies (Marsh and Rathbun, manuscript) which indicated that dugongs spend most of their time in the vicinity of inshore seagrass beds, about 60% of dugong sightings on the dedicated aerial surveys were associated with known seagrass beds. This figure is probably an underestimate reflecting our incomplete knowledge of seagrass distribution away from the coast.

Between 1984 and 1988, Dr R G Coles and his co-workers in the Queensland Department of Primary Industries mapped the seagrass beds in the inshore waters of the Great Barrier Reef Marine Park between the tip of Cape York and Water Park Point (22°56'S, 150°47'E). Because of the huge area involved, this was a broad-scale mapping exercise in which the transects were spaced at 5 nautical mile

(9.26 km) intervals along the coast. Some small beds of seagrass have undoubtedly been missed from the resultant maps, and it is likely that the areas of some of the other beds have been underestimated.

Table 2: Distribution and abundance of dugongs in the Great Barrier Reef Marine Park on the basis of aerial surveys conducted between 1985 and 1987.

Area **(estimate ± S.E.)**	**Number of dugongs**	**Precision**
Far Northern Section (northern boundary to Hunter Point)[1]	1 sighting only[2]	
Far Northern Section (Hunter Point to southern boundary) + Cairns Section (northern boundary to Cape Bedford)[3]	8110 ± 1073	0.13
Cairns Section (Cape Bedford to southern boundary)[4]	6 sightings only[2]	
Central Section[4]	1532 ± 273	0.18
Capricorn Section[5]	1947 + 369	0.19
TOTAL	11589 ± 1167	0.10

[1] surveyed in November, 1987

[2] too few sightings to estimate numbers

[3] surveyed in November, 1985

[4] surveyed in October, 1987

[5] surveyed in November, 1986

The dedicated aerial surveys conducted for dugongs in this project were also designed to obtain a large-scale picture of their distribution and abundance, and some minor dugong areas were undoubtedly missed. Some have shown up in the incidental sightings (Spencer, manuscript). Much of the region was surveyed only once. As both the results of the surveys (Marsh and Saalfeld, manuscript a) and the tracking studies (Marsh and Rathbun, manuscript) indicate that dugongs undergo local movements, our knowledge of dugong distribution in the region is still incomplete. Nevertheless, there is very good agreement between the dugong and seagrass distribution maps in inshore areas (Figure 2), and I believe that most of the major dugong areas which merit consideration in the preparation of zoning plans have been identified, unless dugongs use specialized mating and calving areas away from seagrass beds.

Far Northern Section

The Far Northern Section has the highest area of inshore seagrasses in the GBRMP (about 750 km^2) plus significant seagrasses on some mid-shelf reefs particularly in the Princess Charlotte Bay region

(Hopley, 1982). This is also the most important dugong area in the Park, with more than half the dugongs in the GBR region. Dugongs are distributed all along this coast, especially in the sheltered bays (Figure 2a). Dugongs also use the inshore and midshelf reefs in this Section, particularly the large platform reefs such as Corbett Reef in Princess Charlotte Bay and the mid-shelf reefs near the Howick Islands.

The Starcke River region which straddles the Cairns and Far Northern Sections of the GBRMP is the most important dugong area in the Park. I estimate that about 20% of the region's dugongs occur in this area. The estimated area of seagrass in this region (129 km^2) is almost certainly seriously under-estimated (see Figure 4 and Table 4 below), especially at its seaward margin.

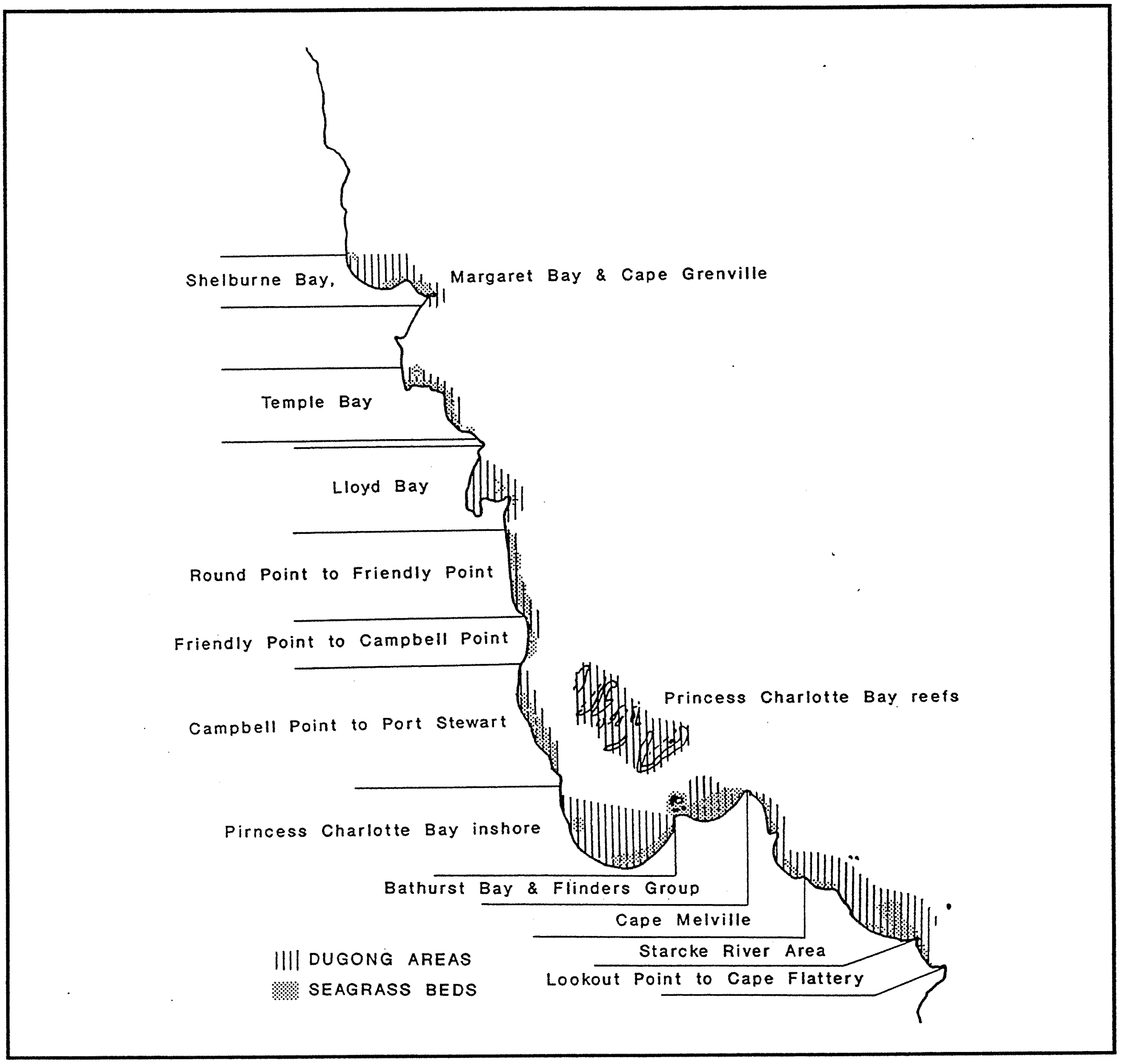

Figure 2a. The distribution of known major dugong and inshore seagrass areas in the Far Northern Section of the GBRMP and the Cairns Section north of Cape Bedford. The distribution of dugongs suggests that the seaward margins of some of the seagrass beds have been underestimated. Seagrasses also occur on the planar reefs in Princess Charlotte Bay (Hopley, 1982).

Cairns Section

South of Cape Bedford, the Cairns Section has little seagrass (about 34 km^2), and although dugongs occur along this coast in low densities there are probably no areas of great significance. Dugongs are occasionally sighted on the mid-shelf reefs in the Cairns Section.

Central Section

The estimated area of seagrass in the Central Section is 357 km^2, and this Section is estimated to contain about 13% of the dugongs in the GBR. Of particular importance are the sheltered areas such as the Hinchinbrook Island area, Cleveland Bay, Upstart Bay and Edgecumbe Bay (Figure 2b). I know of no reports of dugongs using the mid-shelf reefs in this region, but they are seen around some of the offshore islands such as the Whitsundays.

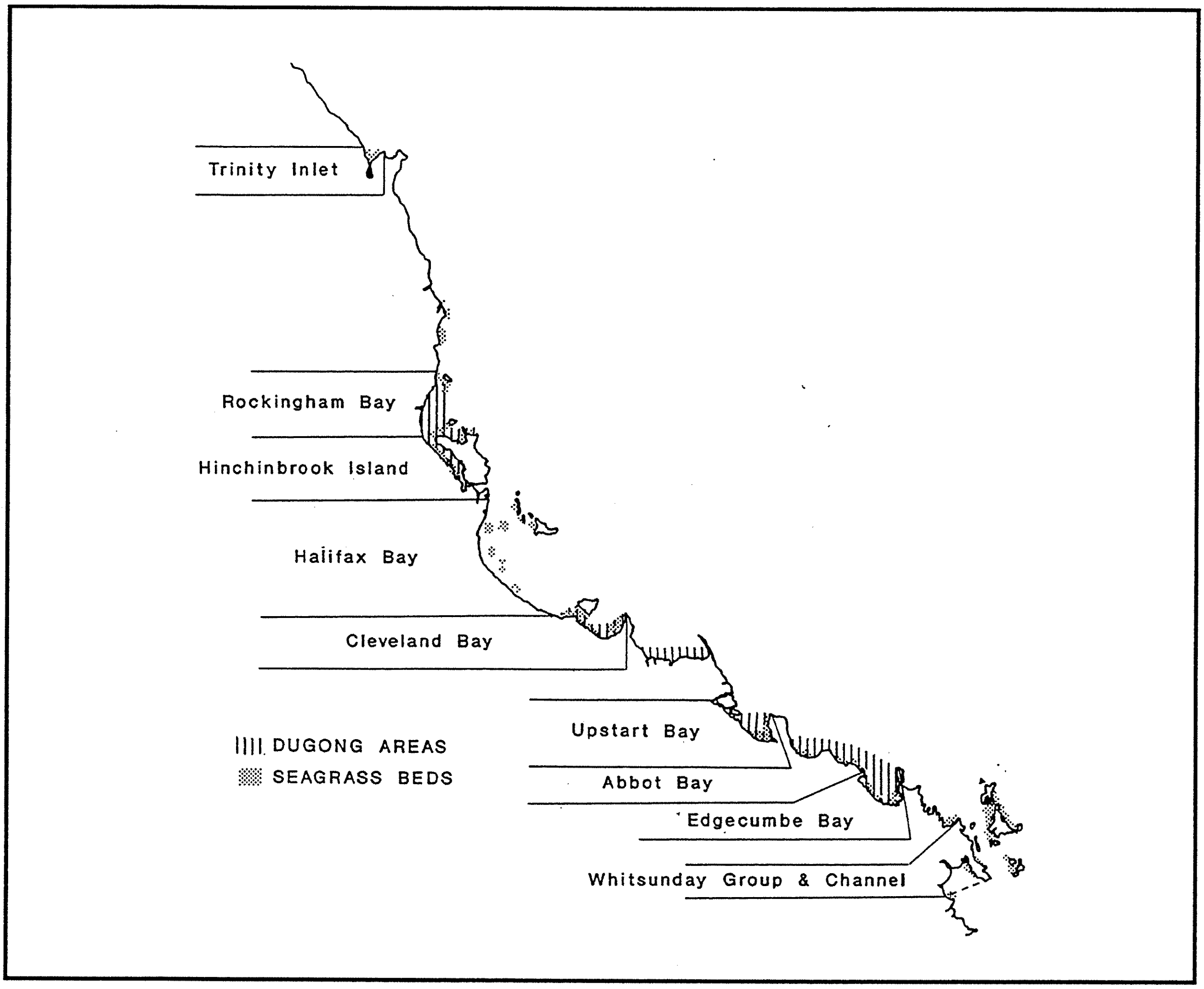

Figure 2b. The distribution of known major dugong and inshore seagrass areas in the Cairns Section of the GBRMP south of Cape Bedford and the Centrl Section. The distribution of dugongs suggests that the seaward margins of some of the seagrass beds have been underestimated.

Mackay/Capricorn Section

The pattern of dugong distribution in the Mackay/Capricorn Section (Figure 2c) is very similar to that in the Central Section, and the estimated dugong population is about 17% of that in the GBR region. The area of seagrass (186 km^2) is underestimated as figures are not available from Water Park Point south. The most important dugong areas are the Port Newry area (where the distribution and abundance of dugongs suggest that the area of seagrass is probably seriously underestimated), Llewellyn and Ince Bays, Shoalwater Bay, Port Clinton, and Rodd's Bay. Dugongs have occasionally been sighted around some of the offshore islands such as North West and Lady Elliott.

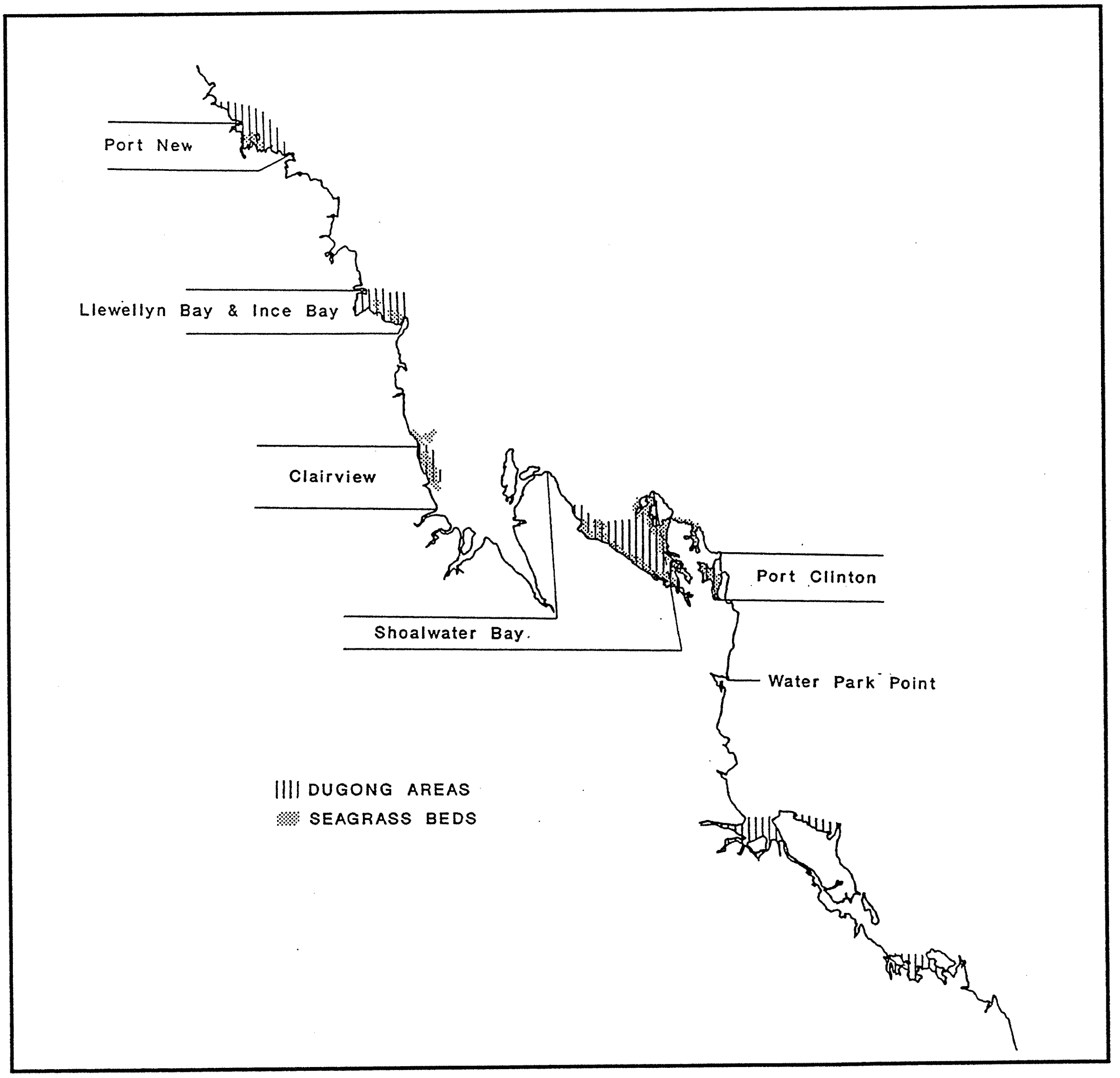

Figure 2c. The distribution of known major dugong and inshore seagrass areas in the Mackay/Capricorn Sectionof the GBRMP. The distribution of dugongs suggests that the seaward margins of some of the seagrass beds have been underestimated. To date the area south of Water Park Point has not been surveyed for seagrasses.

Group size

Although dugongs have been observed in tightly clustered herds of up to several hundred animals (e.g Heinsohn, *et al.*, 1978; Spencer, manuscript; personal observations), during our dedicated aerial surveys in the GBRMP (Marsh and Saalfeld, manuscripts a and b), the largest group sighted was of 20, and only about 13% of animals sighted were in groups of greater than five. Sixty-one percent of animals sighted were cow/calf pairs or single dugongs, suggesting that the cow/calf pair is the only long-lasting social unit.

The small mean group size seen on the surveys may have been an artefact of the survey conditions. If a herd is loosely grouped, only a small portion of the herd may be seen at once from a low flying aircraft, even in clear water. Also the dedicated surveys were always conducted when seas were calm; most surveys were conducted in between September and November. Thus the group sizes observed may not be typical of other weather conditions or times of year. Larger groups of 100 or so dugongs are routinely observed in the GBRMP by Coastal Surveillance (Spencer, manuscript).

Assessment of Threats to Dugongs in the GBR region

Traditional hunting

The Great Barrier Reef Marine Park Act (Australia, 1975) does not refer to traditional hunting and fishing interests or suggest that certain areas should be set aside for traditional use. However, the regulations incorporated in Zoning Plans for the various Sections of the Park make provision for traditional hunting in all parts of the Park except Preservation Zones, subject to a permit being granted.

Queensland legislation applies to waters above low water and those inshore waters excluded from the GBRMP. The State Government's Community Services (Aborigines) Act (1984) exempts members of an Aboriginal community residing on Trust Areas (formerly Reserves) from fisheries legislation provided the take is by traditional means for consumption by members of the community; a similar provision is contained in the Queensland Fisheries Act (1976).

The interrelationship of the Commonwealth and State Acts is complicated in the inshore (Queensland) waters of the GBRMP where most dugong hunting occurs. For example, an Aborigine could theoretically be given a permit to hunt dugongs within a specified Zone within the GBRMP, but be prevented from doing so in the Queensland waters within that Zone because he was not a resident of a Trust Area (Australian Law Reform Commission, 1986).

Aborigines and Islanders from the following Trust Areas live adjacent to the GBR region: Bamaga area (Cowal Creek, New Mappoon Seisia, Bamaga), Lockhart River, Hopevale, Wujal Wujal, Yarrabah, and Palm Island. There is no legal hunting in the region south of Palm Island (Figure 3). The extent of illegal hunting is unknown, but I have anecdotal evidence of Aborigines and Islanders hunting in Upstart Bay, and around Mackay and Gladstone. In addition, some members of the Weipa South Aboriginal community occasionally visit relatives at Lockhart River to obtain dugong meat in exchange for alcohol.

Smith (see Smith and Marsh, in press) monitored the dugong catches of members of the Hopevale community for 16 months between 1984 and 1986, and the Lockhart River community for three months in late 1985. Catch statistics are also available for Hopevale for 1987. The total catches were 74 dugongs over four years at Hopevale and 15 over three months (the major annual hunting period) at Lockhart River. Smith concluded that the catch is unselective and well below the sustainable yield of the population based on aerial survey estimates (Smith and Marsh, in press).

The recommendations concerning the management of traditional hunting developed by Smith (1987) and outlined in Smith and Marsh (in press) are currently being evaluated. This management system involves a hierarchical list of management options. In increasing severity, they are:

(a) community dugong hunting permits;

(b) declaring current dugong hunting areas as 'official', hunting areas;

(c) closed seasons;

(d) quotas.

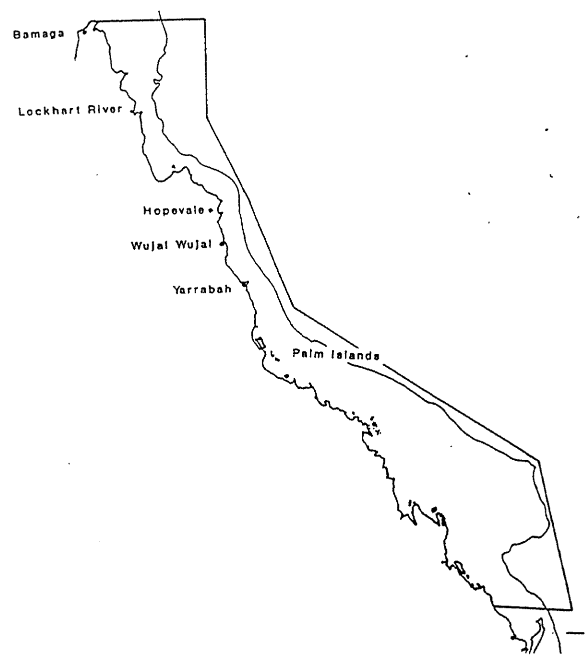

Figure 3. Aboriginal communities bordering the GBRMP which are allowed to hunt dugongs under Queensland law. The members of these communities must apply for a permit from the GBRMPA to hunt dugongs within the Park.

This broad management system allows each community to be covered by the same scheme but permits flexibility to cater for the unique situation experienced at each community. It also allows for applying different options as circumstances change.

The Yarrabah community's requests for permits to hunt on Bat/Tongue Reefs have not been granted, due to the low numbers of dugongs in these areas. Hunters from Yarrabah can hunt in Mission Bay (which is adjacent to their community) without a permit as Mission Bay is not included in the GBRMP.

Permits have been granted to the communities in the Bamaga area, Lockhart River, Hopevale and Wujal Wujal, and a permit has been drafted for the Palm Island community. All are community hunting permits which specify the hunting areas. There is a closed season for dugong hunting at Hopevale to prevent over-exploitation in the dry season when the hunting ground can be accessed by road. There are no quotas.

Commercial gill netting

There is anecdotal evidence that dugongs drown in commercial gill-nets. The number killed is unknown. The anecdotal information and my personal experience (Heinsohn *et al.*, 1976) confirm that several dugongs can be drowned in a single incident. For example, the local Fisheries Patrol Officer informed me that at least seven and possibly up to 14 dugongs drowned in one gill-net set for mackerel in Hervey Bay (just south of the GBR region) in August 1986. There was a similar incident in the same area in August 1988. The second incident resulted in a change in the local fishing regulations. However, such incidents are fairly rare and more likely to occur to fishermen who do not know an area. Fishermen who regularly operate in high density dugong areas typically develop strategies to minimize the chances of dugongs tangling in their nets because of the resultant net damage.

In January 1989, the Queensland Fish Management Authority advised me that there are 227 fishermen in Queensland who nominated net fishing as their principal operation. The number of fishermen with net entitlements is much higher than this. Of these, 531 live in areas adjacent to the GBR region. As many fishermen operate in several Sections of the GBRMP, it is not possible to assess the number of fishermen who are likely to have the potential to catch dugongs incidentally in various areas without access to confidential log book information.

Gill-netting for barramundi is banned under Queensland law from November through January to protect stocks. In addition, under the GBRMP Zoning Plans, gill-netting has been banned from areas zoned Marine National Park 'A' or higher, including some important dugong areas, especially in the Far Northern Section (see Table 4 below). There is currently considerable debate among commercial gill-netters and recreational fishermen about access to barramundi stocks in tourist areas. It is likely that commercial gill-netting will be banned from some of these areas with a concomitant relaxation of the use of foreshore gill-nets to target other species in the mouths of creeks during the barramundi closure.

The dugong population of the GBR region (Table 2) is much greater than I had thought prior to the start of this project, and I now consider that I probably over-estimated the magnitude of the likely impact of commercial gill-netting on dugong stocks (Marsh, 1987). However, this mortality is still of great concern to Aborigines and Islanders who understandably resent their hunting being restricted when the problem of incidental capture of dugongs in gill-nets is still ignored in many areas.

It is probably futile to attempt to obtain a reliable estimate of the magnitude of this incidental take, although a study of the log books would give some idea of the potential problem in various areas. Fishermen are understandably reluctant to admit to drowning dugongs when they know this to be illegal. A more profitable approach would be for the relevant management authorities to supply the fishermen with maps of high density dugong areas, and to advise them to avoid them in order to minimize damage to their nets. It would also be advantageous to dugongs if measures could be advised to discourage fishermen from fishing in unfamiliar areas.

Shark-netting for bather protection

A shark-netting program has operated on major recreational beaches in Queensland since the mid 1960's. There is considerable public support for this practice as a swimmer has never been attacked by a shark on a meshed beach. As detailed by Paterson (1979), shark meshing kills other marine vertebrates including dugongs. Within the GBRMP, the combined toll of dugongs caught in shark nets at Yeppoon, Mackay, Townsville and Cairns from 1964 to date has been 456 (Table 3, and Queensland Department of Harbours and Marine statistics). Most were taken in the first years of netting. Annual catches are now low with only 23 dugong catches for the whole region since July 1983. In view of the large numbers of dugongs killed in the early years of netting (e.g. 81 in the Townsville shark nets in 1964, Paterson, 1979), it would be inadvisable for shark netting to be introduced to other areas which support large numbers of dugongs.

Table 3. Details of dugong catches in shark nets in the GBR region between 1964 and 1983 (Paterson, 1979 and pers. comm. 1984).

Location	Total dugongs caught to July 1983	Maximum caught in one year
Yeppoon	43	12 (1973/4)
Mackay	37	22 (1969/70)
Townsville	249	81 (1964/5)
Cairns	104	20 (1968/9)

It is unfortunate that the shark meshing contractors are not required to record more information (e.g. sex and body length) from the dugongs that drown in their nets. Useful life history information could be obtained if the Townsville shark contractor were required to make dugong carcasses available to the James Cook dugong research group.

Trawling

I know of only two instances of dugongs drowning in trawls and believe it to be a rare event. The most serious impact of trawling on dugongs is likely to be habitat damage resulting from the trawl digging up seagrass. Seagrasses are important as prawn nursery areas (Coles *et al.*, 1987), and there has been considerable pressure from within the industry to ban trawling from known seagrass beds for economic reasons. Trawling is now banned from most of the important dugong areas within the GBR region (it is allowed only in General Use 'A' areas), and I believe that the remaining anomalies will be rectified soon. As discussed below, there certainly needs to be a check on the boundaries of the seagrass beds in some areas eg. Starcke River and Port Newry. The impact of trawling is also reduced by seasonal closures.

Other habitat damage

Most species decline because of destruction of their habitat (Caughley, 1985). Larkum and West (1982) list several sources of potential habitat damage to seagrass beds including:

(1) turbidity increase associated with dredging, industrial or urban influences, and eutrophication;

(2) toxic chemicals, hot water effluent, oil spills, sewerage and changes in salinity.

Except in the areas close to major cities such as Gladstone, Townsville and Cairns, habitat damage to seagrass beds *per se* in the GBR region is probably relatively minor. However, given the commercial value of these areas as prawn nurseries and their conservation value as dugong and green turtle habitats, steps should be taken to minimize damage to such areas in the future.

Status

The first population estimates for dugongs in the Great Barrier Reef Region area are based on the dedicated aerial surveys conducted during this project. I am, therefore, unable to determine whether dugong numbers in this area are increasing, decreasing or stable. Indeed, as argued in Marsh and Saalfeld (manuscript a) and below, I calculate that it will be at least a decade before this can be determined.

I have investigated the relationship between the estimates of the area of seagrass and dugong numbers for 24 sites in the GBR region where Coles estimated the area of seagrass to be 10 km^2. The dugong population estimates for some of these areas should be regarded as very approximate as they were based on few sightings. If two estimates of dugong numbers were available for an area, I used the larger. The results (Table 4 and Figure 4) indicate that there is significant positive linear relationship between the corresponding estimates of dugong numbers and seagrass area in the GBR region (Spearman Rank correlation coefficient = 0.85; n = 24; p.001). The most obvious exception to the overall trend (Figure 4) is the estimated dugong population of the Starcke River region which appears to be too large, reinforcing my view that the area of seagrass in this region has been underestimated.

Table 4 also suggests some other patterns which are relevant to the assessment of the status of the dugong in the Great Barrier Reef Marine Park:

Table 3:Estimated dugong population and marine park zoning status of areas with more than 10km^2 of seagrass in the Great Barrier Reef region. Three important dugong areas in the GBR region have been omitted from this table: large mid-shelf reef in Princess Charlotte Bay (Far Northern Section), Rodd's Bay (Mackay/Capricorn Section) for which no estimates of seagrass are available and Port Newry (Mackay/Capricorn Section) for which the estimate area is less than 10km^2.

Location	Location boundaries	Area of seagrass[1] (km^2)	Estimated dugong population[2]	Dugong density per km^2 seagrass	Major GBRMP Zoning[3]	Minor GBRMP Zoning[3]
Far Northern Section						
Shelburne Bay, Margaret Bay & Cape Grenville	Red Cliffs to Cape Grenville	29.71	367	12.35	MNPB	EX
Temple Bay	Bolt Head to Portland Roads	27.48	304	11.06	GUB	EX/MNPB
Lloyd Bay	Cape Weymouth to Round Pt.	16.71	165	9.87	GUB	GUA/MNPA
Round Pt. to Friendly Pt.	Round Pt. to Friendly Pt.	99.24	713	7.18	GUB	
Friendly Pt. to Campbell Pt.	Friendly Pt. to Campbell Pt.	15.44	296	19.17	MNPB	
Campbell Pt. to Port Stewart	Campbell Pt. to Port Stewart	159.72	941	5.89	GUB	
Princess Charlotte Bay	Port Stewart to Bathurst Heads	66.40	1012	15.24	GUB	
Bathurst Bay & Flinders Group	Bathurst Heads to Cape Melville	202.86	1129	5.57	GUB	EX/MNPA
Cape Melville	Cape Melville to Red Pt.	84.29	974	11.56	PZ	MNPB/EX/GUA
Starcke River Area[4]	Red Pt. to Lookout Pt.	129.54	2549	19.68	SRZ	GUA/MNPB/PZ
Cairns Section						
Lookout Pt. to Cape Flattery	Loockout Pt. to Cape Flattery	10.67	36	3.37	EX	
Cairns Inlet	Ellie Pt. to False Cape	11.85	0	0.00	EX	
Central Section						
Rockingham Bay	Mission Beach to Cardwell	12.99	151	11.62	GUA	GUB/EX
Hinchinbrook Is.	Cardwell to Lucinda	48.17	340	7.06	GUB	GUA
Halifax Bay	Lucinda to Bohle River	22.20	47	2.12	EX	
Cleveland Bay	Bohle River to Cape Cleveland	86.60	375	4.33	GUA	EX/MNPA
Upstart Bay	Burdekin River to Cape Upstart	58.31	380	6.52	GUB	GUA/EX
Abbot Bay	Cape Upstart to Cape Edgecumbe	29.42	177	6.02	EX	
Edgecumbe Bay	Cape Edgecumbe to Gloucester Is.	24.38	208	8.53	GUB	GUA/EX
Whitsunday Group & Channel	Pioneer Pt. to Cape Conway	39.49	62	1.57	GUB	MNPA
Mackay/Capricorn Section						
Llewellyn Bay & Ince Bay	Freshwater Pt. to Cape Palmerston	11.24	222	19.75	GUB	GUA
Clairview	West Hill Is. to St. Lawrence Ck.	20.32	77	3.79	EX	GUA
Shoalwater Bay	Broome Hd. to Cape Townshend	48.36	560	11.58	GUB	GUA/MNPB
Port Clinton	Port Clinton	13.93	142	10.19	EX	

[1] Seagrass areas from R. G. Coles unpublished.
[2] Based on the results of aerial surveys (Marsh and Saalfeld, manuscript a & b).
[3] EX = excluded; GUA (or B) = General Use 'A' (or 'B'); MNPA (or B) = Marine National Park 'A' (or 'B'); PZ = Preservation Zone; SRZ = Scientific Research Zone.
[4] Straddles boundry of Far Northern and Cairns Sections.

(1) The density of dugongs per area of seagrass tends to be higher in the Far Northern Section than in the remainder of the GBR region. This is true even when corrected for the size of the seagrass bed(s) (Figure 5).

(2) Some areas in the Far Northern Section have a high density of dugongs even though they are subjected to traditional hunting (Starcke River area, Lloyd Bay, Temple Bay), and gill netting (Princess Charlotte Bay).

(3) Five of the six seagrass areas with the lowest density of dugongs have high boat traffic: Cairns Inlet, Whitsunday Group and Channel, Halifax Bay, Lookout Point to Cape Flattery, Cleveland Bay. The other such area is Clairview (Table 4). Aboriginal dugong hunters have frequently told me the dugongs do not frequent areas with noisy boats.

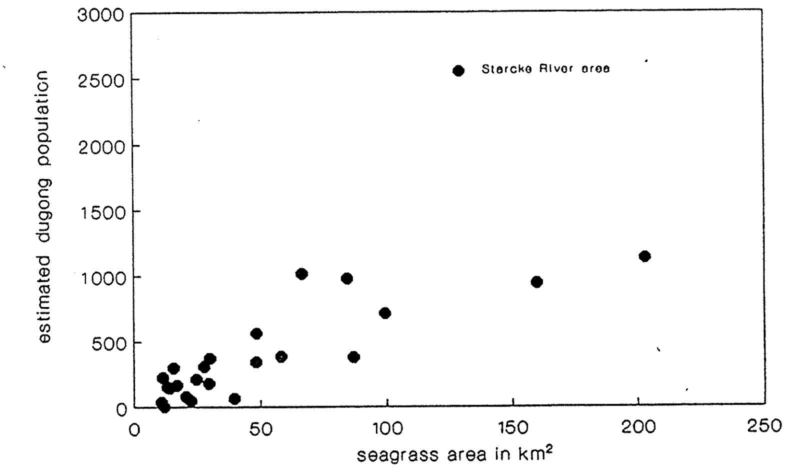

Figure 4. The relationship between dugong numbers estimated on the basis of aerial survey and area of seagrass for sites within the GBR region where the estimated area of seagrass is greater than 10km².

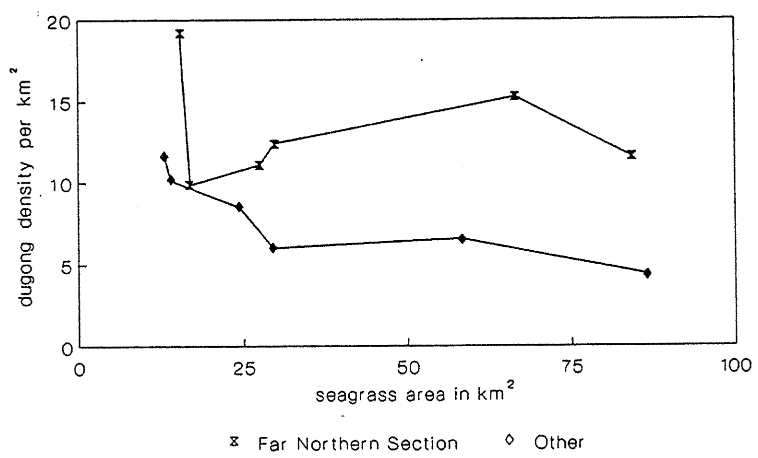

Figure 5. The density of dugongs per area of seagrass in areas of seagrass of comparable size in the Far Northern Section and the remainder of the Park.

Evaluation of current zoning

Given the estimated slow rate of change in dugong numbers, the effects of the current differences in marine park zoning of the 27 major dugong areas (Table 5) are unlikely to have had a significant impact on dugongs as yet. However, it is very obvious from Table 5, that the level of protection afforded important dugong areas is unevenly distributed in the various regions of the Park. In particular, there is no major dugong area south of the Starcke River which has been given Marine National Park status or higher. Because it will not be possible to confirm the status of the dugong populations within the GBR region for at least a decade (see below), I consider that it is important that at least one such area be protected in this way. If the dugong is sensitive to boat traffic as the results in Table 4 suggest, it will also be desirable to carefully manage tourist development adjacent to important dugong areas in the Far Northern, Central and Mackay/Capricorn Sections of the Park, and to minimize development adjacent to prime dugong habitats such as the Starcke River area.

Table 5. The present zoning status of the major dugong areas in the GBRMP (Figure 2). The figures are the number of dugong areas in each Section with the relevant zoning status. When a dugong area includes more than one zone, the zoning status of the area of highest dugong density is used. The Starcke River area which spans the boundary of the Cairns and Far Northern Sections is included in the Far Northern Section.

SECTION	PZ/SRZ[1]	MNPB	MNPA	GUB	GUA	EX
Far Northern	2	3		6		
Cairns						2
Central				4	2	2
Mackay/Capricorn				3		3

[1] **PZ**=Preservation Zone; **SRZ**=Scientific Research Zone; **MNPA/B**= Marine National Park 'A'/'B'; **GUA/B**=General Use 'A'/'B'; **EX**= Excluded.

Future monitoring of dugong numbers

As outlined above, dugongs are long-lived animals with a natural rate of increase which is unlikely to exceed 5% per year even with low natural mortality and no anthropogenic causes of mortality. Under the present zoning and management regulations, the level of man-induced mortality in most parts of the GBRMP should be low. Thus, barring catastrophes, the annual rate of population change is also expected to be relatively low.

When designing a monitoring program for a vulnerable species such as the dugong, the consequences of failing to pick up a declining trend are more serious than the consequences of deciding that a declining trend is occurring when it is not. Thus it is particularly important to consider Type 2 statistical errors. If this expected slow rate of dugong population change is to be monitored within an acceptable range of statistical error, the precision of the population estimates will have to be high. Under a constant intensity of sampling, the precision of a population estimate improves as the size of the survey area is increased as evidenced by Table 2 (see also Tables 4 in Marsh and Saalfeld, manuscripts a and b). Thus future surveys for dugongs in the GBRMP should cover large areas e.g. the whole region north or south from Cape Bedford. October-November is the only time of year when weather conditions are likely to be optimal for a period long enough to survey such large areas adequately, making it unrealistic to plan more than one survey of the area in any one year. (It would not be logistically feasible for the same crew to survey the whole reef region in one October-November period using the designs used in this study).

Gerrodette (1987) outlines procedures for estimating the minimum number of samples required to detect a trend in numbers using linear regression. His technique has been used to investigate how long it would take to detect with acceptable levels of confidence that a dugong population which was decreasing at 5% per year was in fact declining i.e. that the slope of the regression line was significantly less than 0. The following assumptions were made:

(1) improvements in survey design would increase the precision to 11%;

(2) the coefficient of variation is inversely related to the square root of abundance as predicted for strip transects by Seber (1982). The probabilities of a Type I error α and a Type II error β were both set at 0.05.

It is estimated that it would take 9 years of annual surveys, i.e. ten surveys, to be able to detect such a decline with 95% confidence. Meanwhile, a dugong population declining at 5% per year would have been reduced to 63% of its size at the time of the first survey. A preliminary indication of such a trend could be obtained more quickly by allowing α and/or β to assume larger values. Of course, a more rapid decline would be detected more quickly with the same frequency of surveys.

As Gerrodette (1987) points out, annual surveys are probably not the optimum frequency of sampling for a population that is changing slowly. As the interval between surveys increases the effective rate of change per interval increases, and the required number of surveys therefore decreases (see Gerrodette, Table 2). For example, two dugong surveys 10 years apart could establish with 95% confidence that a population decreasing at 5% per year is declining. Such a low survey frequency would obviously provide substantially less information than annual surveys.

Any sampling strategy will be a compromise between information and cost. The GBRMPA is required by law to revise zoning plans every five years. Given the expense, time and personnel needed to conduct large-scale surveys in remote areas, I suggest that this would also be an appropriate interval between dugong surveys in the GBRMP, and that the areas north and south of Cape Bedford should be surveyed in consecutive years at five year intervals.

In order to maximize the capacity for such surveys to detect changes in dugong numbers, future surveys should use the designs developed in this study (except that it would be reasonable to reduce or eliminate sampling in areas where no dugongs were sighted in the 1984-1987 and which contain no suitable habitat). The cost effectiveness of surveying areas of low dugong density will depend on the value to the Authority of the information obtained about the distribution and abundance of sea turtles (Marsh and Saalfeld, in press and in prep a) and cetaceans (Marsh and Saalfeld, in prep b).

Information on dugong sightings obtained from the Q.NPWS monitoring program should be collated in a data base to provide additional information on dugong habitat usage. However, these data will not be suitable for documenting population trends.

Future research

The research to date suggests that the most appropriate strategy for conserving dugongs is to protect their seagrass habitats and to minimize man-induced mortality in areas of high dugong density. The success of this strategy will be lessened if dugongs use specialized mating and calving areas which are not associated with seagrass beds. Long-term monitoring of adults fitted with combined conventional and satellite transmitters as developed by Marsh and Rathbun (manuscript) is required to determine this. It would be profitable if this research were carried out initially in areas where dugongs occur in clear water e.g. Moreton Bay near Brisbane. The research should then be extended to key areas in the Far Northern Section of the Park. It would be particularly useful, if time-depth recorders could be attached to the radio-tracked animals to document the proportion of time individual dugongs spend at the surface so that the proportion of animals which are unavailable to observers due to water turbidity availability bias) can be estimated more accurately. This would lead to more accurate population estimates and allow a better evaluation of the status of the dugong within the GBRMP.

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Part 2

Papers reporting the results of the dedicated aerial surveys

This volume includes the following papers and report which have resulted from the dedicated aerial surveys conducted during this project:

Marsh, H., and Sinclair, D.F. (1989) Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. *J. Wildl. Manag.* **54**(4).

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

Marsh, H., and Saalfeld, W.K. (1989) The distribution and abundance of dugongs in the northern Great Barrier Reef Marine Park. *Aust. Wildl. Res.* **16**(5).

Marsh, H., and Saalfeld, W.K. (manuscript) The distribution and abundance of dugongs in the southern Great Barrier Reef Marine Park. Submitted to *Aust. Wildl. Res.*

Marsh, H., and Saalfeld, W.K. (1988) The distribution and abundance of dugongs in the Torres Strait region. Report to the Australian Fisheries Service, the Great Barrier Reef Marine Park Authority and the Fisheries Management Branch of the Queensland Department of Primary Industries, June 1988.

Marsh, H., and Saalfeld, W.K. (1989) Aerial surveys of sea turtles in the northern Great Barrier Reef Marine Park. *Aust. Wildl. Res.* **16**(3).

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CORRECTING FOR VISIBILITY BIAS IN STRIP TRANSECT AERIAL SURVEYS OF AQUATIC FAUNA

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Abstract: We develop methodology for correcting for visibility bias by calculating and applying survey-specific correction factors in strip transect aerial surveys of aquatic fauna and incorporating their associated errors into the population estimate. The technique is applicable at all densities of the target species. Perception bias (the proportion of groups of the target species that are visible in the transect yet missed by observers) is corrected for using a modified Petersen estimate calculated for each of 2 teams of 2 observers with 1 team on either side of the aircraft. Within a team, each observer reports their uncolluded observations into a separate track of a 2-track tape-recorder, so that after the survey, each group can be characterized as being seen by only 1 (specified) or both members of the team. A correction factor is also suggested to standardize for the proportion of animals which are unavailable to observers because of water turbidity.

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aerial surveys, aquatic fauna, dugongs (Dugong dugon), survey-specific, correction factors, visibility bias.

Aerial surveys have been used to estimate population sizes of wildlife since the late 1940's (Caughley 1979). The technique has been plagued by the problem of "visibility bias" resulting from animals being missed by observers. Caughley (1977:35) presents a table of data from a wide range of wildlife surveys showing that it is not unusual for 50-60% of animals to be missed. There are 2 categories of missed animals: those that are potentially visible to observers but are not seen (perception bias), and those that are not available to observers because they are concealed by other animals, vegetation, or turbid water (availability bias).

Caughley (1979) argued that aerial survey estimates are most useful as indices tracking relative density over time, because the bias becomes irrelevant as long as it is held constant by rigid standardization of procedures such as the transect width and the height and speed of the aircraft, and the repeated use of the same survey crew. It is, however, impossible to standardize many other factors that influence visibility bias. Factors such as variable vegetation density, water turbidity, time of day, weather conditions, group size, behavior, and distribution of the target species have major effects on the number of animals sighted in aerial surveys (Bayliss and Giles 1985, Hill et al. 1985, Packard et al. 1985). As such factors have repeatedly been shown to vary even between repeat surveys of the same area, we believe that it is important to develop survey-specific correction factors to correct for perception and availability biases if absolute population estimates are required, or at least to standardize for these biases if trends in numbers are being monitored.

The Petersen mark-recapture model has been used by Henney et al. (1977), Magnusson et al. (1978), Grier et al. (1981), Caughley and Grice (1982), Bayliss (1986), and Eberhardt and Simmons (1987) to develop a correction factor for "visibility bias" (sensu perception bias as defined above). In the technique used by Caughley and Grice (1982) and Bayliss (1986), the target species was counted independently by 2 observers seated behind each other on the same side of the aircraft, simultaneously scanning the same strip transect. The first observer saw (marked) a group which then might or might not be seen by the second observer. Hence, the second observer saw groups of animals in 2 categories: those that were "marked" and which he "recaptured" and those that were "unmarked". As detailed in Caughley and Grice (1982), these data were then used in equations derived from the Petersen estimate to estimate the probability of a group being seen (counted) by each observer. These estimates formed the basis of a correction factor that was used to multiply the observed density of groups of the target species and provide an estimate of true group density. Caughley and Grice (1982) suggested that this correction factor could then be applied to counts obtained in subsequent surveys of the same target species on the assumption that the bias did not vary between surveys. This assumption is unwarranted as discussed above.

There are 2 additional problems with the techniques described by Caughley and Grice (1982) (Pollock and Kendall, 1987). It assumes that all animals are equally catchable and that there is no difficulty in deciding which animals were seen by both observers. The first assumption is clearly violated. Animals that are unavailable to observers have a zero probability of being caught. Bayliss (1986) dealt with this problem by limiting his counts to groups of dugongs (Dugong dugon) on the water surface and assuming that all of these were equally available. He then used a theoretical correction for submerged dugongs to yield a total population estimate. If the only animals seen on a transect are under the water and therefore not scored, this technique can lead to serious biases in both relative and absolute population estimates, and in density distribution maps. This problem is compounded by other sources of sighting heterogeneity such as group size and glare off the surface of the sea.

A more reasonable assumption would be that all available animals are equally catchable. There may be problems with this assumption, however, as the search images of tandem observers are not independent. Because marking and recapturing occur at the same instant, the search image transmitted to both observers would be expected to be nearly identical. If this is so, their specific probabilities of detection, group by group, will have a correlation approaching unity which negatively biases the population estimate (Seber 1982).

The problem of the difficulty in deciding which animals were seen by both observers (especially if the population is dense) means that the technique of Caughley and Grice (1982) and Bayliss (1986) is applicable only at very low densities of the target species. These authors divided each transect into 5-km units, separated by a 7-second pause during which the counts for the last unit were recorded. If both observers recorded a group of animals in the same time slot, it was assumed to be the same group; this procedure is also likely to bias the population estimate negatively.

We develop procedures for using this tandem observer technique to develop survey-specific correction factors for perception bias, even in areas of high animal density. Procedures are also outlined to standardize for availability bias in aerial surveys of large, aquatic animals such as dugongs, and to incorporate the errors in the correction factors into the standard error of the final population estimate.

We thank the Great Barrier Reef Marine Park Authority for supporting efforts to improve dugong aerial survey technique. Earlier versions of this manuscript benefitted from the comments of P. Bayliss, G. Caughley, R.E. Jones, J. Kerr, and an anonymous referee.

SURVEY PROCEDURE

Our procedures were developed for large scale surveys of dugongs in northern Australia. We flew a twin-engine Partenavia 68B at 137 m at 185 km/hour along predetermined transects. The pilot, a front-right survey leader, 2 mid-seat observers, and 2 rear-seat observers comprised the survey team. The middle and rear-seat observers on the same side of the aircraft formed a tandem team searching the same (200-m wide) strip transect defined by transect markers attached to (artificial) wing-struts.

Data were recorded by the survey leader using an Epson HX20 portable computer (Epson, Japan) programmed as a data logger and timer, and equipped with a printer that produced an immediate hard copy of the data. The rear-seat observers reported their sightings to the survey leader via a 2-way intercom system connected to 1 track of a 2-track tape recorder. The mid-seat observers were visually screened from the rear-seat observers with a curtain and acoustically isolated from the other crew (apart from each other). They reported their sightings into the second track of the tape-recorder. The arrangement and duties of the crew are summarized in Figure 1.

All reports from observers were in standardized format; e.g. dugongs: group size, number of calves, number at the surface, position of sighting in the transect.

The top (furthest from aircraft), middle, and bottom thirds of the transect were color-marked on the artificial wing strut. The position of the sighting in the transect was recorded to increase the probability of distinguishing between different sightings reported simultaneously by both members of a tandem team.

Surveys were carried out only in fine conditions and in calm seas (≤ Beaufort 3). The surveys were timed to minimize glare off the surface of the water associated with a low or midday sun.

After the survey, the tape record of each transect was used to check and edit the computer records, so that each sighting could be coded as being made by 1 (specified) member or both members of a tandem observing team. The reports of team members were deemed to be different if they were unambiguously distinct (usual situation) or if they were separated by ≥5 seconds. Discrepancies between dual sightings of the same group were also noted.

CORRECTING FOR PERCEPTION BIAS

Let S_m = number of groups seen by the mid-seat observer only,

S_r = number of groups seen by the rear-seat observer only,

and b = number of groups seen by both observers.

This fits into the framework of the Petersen mark-recapture model, in which the ($S_m + b$) groups seen by the mid-seat observer are "marked", and b of these groups are "recaptured" by the rear-seat observers. The Petersen estimate (Seber 1982) for the total number (N) of groups available to the observers is:

$$\hat{N} = \frac{(S_m + b)(S_r + b)}{b} \quad . \qquad (1)$$

For given observed numbers ($S_m + b$) and ($S_r + b$), b has a hypergeometric distribution (Seber 1982) and the estimated variance (var) of $\hat{N}$ is

$$\mathrm{var}\ (\hat{N}) \quad = \quad \frac{S_m S_r (S_m + b)(S_r + b)}{b^3} \quad . \qquad (2)$$

Chapman (1951) showed that $\hat{N}$ is biased and proposed a modified estimate,

$$\hat{N} = \frac{(S_m + b + 1)(S_r + b + 1)}{b + 1} - 1,$$

which is unbiased for $(S_m + S_r + 2b) > N$. Seber (1982) estimated the variance of this modified $\hat{N}$ as $\dfrac{S_m S_r (S_m + b + 1)(S_r + b + 1)}{(b + 1)^2 (b + 2)}$.

This variance estimate is also unbiased for $(S_m + S_r + 2b) > N$. The results of all of our dugong surveys (Table 1) satisfy this condition, and the modified $\hat{N}$ has optimal statistical properties as an estimator of the total number of groups available to the observers. Although slightly biased, the estimates of $\hat{N}$ and var $(\hat{N})$ in equations (1) and (2) are adequate for our purposes.

The important point to recognise is that $\hat{N}$ is an estimate of the number of groups of animals available to the observers, and not necessarily of the total number of groups in the population. Provided that it is clear which groups are seen by both observers, the main assumption being made is that all available groups of animals are equally catchable.

Our survey results suggest that this assumption is not unrealistic for dugongs. In an experimental evaluation of aerial survey techniques during which 341 groups were sighted, Marsh and Sinclair (in press, Table 3) used log-linear models to show that the chance of an observer missing a group of >5 dugongs was not significantly different ($\underline{p} \geq 0.43$) from the chance of missing a smaller group. Three of 4 observers missed a group of $\geq$ 10 dugongs (1 occasion each).

The number of groups observed by the tandem team is $(S_m + S_r + b)$. It is convenient to write $\hat{N}$ as

$$\hat{N} = (S_m + S_r + b) \cdot \frac{(S_m + b)(S_r + b)}{b(S_m + S_r + b)},$$

and regard $\frac{(S_m + b)(S_r + b)}{b(S_m + S_r + b)}$ as the perception correction factor, to be applied to the number of groups observed to estimate the true number of groups available to the observers.

Using the delta method (Seber 1982), the approximate variance of the perception correction factor can be shown to be:

$$\frac{S_m S_r \ (S_m + b)(S_r + b)(S_m + S_r)^2}{b^3 \ (S_m + S_r + b)^4} .$$

Thus the approximate coefficient of variation of the perception factor (C_p) is

$$C_p = \frac{S_m + S_r}{S_m + S_r + b} \cdot \sqrt{\frac{S_m S_r}{b(S_m + b)(S_r + b)}} . \qquad (3)$$

Perception correction factors for the port and/or starboard teams on various dugong surveys range from 1.02 to 1.20 (Table 1). The perception correction factors obtained for Moreton Bay (Table 1) were compared empirically with those that would have been obtained using the recording technique of Caughley and Grice (1982) and Bayliss (1986) by dividing each transect a posteriori into a series of 97-second sampling units, each unit representing an area of 2 km^2 at a survey altitude of 137 m. If each member of a tandem pair recorded a group of dugongs in the same unit, it was assumed to be the same group regardless of the timing of the observations. Use of sampling units rather than the 2-track tape-recorder resulted in underestimation of the correction factors for the observing teams by 2.9 and 4.5%. Use of the 2-track tape-recorder clearly reduces errors in deciding which groups have been sighted by both observers.

CORRECTING FOR AVAILABILITY BIAS

The major source of availability bias in aquatic surveys is water turbidity. Conditions can range from extremely turbid so that only animals on the surface are available to very clear when all animals are potentially visible.

Let $\hat{p}_s$ be the proportion of observed animals at the surface in an aerial survey over clear water and $\hat{p}_u$ the proportion seen at the surface in a second survey over more turbid water. Then assuming that the proportion observed at the surface is independent of the observer (as suggested by our data [Marsh and Sinclair in press]), and that $\hat{p}_s$ is a valid estimate of the proportion of animals at the surface for all habitats and under all survey conditions, $\hat{p}_u/\hat{p}_s$ would be an index of the availability bias at the time of the second survey which could be used as the availability correction factor.

Using the delta method, the approximate variance of $\hat{p}_u/\hat{p}_s$ is given by

$$\mathrm{var}\,\frac{\hat{p}_u}{\hat{p}_s} = \frac{1}{\hat{p}_s^{\,2}} \cdot \frac{\hat{p}_u(1 - \hat{p}_u)}{N_u} + \frac{\hat{p}_u^{\,2}}{\hat{p}_s^{\,4}} \cdot \frac{\hat{p}_s(1 - \hat{p}_s)}{N_s}$$

where N_u and N_s are the sample sizes on which $\hat{p}_u$ and $\hat{p}_s$ are based. The approximate coefficient of variation of the availability correction factor is

$$C_a = \sqrt{\frac{1 - \hat{p}_u}{\hat{p}_u N_u} + \frac{1 - \hat{p}_s}{\hat{p}_s N_s}} \quad . \qquad (4)$$

In view of its untested reliability, this correction for availability bias is best considered as a means of standardizing fluctuating availability bias for repeat surveys of the same area under conditions of varying water turbidity.

Most of the dugongs sighted in Marsh and Sinclair's (in press) experimental evaluation of dugong aerial survey techniques in Moreton Bay were in extremely clear, shallow (<5 m) water over white sandbanks covered with sparse seagrass. All animals in this area were potentially available. By comparing the uncolluded observations of tandem observers, Marsh and Sinclair (in press) showed that observers had difficulty recording the position in the water column of dugongs in larger groups. There was, however, very good agreement between observers in their reports of how many dugongs in groups of $\leq$ 5 were at the surface. This proportion (80/480 or 16.7%) is not significantly different from that obtained independently from vertical color photographs of dugongs (68/486 or 14%) that have been taken under excellent conditions on the same sandbanks on other occasions.

We tentatively propose 80/480 as an unbiased estimate of the proportion of dugongs at the surface in Moreton Bay at the time of our aerial survey experiment. Further, assuming that this proportion is valid for all habitats and at all times, it can be used as the estimate for $\hat{p}_s$ for surveys of dugongs over shallow waters when the sea is calm. These conditions apply to most dedicated aerial sightings of dugongs in northern Australia.

Availability correction factors for the port and/or starboard team have been calculated for various dugong surveys using 80/480 as the estimate for $\hat{p}_s$. The estimates range from 1.06 to 3.08 (Table 1). These have proved a successful means of standardizing the availability bias; population estimates obtained from repeat surveys of the same area under different weather conditions are within about 10% of each other (Marsh and Saalfeld, in press). The proportion of dugongs on the surface used as the standard for these estimates of the availability correction factor (16.7%) is greater than the 1.9% obtained from shore-based observations in muddy water by Anderson and Birtles (1978).Hence, it is likely that the population estimates listed in Marsh and Saalfeld (in press) that are based on the correction factors for availability bias in Table 1 are conservative. A more accurate assessment will require more data on dugong diving and surfacing under different environmental conditions.

APPLICATION OF CORRECTION FACTORS

The following steps convert counts of groups of the target species obtained during strip transect aerial surveys to population estimates:

(1) Classify each group as being observed by 1 (specified) member or both members of the appropriate tandem team.

(2) Calculate the mean group size for the whole survey area at the time of the survey and the standard error of the group sizes.

(3) Calculate the survey-specific perception correction factors (1 for each tandem team) and availability correction factor as detailed above.

(4) Calculate for each transect the total number of groups sighted by the members of the port and starboard tandem teams, respectively.

(5) Obtain the corrected number of animals per transect as follows: multiply each of the 2 values in step (4) by

(i) the appropriate perception correction factor to obtain the Petersen estimate for the number of available groups;

(ii) the availability correction factor and

(iii) the mean group size of the target species in the survey area;

then sum the 2 corrected values for each transect.

(6) Use the corrected number sighted for each transect and, if necessary, the Ratio Method (Cochran 1963, Jolly 1969, Norton-Griffiths 1978, Caughley and Grigg 1981), to estimate the population size and its associated sampling variance. The ratio method allows for transects of different sizes and is applied as follows. Let

T = total number of transects that could be fitted into the census zone,

t = number of transects sampled,

A = area of census zone,

a = area of any 1 transect,

y = total corrected number of animals counted in that transect,

$\hat{Y}$ = estimated size of the population in the census zone,

$\hat{R}$ = the ratio of the corrected number of animals counted to the area searched = $\Sigma y/\Sigma a$,

S_y^2 = variance between the corrected number of animals counted on all transects

$$= \frac{1}{t-1} \cdot \left[\Sigma y^2 - \frac{(\Sigma y)^2}{t}\right],$$

S_a^2 = variance between the areas of all the transects,

$$= \frac{1}{t-1} \cdot \left[\Sigma a^2 - \frac{(\Sigma a)^2}{t}\right],$$

S_{ay} = covariance between the corrected number of animals counted on a transect and the area of the transect,

$$= \frac{1}{t-1} \cdot \left[\Sigma ay - \frac{(\Sigma a)(\Sigma y)}{t}\right],$$

and S^2 = sampling variance of $\hat{Y}$.

Then $\hat{Y} = A \cdot \hat{R}$,

$$\text{and} \quad S^2 = \frac{T(T-t)}{t} \cdot (S_y{}^2 - 2\hat{R}S_{ay} + \hat{R}^2 S_a{}^2) \quad .$$

(7) Calculate the total variance of the density or population estimate by adding the errors due to the estimation of the mean group size and the correction factors to that due to sampling variability in step (6). Following Jolly and Watson (1979), this gives an approximate variance of the total population estimate of

$$S^2 + \hat{Y}_p{}^2(C_g{}^2 + C_{pp}{}^2 + C_a{}^2) + \hat{Y}_s{}^2(C_g{}^2 + C_{sp}{}^2 + C_a{}^2) \qquad (5)$$

where S^2 is the sampling variance of the corrected population estimates in each transect in step (6); $\hat{Y}_p$ and $\hat{Y}_s$ are the contributions to the corrected population estimate made by the port and starboard observing teams respectively; C_g is the coefficient of variation (standard error/mean) of the mean group size; C_{pp} and C_{sp} are the respective coefficients of variation of the perception correction factor for each transect for the port and starboard teams as given by equation (3); and C_a is the coefficient of variation of the availability correction factor, equation (4). The standard error of the population estimate and associated confidence intervals are then readily obtained.

Parallel calculations can be performed to estimate the population density, its standard error and associated confidence intervals. As Jolly and Watson (1979) stated, implicit in equation (5) is the assumption that the correction factors are mutually independent and also independent of the survey observations. As the correction factors are based on the total counts for an entire survey, they would not be expected to be correlated with the observations from individual transects. Our data indicate that, at least for dugongs, the perception correction factor is not correlated with the availability correction factor ($r = 0.264$, 11 df; $p > 0.20$) or the mean group size ($r = 0.174$, 11 df; $p > 0.50$). However, the availability correction factor is correlated with mean group size (r = -0.864, 5 df; $p < 0.01$). It must be remembered that we are dealing with approximations; we are confident that equation (5) provides a more realistic approximation of the estimated variance of the population size than that obtained by ignoring errors in the estimated correction factors (i.e. simply S^2).

ASSESSMENT OF PROCEDURES

The system of using 2 teams of tandem observers, a 2-track tape-recorder and a micro-computer has advantages over previous methodologies. Survey-specific correction factors compensate for visibility biases that cannot be eliminated by a rigid standardization of procedures, such as fluctuations in the biases due to sea state, glare, cloud cover, and water turbidity. Survey-specific correction factors also reduce the need to use the same observers for each survey, especially as new observers can be readily trained using the 2-track tape-recorder. This recorder also reduces errors in deciding which animals were seen by both members of a tandem team, even when the population is dense. All observations of the target species within the transect by both members of each tandem team are used in the final population estimate and in the calculation of the correction factors. This reduces the biases, especially when the population is sparse.

The system also has some disadvantages. This procedure requires a crew of 6 (Fig.1). Provided that trained observers are available, this is not a disadvantage in marine surveys where 2-engine aircraft are required for safety reasons. However, it could result in a substantial increase in cost when a twin-engine aircraft is not mandatory. The system can be modified for a 4-seater aircraft with a tandem team on the right side of the aircraft only, along the lines suggested by Caughley and Grice

(1982). However, the rear-seat observers should alternate to and from the right side of the aircraft to form a tandem team with the observer in the front right seat, so that the correction factors for perception bias can be calculated separately for each rear-seat observer.

We used a tandem team on 1 side of the aircraft when training a new observer (Marsh and Saalfeld, in press) with 1 trained observer and the trainee on the other. During training, the intercom system was switched so that the trainee could hear the reports of his counterpart on the same side of the aircraft. This system greatly reduced the period required to train reliable observers.

The major disadvantage of using our system in a 4-seater aircraft would be that there would be no room for a survey leader as defined in Figure 1. Many of the survey leader's duties (e.g. checking the position, height, and speed of the aircraft) would be unnecessary when using a trained pilot (particularly a person with scientific training) in an aircraft equipped with a radar altimeter. It would not be possible, however, to obtain a computer record of the sightings of the rear-seat observers if everyone but the pilot were acting as observers. The computer record is irreplaceable as a back-up in the case of tape recorder failure. Our computer also has an inbuilt printer that gives an immediate hard copy of all entries, preventing undetected computer malfunction.

Another disadvantage of our system is that all the voice tapes have to be listened to in real time after the survey to record the sightings of the mid-seat observers. These sightings then have to be edited on to the computer files. In all, this involves an estimated 2 hours of work for every hour of survey time. The resultant additional cost is nonetheless minor in comparison to the cost of the aircraft charter.

On balance, it is considered that this methodology overcomes many of the problems of previous mark-recapture survey methods, especially for surveys of aquatic fauna. The problem of determining whether a group was seen by 1 or both members of a tandem team has been solved by the use of the 2-track tape recorder, and the system of recording the position of groups on the transect. This makes the method useful even when the density of the target species is high. Even though the problem of the correlated search image of tandem observers has not been eliminated, its impact is minimized by the steps taken to reduce sighting heterogeneity such as limiting the surveys to days when the sea is calm and the weather fine, and timing them to minimize glare off the surface of the water. Because it is impossible to eliminate all biological and environmental biases, the development of techniques to estimate survey-specific correction factors to compensate for perceptual and availability biases should find application in aerial surveys of other species.

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LEGEND TO FIGURE:

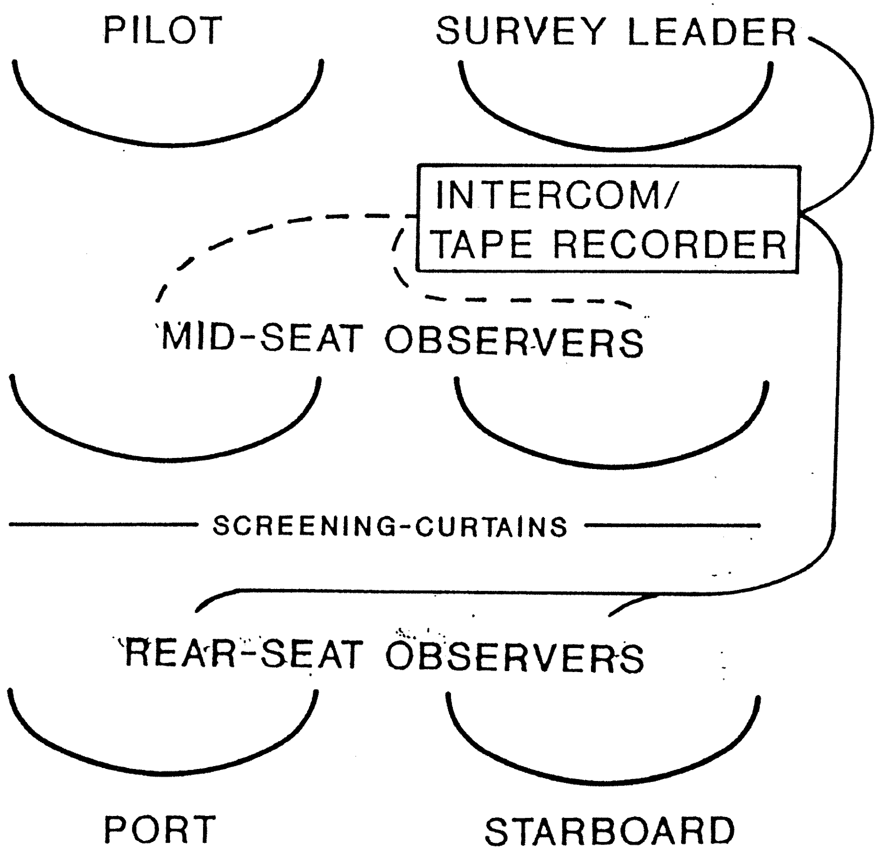
Fig. 1. Diagrammatic representation of the arrangement and duties of the crew used to aerial survey dugongs in Australia.

Table 1: The groups sighted and the perception and availability correction factors developed for various aerial surveys for dugongs in northern Australia. Except where indicated, all counts were made from a survey height of 137 m. C_p is the coefficient of variation of the perception correction factor (eq 3), C_a is the coefficient of variation of the availability correction factor (eq 4) and C_g is the ratio of the standard error to the mean of the group size.

Survey date	Blocks	Side of aircraft	No. of groups of dugongs counted mid-seat only (S_m)	rear-seat only (S_r)	both (b)	$\hat{N}$	Correction for perception bias (C_p)	Correction for availability bias (C_a)	$\bar{x}$ group size (C_g)
Far Northern Section and northern part of the Cairns Section of the Great Barrier Reef Marine Park									
Apr 1985		S	10	7	12	34.83	1.20 (0.069)	1.95 (0.19)	1.57 (0.07
Nov 1985	area 1	P	36	18	58	123.17	1.10 (0.019)	2.62 (0.12)	1.47 (0.04
		S[a]	16	18	30	73.60	1.15 (0.035)		
	area 2	P	5	3	12	21.25	1.06 (0.028)	1.44 (0.23)	1.53 (0.09
		S	2	3	15	20.40	1.02 (0.009)		
Northern-half of the Central Section of the Great Barrier Reef Marine Park									
Sep 1986		P	8	6	11	29.36	1.17 (0.065)	3.00 (0.17)	1.29 (0.10
		S	5	2	7	15.43	1.10 (0.057)		
Mackay/Capricorn Section of the Great Barrier Reef Marine Park									
Nov 1986		P	5	8	16	31.50	1.09 (0.032)	3.08 (0.15)	1.35 (0.13
		S	5	5	18	29.39	1.05 (0.018)		
Torres Strait									
Nov 1987		P	12	23	65	104.25	1.04 (0.009)	2.72 (0.12)	1.39 (0.05
		S[a]	18	19	46	90.43	1.09 (0.019)		
Moreton Bay (south east Queensland)									
Jun 1985		P	17	19	50	92.46	1.08 (0.016)	1.06[b] (0.14)	2.08[b] (0.14)
		S[a]	10	8	28	48.86	1.06 (0.018)		

[a] Starboard team not available for entire survey.

[b] Includes counts made from a flying height of 274m.



PILOT

FLYS/NAVIGATES AIRCRAFT
BLOWS WHISTLE AT START AND END OF TRANSECT
USES STOPWATCH TO CHECK NAVIGATION

SURVEY LEADER

MANAGES SURVEY: RECORDS AIRCRAFT HEIGHT, LANDMARKS, BEAUFORT SEA STATE, STANDARDIZED OBSERVATIONS OF REAR-SEAT OBSERVERS INTO DATA-LOGGER

MID-SEAT OBSERVERS

(CAN COMMUNICATE ONLY WITH EACH OTHER DURING TRANSECTS)

REAR-SEAT OBSERVERS

(CAN COMMUNICATE ONLY WITH EACH OTHER AND SURVEY LEADER DURING TRANSECTS)

(ALL MEMBERS WEAR POLAROID SUNGLASSES)

——— TRACK A OF INTERCOM/TAPE RECORDER
- - - - - TRACK B OF INTERCOM/TAPE RECORDER

An Experimental Evaluation of Dugong and Sea Turtle Aerial Survey Techniques

Running head–line: Aerial Survey Technique for Dugongs and Turtles.

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Abstract

Some factors which affect the aerial counts of dugongs and sea turtles were examined experimentally. There was no significant difference in the observed density of dugongs when survey height was doubled from 137m to 274m with an accompanying doubling of transect width on either side of the aircraft from 200m to 400m. In contrast, a significantly higher density of turtles was observed at the lower height/narrower transect width. Neither the higher level of glare on the exposed side of the aircraft, the time of day, nor the time from high tide made a significant difference to the observed densities of dugongs or turtles. The survey crew included a tandem team of two observers on each side of the aircraft who reported their uncolluded observations into separate tracks of a two–track tape–recording system. This allowed the reports of tandem observers to be compared in order to assess observer reliability. Overall, observers missed over 40% of dugong groups and over 80% of turtles visible within the transect including groups of more than 10 dugongs. The chance of observers missing a group of dugongs was independent of group size. There was little disagreement between tandem observers about the identification of animals, or the position of animals in the water column. However, observers differed markedly in their categorization of dugong behaviour and in their counts of animals (particularly dugong calves) in larger groups.

Introduction

The range of the dugong, (Dugong dugon), in Australia extends along about 15000 km of coastline, and beyond 58 km from the coast in some areas. Aerial survey is the only feasible method of censusing dugongs over such remote and extensive areas. However, the technique is inaccurate and often provides gross under–estimates of animal numbers (Caughley et al. 1976). Consequently, Caughley (1979) has argued that aerial survey estimates are probably most useful as indices for tracking relative density over time. For this purpose, an important requirement is that survey procedures be rigidly standardized.

Aerial survey procedures for dugongs are still being developed. Early surveys (e.g. Heinsohn et al. 1976; Anderson and Birtles 1978; Brownell et al. 1981; Elliott 1981; Marsh et al. 1981; Prince et al. 1981; Anderson 1982) were essentially qualitative, their main use being to identify areas of relatively high dugong density.

Because of the extensive distribution of dugongs in Australia, the first two quantitative surveys (Bayliss 1986; Marsh 1986) used a strip transect technique, developed by Caughley and Grigg (1981) to survey kangaroos in the outback. However, there were differences in the procedures used in the dugong surveys. Marsh (1986) surveyed at 274 m (900 feet) with a transect width of 400 m on each side of the aircraft. Bayliss (1986) flew at 137m (450 feet) with a transect width of 200m on each side of the aircraft on the basis of a preliminary experiment which showed that the observed density of animals (based on the combined sightings of dugongs, dolphins and sea turtles) was significantly greater with the 137m/200m survey regime than with the 274m/400m regime. Flying at the lower height/narrower transect width doubles the survey time needed to achieve the same sampling fraction. This cost differential is substantial given the vast areas to be covered and the high sampling intensity required to achieve a useful index of density. (The population estimates of both Bayliss and Marsh had a precision (standard error/mean as a %) of about 18% at a survey intensity of about 7%).

In this paper, the effect of survey height/transect width on the sightability of dugongs has been re–examined in an experiment which also tested the effects of glare off the surface of the sea, time of day, and tidal cycle on observed dugong density. Other large marine vertebrates were also counted during the experiment allowing parallel questions to be addressed with respect to sea turtles (probably green turtles, Chelonia mydas).

The survey crew included a tandem team of two observers on each side of the aircraft who reported their uncolluded observations into separate tracks of a two–track tape–recording system. This allowed the reports of tandem observers to be compared in order to assess observer reliability.

Methods

Design

The experiment involved flying eight transects over a small part of Moreton Bay (Fig. 1) twice daily within three hours of high tide at the Brisbane Bar on June 2, 5, 6, 7 and 8, 1985. Plans to run the experiment over five successive days were abandoned due to unsuitable weather on June 3 and 4. To aid navigation, eight east–west transects were selected a priori on the basis of clearly defined end–points in an area of known high dugong density (Fig. 1). The transects ranged in length from 21.2 km to 25.1 km.

Five daily flight plans were drawn up in advance and flown in random order. Each plan was defined by the following variables which were selected using random number tables:

(1) the starting transect (T1, T2, T3, T4, T5, T6, T7 or T8);

(2) the direction of travel for the starting transect (west or east) which defined the direction of travel for all subsequent transects as each transect after the first was flown in the opposite direction to its immediate predecessor;

(3) the direction of movement between successive (adjacent) transects (north or south); and

(4) the height at which each transect was to be flown initially (137m or 274m). The second time each transect was flown, it was done at the alternative height and in the opposite direction.

Thus each transect was flown at each height on each day, once in an easterly direction, and once in a westerly direction. Direction of the aircraft determined the level of the factor glare on each side of the aircraft. Operational constraints necessitated confounding height and glare.

Survey Technique

All transects were flown at a ground speed of 185 km per hour (100 knots), the slowest speed the aircraft (a Partenavia 68B) could safely maintain within the range of acceptable wind conditions.

The survey team comprised a commercial pilot with previous dugong survey experience, a front–right survey leader, two mid–seat observers, and two rear–seat observers (see Fig. 1 in Marsh and Sinclair, 1989). All team members occupied the same seats throughout the experiment. .The middle and rear seat observers on the same side of the aircraft formed a tandem team searching the same transect. All observers had experience with dugong surveys on which turtles and dolphins were also reported. The two rear–seat observers had acted as observers on a quantitative dugong survey less than two months previously. In contrast the two mid–seat observers had been involved in qualitative surveys only.

Transect width, demarcated by fibre–glass rods attached to artificial wing–struts, was 200m on either side of the aircraft at the survey height of 137m; 400m at 274m. The rods were positioned specifically for each rear–seat observer and checked empirically prior to the survey as outlined by Norton–Griffiths (1978). During this check it was also confirmed that the transect width scanned by both the observers in a tandem team was similar. Tape was placed on the windows of the aircraft to ensure that each observer kept his/her head in the correct position during flight (see Norton–Griffiths, 1978). Within the constraints imposed by these marks, each observer adjusted his/her viewing angle to minimize the effect of glare. All crew members wore identical polarized sunglasses.

Data were recorded by the survey leader using an Epson HX20 portable micro–computer programmed as a data–logger and timer, and equipped with a printer which produces an immediate hard copy of the data. The time of entry for each observation was recorded automatically, enabling its position to be plotted on a map at a later date for habitat analysis.

The survey leader was responsible for keeping a regular check on aircraft speed and altitude (measured by pressure altimeter), and for recording details of weather conditions including wind speed and direction, cloud cover (oktas), the nature of the sea surface (Beaufort scale), the times at which each transect began and ended, and the observations of the rear–seat observers, including the relative amounts of glare off the surface of the water on either side of the aircraft. The start and end of each transect were announced by a whistle blown by the pilot.

The rear–seat observers communicated with the survey leader via a two–way intercom system connected to one track of a two–track tape–recorder. They reported the following information in standardized format at the time of first sighting:

(1) Dugongs: group size, number of calves, behaviour (swimming, idling, feeding, diving), number at the surface.

(2) Turtles: group size, position in the water column (surface or underneath).

(3) Dolphins: group size, number of calves, species, reliability of specific identification (certain, uncertain), position in the water column.

(4) Incidental sightings of rays, sea snakes, sharks, surface plankton.

During the transects the mid–seat observers were visually screened from the rear–seat observers with a curtain, and acoustically isolated from the other crew (apart from each other). They reported their sightings in the standard format into the second track of the tape–recorder. Between transects the intercom channels were switched so that all members of the crew could communicate. Daily schedules were arranged so that the surveys were conducted between 0830 and 1300 hours. A maximum of 3.2 hours (2.5 hours survey time) was spent in the air at one time.

Post–survey Data Review

The tape record of each transect was used to check and edit the computer records, so that each sighting could be coded as being made by one (specified) member or both members of a tandem observing team. The reports of team members were deemed to be different if they were unambiguously distinct (usual situation) or if they were separated by approximately five seconds or more. Discrepancies between dual sightings of the same group were also noted.

Analysis

(i) Analysis of variance

Analysis of variance was used to determine the effect of the various survey variables (survey height/transect width; tandem observing team; glare) on the density of dugong and turtle sightings. Day and transect were treated as random effects. As the factor glare was not orthogonal to survey height/transect width and tandem observing team, the effect of glare was analyzed separately at each level of survey height/transect width. The possible effects of time of day and tidal cycle were investigated using analysis of covariance. Input data were the densities of dugongs and turtles observed by each tandem team on each transect, at each survey height/transect width on each day.. The densities were log–transformed for analysis to equalize the error variances.

(ii) Log–linear models

The counts of dugong groups were cross–classified in a number of 3–way arrays. These contingency tables were analyzed using log–linear models (Fienberg 1980) to test various hypotheses concerning factors which could affect sightings. A standard hierarchical model–fitting procedure was adopted, with only significant effects being retained in the model. The absence in the final model of an interaction term between a pair of factors indicated that those factors were acting independently. The goodness–of–fit of a model was gauged by the log–likelihood χ^2 value.

The G statistic used in the analysis of other results as indicated in the text was calculated using Williams' correction (Sokal and Rohlf, 1981).

Results

Summary of Sightings

A total of 341 groups of dugongs, 206 groups of turtles and 15 groups of dolphins were sighted during the experiment. The daily cloud and sea conditions encountered are summarized in Fig. 2.

(i) Dugongs

A group of dugongs was defined as a subjectively distinct clump. The frequency distribution of dugong group sizes is summarized in Fig. 3. Group size ranged from one to 20 with a mean of 2.08 ± (S.E.) 0.139 dugongs. Large groups were relatively rare; 61.6% of groups consisted of a single animal, 83% consisted of a single animal or a cow–calf pair. All but fifteen dugong groups (4.4%) were sighted on the shallow sandbank area west of South Passage bounded by the five metre depth contour line (Fig.1).

(ii) Turtles

It is usually much more difficult to define a group of turtles than a group of dugongs, and group sizes of more than one typically represent turtles seen in quick succession rather than a cohesive group. The frequency distribution of turtle group sizes is summarized in Fig. 4. The largest group comprised nine turtles; the mean group size was 1.14. We were unable to confirm the specific identification of the turtles, although they were almost certainly *Chelonia mydas* (C.J. Limpus,. personal communication). Twenty–five percent of turtle groups were seen away from the sandbanks west of South Passage, a significantly larger proportion than for dugongs ($G = 39.96$, 1 d.f., $p < 0.001$).

Effects of Survey Variables

The results of the analyses of variance examining the effects of the three survey variables (survey height/transect width referred to as survey regime, tandem observing team, and glare) on the observed densities of dugongs and turtles are given in Table 1.

The day 1 turtle sightings were excluded because the two mid–seat observers included 'possible turtles' in their counts; more rigorous standards were applied on the other days. Glare was always higher on the north–side of the aircraft on days 2 through 4, but inconsistent on days 1 and 5. Consequently, results from the latter days were also excluded from the analysis of the effect of glare.

None of the three survey variables had a significant effect on observed dugong density. However, for turtles a significantly higher density was recorded at the 137m/200m survey regime and the two tandem teams differed significantly in their observed densities. The differences were large both on and off the sand bank area, and were consistent for both survey regimes.

Glare had no effect on either dugong or turtle counts and inclusion of time from dawn and time from high tide as covariates had minimal effect on the analysis, and did not alter the results.

There were no significant differences in observed turtle density ($P > 0.05$) between days 2–5. For dugongs, however, the differences in daily sightings were significantly different ($P < 0.05$), day 2 being significantly higher and day 5 significantly lower than the other days (Fig. 2).

The differences between days in the observed density of turtles both on the banks and over the full transects were not statistically significant (Fig. 2). However, they do coincide with the corresponding changes in sea state; fewer turtles were seen in rougher seas (Fig. 2). In contrast, the significant differences between days in observed dugong density show a pattern which does not coincide with changes in sea state and cloud cover (Fig. 2). A large aggregation of dugongs was observed adjacent to the survey area on the seaward side of South Passage on day 5, suggesting that at least some of the observed difference in dugong density between days was due to animals moving from the survey area.

Comparison of Tandem Observers

Of the animals sighted during the experiment, 57% of the dugong groups and 18% of the turtle groups were seen by both members of either team of tandem observers. This allowed the observations of tandem team members to be compared directly as follows.

(i) Species identification

Tandem observers differed on at most seven occasions (3% of the number of dual sightings of all animals); three at a height of 137m, four at 274m. On two occasions, one observer classified an animal as a dugong when his/her counterpart was unsure. A further two animals classified as dugongs by one observer were apparently classified as a turtle and a dolphin respectively by the other. Other disagreements over identification were one turtle/ray, a group of dolphins/fish and a dolphin/shark.

(ii) Dugongs

The proportion of groups sighted by one or both observers in the port and starboard teams at each survey regime is summarized in Fig. 5. which shows that all observers missed a substantial proportion of dugong groups. The log–linear model relating frequency of sightings to sighting class (mid–seat observer only, rear–seat observer only, or both observers), survey regime (137m/200m, 274m/400m) and estimated group size (1, 1 – 5, >5) contained no interaction terms. Thus, the chance of an observer missing a group of between 6 and 20 dugongs was not significantly different from the chance of missing a smaller group at either survey regime (port team: χ^2=12.19; d.f.=12; p=0.43; starboard team: χ^2=4.58; d.f.=12; p=0.43). Three of the four observers missed a group of 10 or more dugongs (one occasion each).

Group size. The estimate of group size differed in 21 (11%) of the 193 groups sighted by both members of a tandem observing team. Discrepancies were significantly more likely for groups of more than five dugongs than for smaller groups (G=26.516, d.f.=1: p<0.001). The tandem observers obtained the same count for only six of the 16 groups of more than five dugongs. The greatest discrepancy was between corresponding group size estimates of 14 and 19 dugongs; in most instances the discrepancy was one or two. On four occasions the difference occurred because one of the tandem observers failed to see a calf.

When members of a tandem team disagreed about group size, the lower count was arbitrarily used in all analyses including the estimate of mean group size (2.08). If the estimates of the rear–seat observers only had been used, the mean group size would have been 2.12. The corresponding figure for the two mid–seat observers was very similar (2.14).

The proportion of groups in which the size estimates of both tandem observers were identical was consistent over survey regimes and observer teams (χ^2=1.92; d.f.=3; p=0.59). All observers reported that they did not have time to count calves in large groups, and the proportion of calves counted in groups of five or more dugongs (Fig. 3b) was significantly lower than that in groups of two to four dugongs (G=33.5; d.f.=1; p<0.001). There is no evidence to suggest that the relative frequency of calves should be less in large groups of dugongs than in smaller groups.

Behaviour. The two members of a tandem observing team differed in their categorization of the behaviour of 43 (22%) of the 193 groups sighted by both of them. However, the proportion of behaviours which were classified similarly by both members of a tandem team did not vary significantly with survey regime (χ^2=3.32; d.f.=2; p=0.19).

These results indicate that observers cannot reliably classify dugong behaviour into even simple categories in the time available, at least without further training.

Number of dugongs at the surface. There were 172 groups for which both members of a tandem observing team counted the same number of dugongs. The tandem observers differed in their assessment of the number of dugongs at the surface in only nine of these (5%). This proportion did not vary significantly with survey regime and observer team (χ^2=2.49; d.f.=3; p=0.49).

Individual dugongs were often seen in the process of surfacing or diving while an observer scanned the surface of the sea. It is therefore likely that some dugongs will be seen at different stages of this behaviour by different observers. Under these circumstances, the 5% disagreement over the position of dugongs in the water column is not surprising. The position of a dugong in the water column can thus be assessed reliably using either survey regime.

The bottom was clearly visible when flying over the sandbanks, and so it was theoretically possible to see all dugongs present. In contrast, the bottom was not usually visible during the remainder of the transects which were over deeper water and not all of the dugongs below the surface would have been visible. The proportion of the dugongs sighted that were classified as being on the surface varied from 18/37 (48.6%) off the banks to 91/673 (13.5%) on the banks. The difference is significant ($\underline{G}$=20.45; d.f.=1; $\underline{p}$< 0.001) and forms the basis of the 'availability correction factor' developed by Marsh and Sinclair (1989).

On the sandbanks, the proportion of dugongs classified as being on the surface was significantly less for groups of more than five dugongs (11/193) than for smaller groups (80/480) ($\underline{G}$=16.219; d.f.=1; $\underline{p}$<0.001), presumably because the observers did not have time to record accurately the proportion on the surface for the bigger groups. The proportion of dugongs in groups of five or less on the sandbanks that were recorded as being on the surface (80/480 or 16.7%) should be a reliable estimate of the proportion on the surface in this area at the time of the survey. This value is not significantly different from that obtained independently from vertical colour photographs of dugongs (68/486 or 14.0%) which were taken under excellent conditions on the same sandbanks in October 1984 and December 1985. ($\underline{G}$ =1.33; d.f.=1; $\underline{p}$>.10).

(iii) Turtles

The number of groups in each sighting class (mid–seat observer only, rear–seat observer only, both observers) for the port and starboard teams at each survey regime is summarized in Fig. 5. The proportion of groups in each sighting class was independent of survey regime (port team: $\underline{G}$=2.74; d.f.=2; $\underline{p}$> 0.10; starboard team: $\underline{G}$=0.64; d.f.=2; $\underline{p}$>0.5).

There were no discrepancies between the reports of tandem observers regarding the same group of turtles apart from disagreement about whether two (separate) turtles were on the surface or not.

The proportion of turtles classified as being on the surface was independent of survey height/transect width ($\underline{G}$=1.32; d.f=1; $\underline{p}$>0.10). Overall, 38% (81/234) of turtles were classified as being on the surface. This is undoubtedly an overestimate. Many bottom–dwelling turtles were not recorded by observers due to uncertainty as to whether the animals were turtles or rays.

Discussion

Reliability of Observers

Analysis of variance indicated a significant difference between the tandem teams in the observed density of turtles (but not dugongs) at both survey regimes. This was due to the port mid–seat observer recording far more turtles than any of the others (Fig. 5), suggesting that training was inadequate for spotting turtles. It would be particularly valuable if such training also enabled observers to identify turtles to species from the air.

The two–track tape recorder allowed observer reliability to be assessed in detail by comparing the dual sightings of tandem observers. The comparisons indicate that there was little disagreement about species identification or the position of dugongs or turtles in the water column. However, the level of disagreement about the behaviour of dugongs (22% of dual sightings) was so high that we decided to discontinue collecting such data.

Observers had difficulties in recording data from dugongs in large groups. As a result, groups of more than ten animals are now photographed. When a large group is encountered, the transect is discontinued at a convenient reference point in order to return to photograph the group (see Marsh and Saalfeld, 1989) as suggested by Norton–Griffiths (1978). The transect is then resumed. Such groups are then 'stratified out' of the population estimate based on the transect count, and included in a separate 'strata of large herds' (Norton–Griffiths, 1978).

We were surprised that the chance of an observer missing a group of dugongs was independent of group size, as this is not only counter–intuitive, but differs from the result obtained for some other species (Newsome et al., 1979; Samuel and Pollock, 1981; Gasaway et al., 1985; Samuel et al., 1987). Our result is probably partially due to the relatively small range of group sizes encountered (Fig. 3), and the low number of groups with more than five dugongs. The failure of three of the four observers to see a group of more than 10 dugongs within the transect is unlikely to be due to edge effects as subsequent experiments have shown that the sightability of dugongs is constant across the width of the transect (Marsh and Saalfeld, manuscript). We postulate that most large groups are missed when an observer interrupts his search pattern because his eyes linger on an animal in order to check its identification. Marsh and Sinclair (1989) outline methods for correcting for animals which are visible in the transect but missed by observers.

Factors Affecting Visibility

On the basis of a preliminary experiment, Bayliss (1986) suggested that it is preferable to survey dugongs at an altitude of 137m and a transect width of 200m rather than an altitude of 274m and a transect width of 400m. However, although the combined doubling of survey altitude and transect width reduced the observed density of dugongs by 50%, the difference was not statistically significant due to the small sample sizes in Bayliss's study (see his Fig. 2). Our results, which are based on a substantially larger sample size, indicate that there is no significant difference in observed dugong density between the two survey regimes. The experiment confirmed Bayliss' (1986) result that a significantly higher density of turtles is observed at the lower height/narrower transect width. If density estimates are required for both dugongs and turtles, it is clearly preferable to use the 137m/200m regime. However if dugongs are the only species of interest, the same precision should be achieved by spacing the transects twice as far apart and surveying at the 274m/400m regime rather than at the 137/200m regime with the transects closer together, although the associated distribution maps would be less detailed at the lower sampling intensity.

Two other factors need to be considered when deciding on the preferred regime. Caughley and Grigg (1981) point out that a high proportion of the hours in the air required to complete a survey are spent in relocating the aircraft rather than surveying, especially when operating in remote areas. Thus doubling the time spent in surveying will not necessarily double the cost of a survey. In addition, the actual numbers of dugongs seen per unit survey time is usually very low (see Bayliss, 1986; Marsh, 1986).

As observers are much more alert and interested when they are actually recording sightings, it is advantageous to record other large vertebrates (mainly turtles) during a dugong survey. It is suggested therefore, that dugongs should be surveyed in conjunction with other large vertebrates using the 137m/200m survey regime.

No difference was detected in the observed density of dugongs or turtles that could be attributed to the higher intensity of glare encountered on the north side of the aircraft on days 2–4. However, Marsh (1986) found that counts of dugongs were depressed on the glary side of the aircraft during an aerial survey in Torres Strait (10°S) in which the transects were aligned north–south rather than east–west as in this study. Holt and Cologne (1987) also found that glare depressed dolphin sightings. The effects of glare are very variable (unpublished data), and are probably best compensated for by giving careful consideration to how transects should be angled, by supplying observers with polarized sunglasses, and by using survey–specific correction factors to counter perception bias i.e. animals which are visible in the transect and missed (see Marsh and Sinclair, 1989).

Biological Insights

The low density of dugongs observed in the survey area on June 8 (Fig. 2) and the concomitant observation of a large aggregation on the seaward side of South Passage suggest that most of the dugongs had moved from their feeding grounds into more oceanic water. The unusually cold weather provides a plausible explanation of this behaviour. (The lowest daily maximum temperature for the area for seven years was recorded on June 6). Unfortunately, sea surface temperatures in the survey area were not measured during this survey, but the temperature of the adjacent oceanic water dropped 3°C between June 2 and 7 (data are not available for June 8) (Fig. 2). The only June day for which surface water temperature data for both areas is available is June 9 1976 when the water temperature on the seaward side of Stradbroke Island was 3°C higher than on the sandbanks. Anderson (1986) observed dugongs concentrating in tongues of warm oceanic water during the winter in Shark Bay, Western Australia, which is at a similar latitude to Moreton Bay.

Aerial surveys designed to obtain absolute estimates or indices of dugong abundance should be designed to cover areas large enough to accommodate movements such as these.

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Legend to Figures

Figure 1: Map of the survey area in Moreton Bay showing the locations of the aerial survey transects.

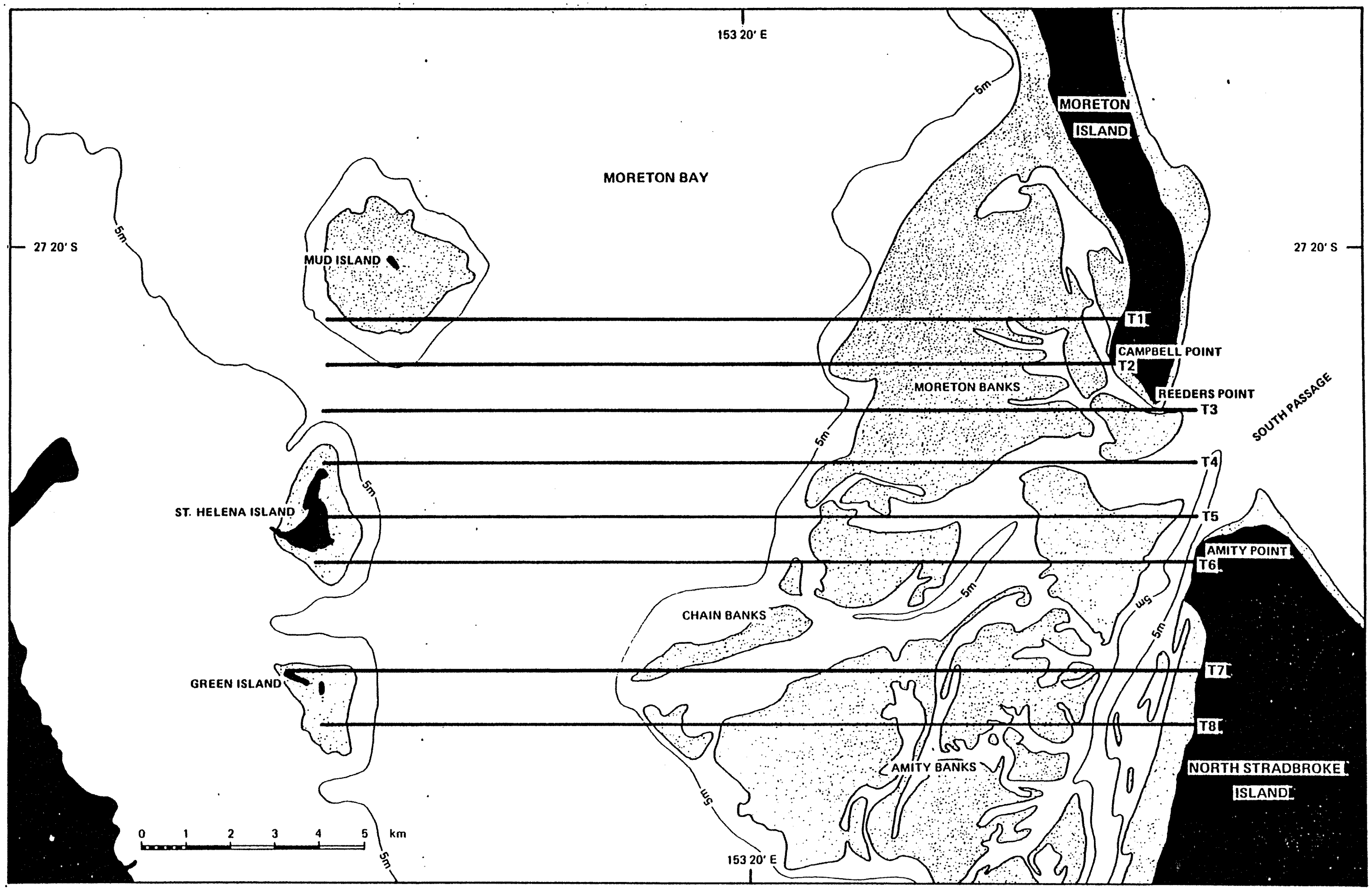
Figure 2: Changes in the mean daily observed density of dugongs and turtles in relation to the weather conditions encountered. The sea surface temperatures were measured at Point Lookout on the ocean side of North Stradbroke Island by the shark meshing contractor employed by the Queensland Department of Harbours and Marine. The limited data available suggest that the corresponding temperatures in the survey area would have been at least 3°C colder. ■ mean densities of dugongs or turtles calculated over the full transects, ● mean densities of dugongs or turtles calculated over the sandbank area only. The range bars indicate the pooled standard errors from the Analysis of Variance.

Figure 3a Frequency distribution of group sizes of dugongs and

b The number of dugongs in groups of various sizes and the corresponding calf counts. The calf counts are likley to be negatively biased (see text).

Figure 4: Frequency distribution of group sizes of turtles. A group tended to represent a number of animals seen in rapid succession rather than a cohesive entity.

Figure 5: Proportion of dugong and turtle groups sighted by the mid–seat observer, the rear–seat observer or both observers in each tandem team. The data are presented separately for each survey regime, and for dugong groups in different size categories



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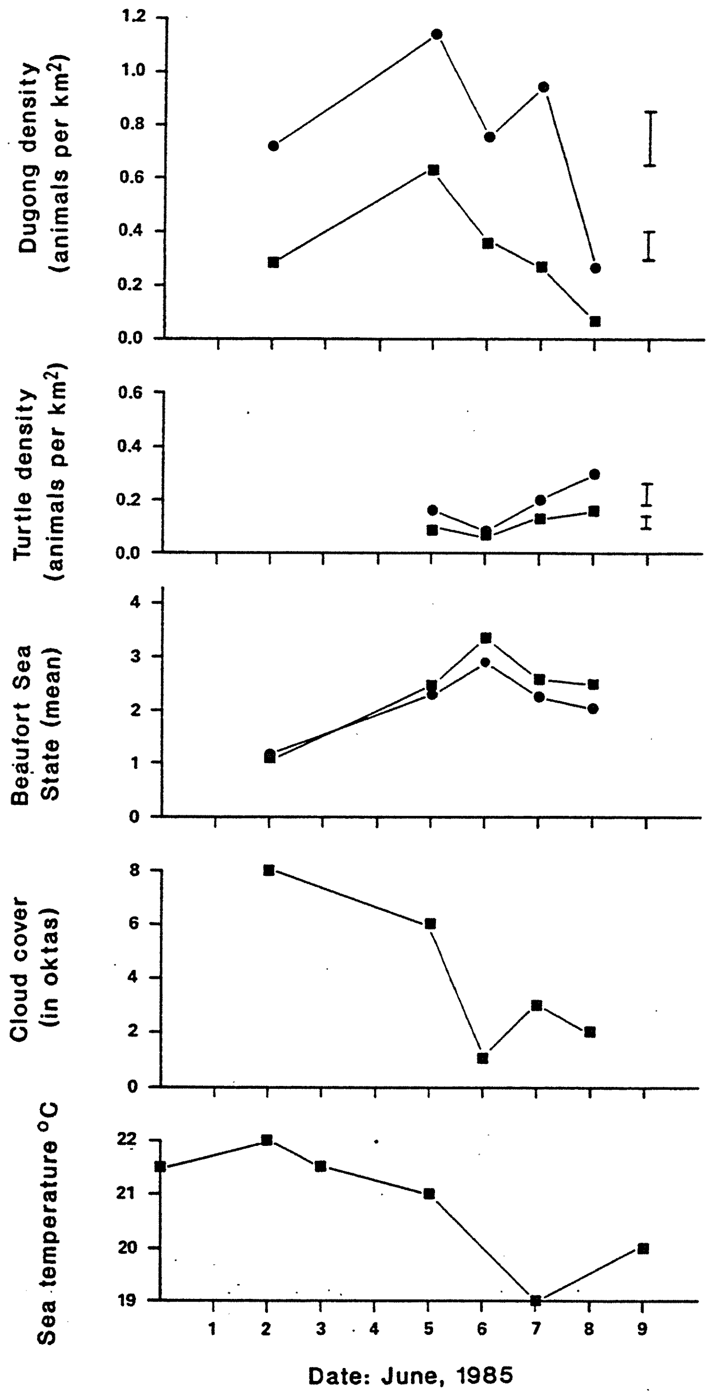

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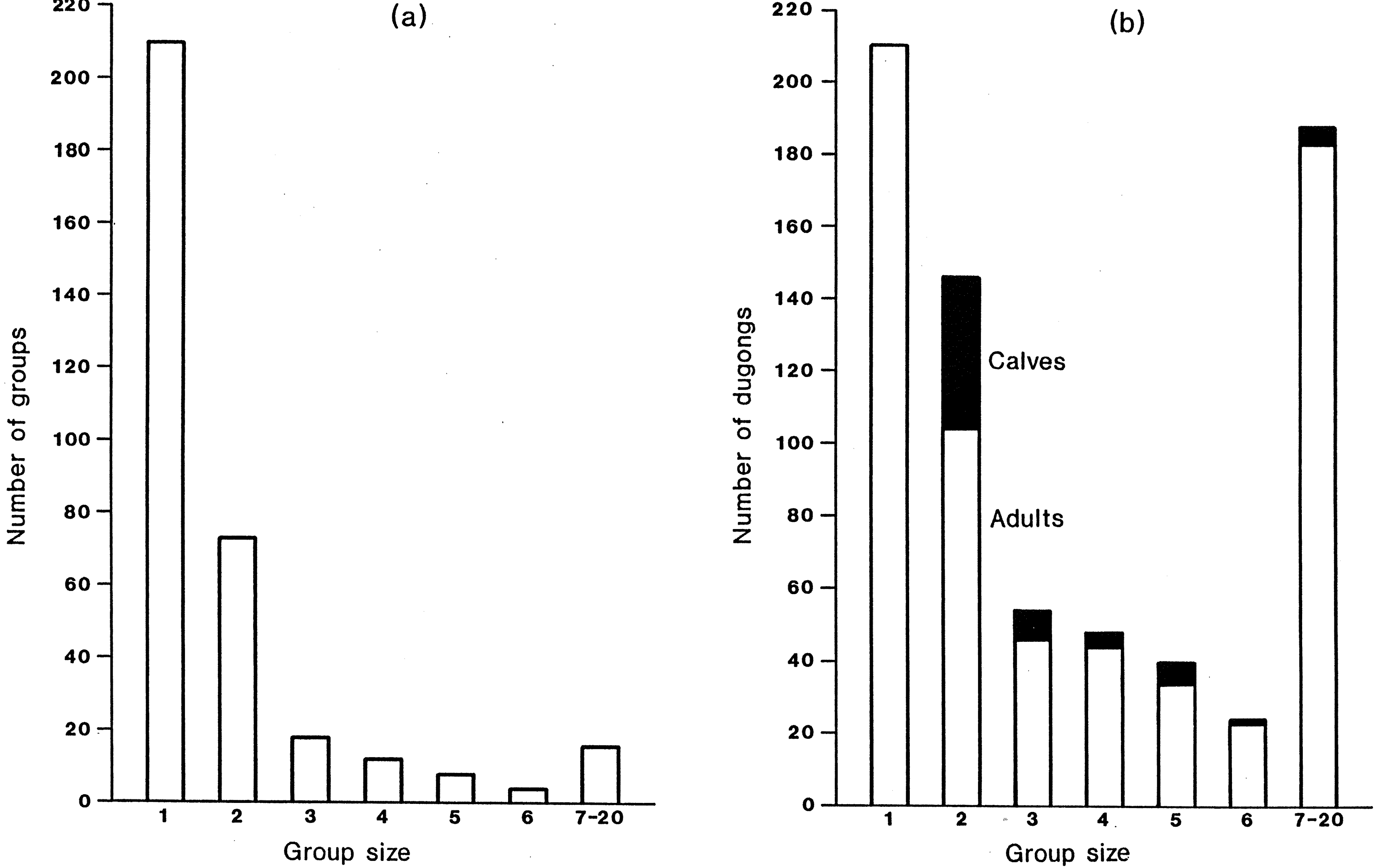
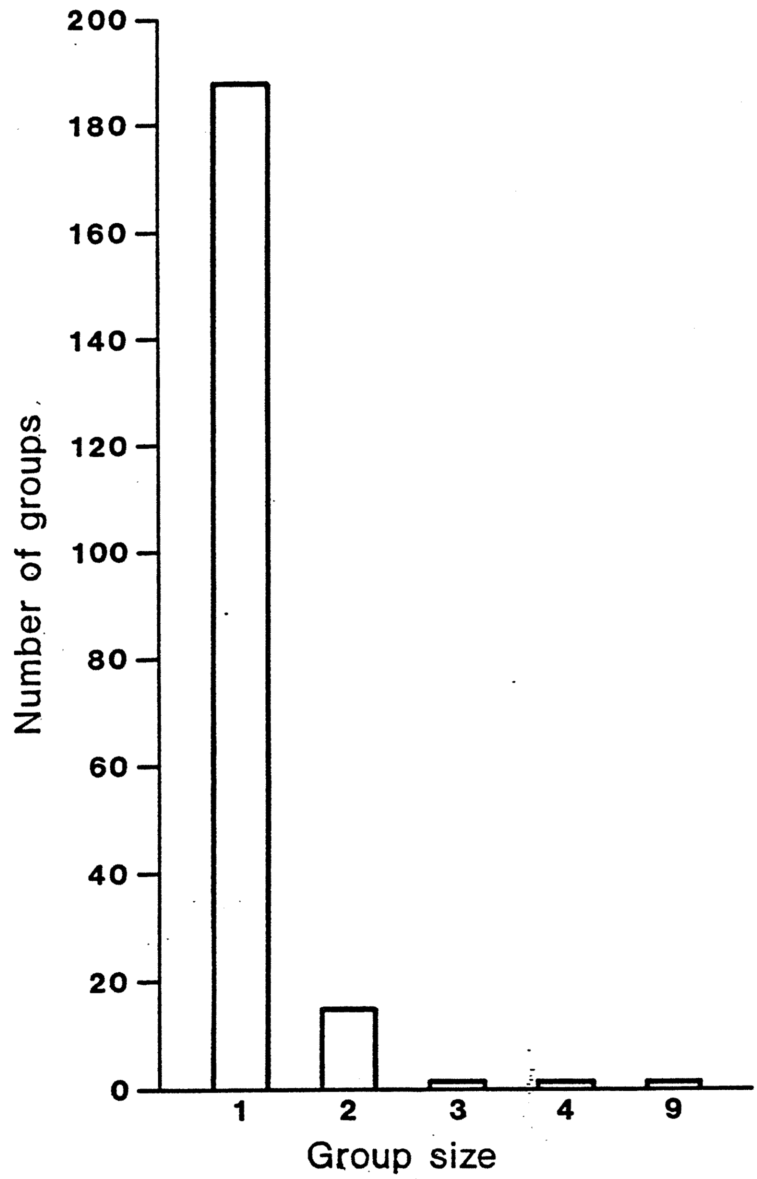


Fig. 3. Frequency distributions of (a) group sizes of dugongs; (b) the number of dugongs in groups of various sizes and the corresponding calf counts. The calf counts are likely to be biased (see text).



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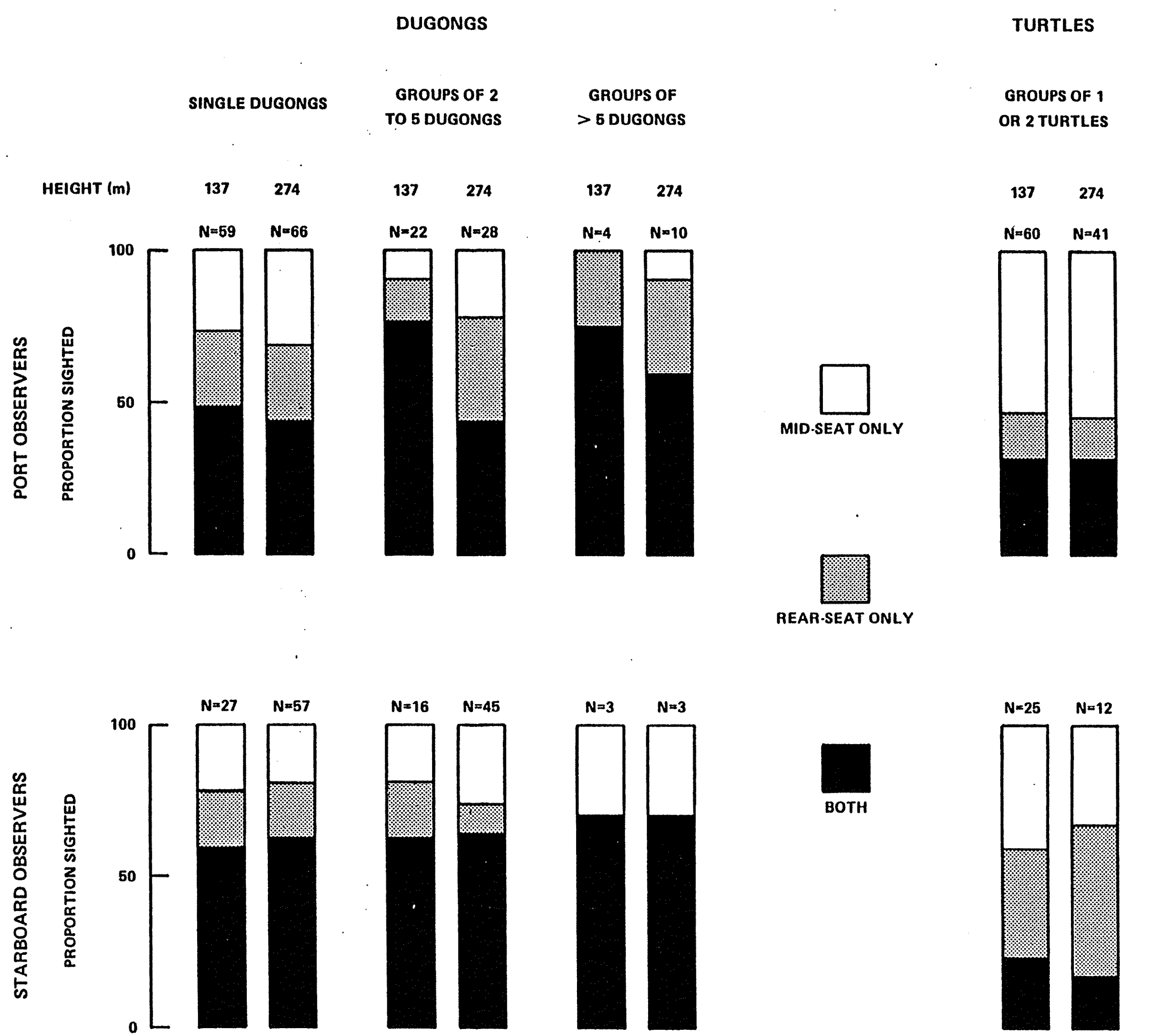

Fig. 5. Proportion of dugong and turtle groups sighted by the mid–seat observer, the rear–seat observer or both observers in each tandem team. The data are presented separately for each survey regime, and for dugong groups in different size categories

The Distribution and Abundance of Dugongs in the Northern Great Barrier Reef Marine Park

Running Head: Dugong Aerial Surveys

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Abstract

In 1984 and 1985, dugongs were censused from the air at an overall sampling intensity of 9% over a total area of 31 288 km2 within the northern sections of the Great Barrier Reef Marine Park. Sightings were corrected for perception bias (the proportion of animals visible in the transect which are missed by observers), and availability bias (the proportion of animals that are invisible due to water turbidity) with survey-specific correction factors. There were no significant differences between population and density estimates obtained from repeat surveys of the same areas. The resultant population estimate ($\pm$ s.e.) was 8 110 $\pm$ 1 073 dugongs at an overall density ($\pm$ s.e.) of 0.26 $\pm$ 0.03 km^{-2}, a precision of 13%. Dugongs occurred up to 58 km offshore and in water up to 37 m deep. The highest density of animals was seen on coastal seagrass beds at depths of <5 m. Maps of density and distribution are given. The design and timing of future surveys is also discussed.

Introduction

This paper outlines the results of aerial censuses of dugongs, *Dugong dugon*, conducted over a total area of 31 288 km^2 in the northern sections of the Great Barrier Reef Marine Park in 1984 and 1985.

The aims were:

(1) to estimate the size of the population in order to assess the likely impact of indigenous hunting;

(2) to obtain a precise index of dugong density as a basis for monitoring population changes;

(3) to determine the pattern of regional variation in dugong density within the Great Barrier Reef lagoon and to compare this with the known distribution of seagrass beds;

(4) to investigate whether the pattern of dugong density is temporally constant;

(5) to determine the size of dugong groups and the incidence of calves;

(6) to evaluate and improve dugong aerial survey methodology.

Methods

The coastal zone of 7 952 km^2 between Cape Bedford (15°15'S., 145°21'E.), Cape Melville (14°10'S., 144°30'E.) and the outer Barrier Reef (Fig. 1) was surveyed between 13 and 15 November 1984 at an overall sampling intensity of 7.6%, and again between 1 and 5 November 1985 at an overall sampling intensity of 9.3%. The corresponding area (15 497 km^2) between Campbell Point (13°32'S., 143°35'E.) and Hunter Point (11°30'S., 142°50'E.) was surveyed between 21 and 26 April 1985 at a sampling intensity of 9.0%, and again between 7 and 8 November and 17 and 21 November 1985. The intervening Princess Charlotte Bay area (7 839 km^2) was surveyed once between 31 October and 7 November 1985 at a sampling intensity of 8.5%. Overall, the sampling intensity for the entire region in the November 1985 survey was 9.0%.

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 1.

Survey Design

For estimation of regional densities of dugongs, the area was divided into thirteen blocks (Fig. 1) on the basis of sampling intensity, depth contours, and/or Aboriginal hunting activity. Block areas were estimated from 1:250 000 maps using a planimeter or a digitising tablet. The areas of major islands were excluded from the block areas. The areas of small (<3 km^2) islands were included in the block areas.

The transect lines flown on the various surveys are shown in Fig. 1. In order to improve precision, all lines were aligned east-west i.e. approximately perpendicular to the depth contours so that both coastal and some offshore waters were included in each transect. For the 1984 survey of blocks 1 through 4, fourteen lines spaced at intervals of 5′ latitude (9.3 km or 5 nm) extended to the outer Barrier Reef. Each pair of these long lines was interspersed with two shorter lines 3.1 km (1.7 nm) apart and extending 21.6 km from the coast. (The latter is the distance flown in seven minutes at 185 km^{-1} [100 knots]). This survey design, which had a 13% sampling intensity inshore and 4.7% offshore, was developed on the assumption that almost all dugongs would be seen close to the coast. This assumption proved incorrect. As a result, in subsequent surveys lines were flown between the coast and the outer Barrier Reef at intervals of 2.5′ latitude to give a sampling intensity of approximately 8% for both inshore and offshore waters, an arrangement which also aided navigation by providing definite start and end points for each transect. Additional lines were flown in two areas of particular interest to the Great Barrier Reef Marine Park Authority: block 2 (sampling intensity 13.0% in 1984 and 16.3% in 1985) and block 11(sampling intensity 25.9% on both surveys).

Methodology

Survey methodology, data handling and analysis techniques were similar to those used in other surveys as outlined by Marsh and Saalfeld (1988) and Marsh and Sinclair (1989).

Correction Factors

Correction factors for perception bias (groups of dugongs visible on the transect line 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 detailed in Marsh and Sinclair (1989). Mean group sizes and their associated coefficients of variation were calculated from the estimates of the size of groups with less than ten animals obtained during the various surveys.

Analysis

Because transects were variable in area, the Ratio Method (Jolly 1969; Caughley and Grigg 1981) was used to estimate density, population size and their associated standard errors for each block for each survey. Any statistical bias resulting from this method is considered inconsequential in view of the high sampling rate (see Caughley and Grigg 1981). Input data were the estimated number of dugongs (in groups of less than ten animals) for each tandem team per transect calculated using the corrections for perception and availability biases. The resultant standard errors were adjusted to incorporate the errors associated with the appropriate estimates of the perception and availability correction factors and the mean group size (Table 2) following the method of Jolly and Watson (1979) (see Marsh and Sinclair 1989). The number of dugongs in groups of greater than ten was added to the estimates of the population and density of the appropriate block at the end of the analysis as outlined in Norton-Griffiths (1978).

Differences in density between years and between blocks for the Cape Bedford - Cape Melville area (blocks 1 through 4), and between seasons and between the inshore and offshore zones for the Campbell Point - Hunter Point area (blocks 6 through 13), were tested separately using analysis of variance with and without measures of cloud cover (oktas) and/or sea state (Beaufort Scale) as covariates. Input data for both analyses were corrected densities per square kilometre based on mean group sizes and the estimates of the correction factors for perception and availability bias, each line within a block (or zone) 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.

There were two fixed factors (blocks and years) in the analysis of the survey results for blocks 2 through 4. (Block 1 was omitted because of the very low number of sightings in 1984 and the absence of sightings in 1985.) Lines within blocks could not be used as a factor because of the differences between years in the survey design (Fig. 1). An unweighted means analysis was used because the number of transects varied by block.

The same lines were flown during the two surveys of blocks 6 through 13 enabling line to be used as a (random) factor in the analysis. However, block was not used as a factor because dugongs were seen on both surveys in three of the eight blocks only. Accordingly, each line was divided into an inshore and an offshore zone at the 10 fathom (18 m) depth contour. Zone and season were treated as fixed factors. A split-plot design (Snedecor and Cochran 1967 p.369-372) was used for the analysis.

Results and Discussion

Reliability of Observers

A total of 128 groups of dugongs were categorized as being seen by both members of a tandem team. Observer reliability was investigated by comparing the reports of team members which were recorded into separate tracks of the two track tape recorder (Marsh and Sinclair 1989). Observers differed in their estimates of group size on six occasions. All of these groups contained six or fewer dugongs and the maximum difference in the count was two. In three instances, the discrepancy was due to one observer's failure to see a calf. The level of observer disagreement over dugong group sizes on these surveys (4.7%) was substantially lower than the 11% recorded by Marsh and Sinclair (in press) for their Moreton Bay experiment in which observers were required to estimate the size of all dugong groups including those with more than ten animals. The Moreton Bay experiment showed that observers found it difficult to count dugongs in large groups. The use of photographs to count dugongs in groups of ten or more during these surveys in Great Barrier Reef waters has clearly improved the accuracy of group size estimates.

During the Barrier Reef surveys, team members apparently differed over specific identity on six occasions (4.7%), compared with 3% in Moreton Bay. Three of the six discrepancies occurred when one observer classified an animal as a dolphin while the other identified it as a dugong; twice one observer classified an animal as a dugong when the other was unsure; once apparently the same animal was called a dugong by one observer, a turtle by the other.

On eleven occasions during the Barrier Reef surveys, one team member described a dugong as being on the surface when his counterpart reported it as beneath the surface (8.6%). The categorization of the rear-seat observer was then used in the analyses. The corresponding discrepancy rate for the Moreton Bay experiment was 5% (Marsh and Sinclair in press). As dugongs are sometimes seen to surface and dive as the aircraft passes overhead, some of these differences are probably real.

Dugong Group Size and Composition

There was no significant difference between the distributions of group size frequency observed on the various surveys (Fig. 2) ($G = 7.5$; $P > 0.25$; 8 d.f.). The largest group (subjectively distinct clumping) seen on any of the surveys was twenty; about 68% of groups contained only a single dugong. The proportion of calves (Fig. 2) ranged from 10.4% to 16.3%. Differences between surveys were not significant ($G = 2.62$; $P > 0.50$; 4 d.f.). This is not surprising. Dugongs calve from August-September through December in this area and calves can stay with their mothers for at least 18 months (Marsh *et al.* 1984). The proportion of calves seen overall (14.7%) is similar to that seen during a survey of the Torres Strait area in November 1983 (14.3%) (Marsh 1986a).

Population and Density Estimates

The value of the mean group sizes and correction factors used in obtaining these estimates are summarized in Table 2. The raw data have been listed in Marsh (1986b). Table 3 gives estimates of density and numbers of dugongs per block on the various surveys, with their associated standard errors. Two standard errors have been listed for each estimate: (1) based on the difference in corrected dugong counts between transects, (2) incorporating the errors in estimating the appropriate correction factors and mean group sizes as well. The resultant increase in the standard error of (2) compared with (1) is relatively small and is mostly due to the availability correction factor which typically has the highest coefficient of variation of the three components of the error summarized in Table 2.

The population estimates sum ($\pm$ s.e.) to 8 110 $\pm$ 1 073 dugongs for the whole region in November 1985 at an overall density ($\pm$ s.e.) of 0.26 $\pm$ 0.03 dugongs per km^2, a precision (s.e./$\bar{x}$) of 13%.

Fig. 3 is a smoothed dugong density distribution map based on the results of the November 1985 surveys with an adjacent map showing the corresponding densities for the Cape Bedford to Cape Melville area based on the results of the November 1984 surveys. These maps should be useful when the zoning plans of the northern sections of the Great Barrier Reef Marine Park are revised. A map of the known seagrass beds in the region (Fig. 4) is provided for comparison. Overall 52% of dugong sightings were associated with known seagrass beds. Fifty-six percent of animals were sighted in depths of less than 5 m (Fig. 5). Coles *et al.* (1987) found that seagrass biomass is greatest in 2-6 m of water along this coast and recorded thirteen species of seagrass at sites less than 2 m deep. Most of the areas where the highest density (>1 per km^2) of dugongs were observed support extensive inshore beds of seagrass species such as *Halodule uninervis*, *Halophila ovalis* and *Halophila spinulosa*, and *Cymodocea serrulata* (Coles *et al.* 1987). These genera also tend to predominate in the stomachs of dugongs from north Queensland (Marsh *et al.* 1982).

Dugongs were sighted up to 58 km from the coast in water of depths ranging to 37 m (Fig. 5). The reasons for their venturing so far offshore is not understood as the distribution of offshore seagrass beds is poorly known. However, *Thallasia hemprichii* and *Cymodocea rotundata* have been recorded from reef platforms in this region (Coles *et al.* 1987), and dugongs were observed on offshore reefs especially in the Princess Charlotte Bay area (block 5). *Halophila decipens* is the only seagrass recorded at depths of greater than 11 m in the Great Barrier Reef lagoon (Coles *et al.* 1987) where it has been recorded from depths of up to 68 m (P. Arnold, in Lanyon 1986). All these genera are eaten by dugongs in this region (Marsh *et al.* 1982).

The results of the analysis of variance used to investigate the differences between the surveys of blocks 2, 3, and 4 held in November in both 1984 and 1985 (Table 4) indicated that densities differed significantly between blocks ($P < 0.001$) but not between years ($P = 0.18$). There was a significant interaction between years and blocks ($P < 0.05$) indicating that the dugongs were dispersed differently in different years. In particular, the results suggest movements of large numbers of dugongs between the high density inshore block 2 and the other blocks. Inclusion of Beaufort sea state as a covariate in the analysis increased the probability of there being no difference in dugong density between years to 0.54, indicating that the lower observed density in 1985 could be explained by the rougher seas (Table 1).

Comparison of the results of the April (post-wet season) and November (pre-wet season) surveys of blocks 6 through 13 in 1985 (Table 5) indicated that densities differed significantly between lines and particularly between zones, with the density significantly higher in the inshore zone than in the offshore zone. However, there was no significant difference in density between seasons, nor was there any significant season by zone interaction indicating that the pattern of dispersion was similar for both surveys. The inclusion of Beaufort sea state and cloud cover as covariates in the analyses made little difference to the result (Table 5) and did not alter any of the conclusions.

The 1984 and 1985 dugong population estimates obtained for blocks 1 through 4 were close, as were the April and November 1985 estimates of the population of blocks 6 through 9 (Table 3). Such agreement, despite the different weather conditions under which the surveys were conducted (Table 1), suggests that the use of survey-specific correction factors to correct for perception and availability biases was successful.

Design of Future Surveys

The population and density estimates obtained for the Cape Bedford - Cape Melville survey in 1984, in which inshore blocks 1, 2 and 3 were surveyed at an intensity of about 13% and the offshore block 4 at an intensity of about 5% (Fig. 1), had a precision based on the standard sampling theory estimates only of 15% (Table 3). This is a substantial improvement on the corresponding precision of 24% obtained for the same area in 1985 when blocks 1, 3 and 4 were surveyed at an intensity of about 8% and block 2 at an intensity of 16%. Future surveys of the areas from Cape Bedford to Cape Melville should be stratified along the lines of the November 1984 survey (see Fig. 1).

Significant numbers of dugongs were observed on the large offshore reefs in Princess Charlotte Bay in November 1985 (Fig. 3). The survey design used for this area (block 5) seems satisfactory as it returned a precision (based on standard sampling theory estimates only) of 16%. However, the corresponding values achieved for the surveys of the area between Campbell Point and Hunter Point (blocks 6-13) were 24%. Most dugongs were seen close to the coast in this region suggesting that precision could be improved by increasing the sampling fraction in the inshore area and reducing it in the offshore area along the lines used for the November 1984 survey of blocks 1 through 4 (Fig. 1).

It is estimated that if the survey designs were modified as outlined above, the precision of the population estimate for the whole area from Cape Melville to Hunter Point (based on standard sampling theory only) could be improved from the 12% obtained in 1985 to about 9% without increasing survey costs. Incorporating the errors in estimating the mean group size and correction factors would be expected to decrease the precision to about 11%.

Timing of future surveys

Dugongs are long-lived animals with a life-span of up to 70 years, a minimum pre-reproductive period of 9-10 years, and a mean calving interval which has been estimated as 3-7 years for various populations (Marsh *et al.* 1984; Marsh 1986a). Marsh (1986a) has calculated that even with the most optimistic combination of these parameters, a low schedule of natural mortality and no anthropogenic causes of mortality, the maximum rate of increase is likely to be of the order of 5% per year. Under the present zoning and management regulations, the level of man-induced mortality in the northern sections of the Great Barrier Reef Marine Park should be low. Thus, barring catastrophes, the annual rate of population change is also expected to be relatively low.

When designing a monitoring program for a vulnerable species such as the dugong, the consequences of failing to pick up a declining trend are more serious than the consequences of deciding that a declining trend is occurring when it is not. Thus it is particularly important to consider Type 2 statistical errors. If this expected slow rate of dugong population change is to be monitored within an acceptable range of statistical error, the precision of the population estimates will have to be high. Under a constant intensity of sampling, the precision of a population estimate improves as the size of the survey area is increased as evidenced by Table 3. Thus future surveys for cover large areas e.g. the whole region from Cape Bedford to Hunter Point. October-November is the only time of year when weather conditions are likely to be optimal for a period long enough to survey such large areas adequately, making it unrealistic to plan more than one survey of the area in any one year.

Gerrodette (1987) outlines procedures for estimating the minimum number of samples required to detect a trend in numbers using linear regression. His technique has been used to investigate how long it would take to detect with acceptable levels of confidence that a dugong population which was decreasing at 5% per year was in fact declining i.e. that the slope of the regression line was significantly less than 0. The following assumptions were made: (1) improvements in survey design would increase the precision to 11%; (2) the coefficient of variation is inversely related to the square root of abundance as predicted for strip transects by Seber (1982). The probabilities of both a Type 1 error α and a Type II error β were set at 0.05.

It is estimated that it would take 9 years of annual surveys i.e. ten surveys to be able to detect such a decline with 95% confidence. Meanwhile, a dugong population declining at 5% per year would have been reduced to 63% of its size at the time of the first survey. A preliminary indication of such a trend could be obtained more quickly by allowing α and/or β to assume larger values. Of course, a more rapid decline would be detected more quickly with the same frequency of surveys.

As Gerrodette (1987) points out, annual surveys are probably not the optimum frequency of sampling for a population that is changing slowly. As the interval between surveys increases, the effective rate of change per interval increases, and the required number of surveys therefore decreases (see Gerrodette 1987, Table 2). For example, two dugong surveys 10 years apart could establish with 95% confidence that a population decreasing at 5% per year is declining. Such a low survey frequency would obviously provide substantially less information than annual surveys.

Any sampling strategy will be a compromise between information and cost. The Great Barrier Reef Marine Park Authority is required by law to revise zoning plans every 5 years. Given the expense, time and personnel needed to conduct large-scale surveys in remote areas, we suggest that this would also be an appropriate interval between dugong surveys in the northern sections of the Great Barrier Reef Marine Park.

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Legend to figures

Fig. 1 Survey areas, showing the survey blocks (1-13) and transect lines used in the 1985 surveys. The transects flown in November 1984 are shown in the adjacent map. The boundary between the inshore blocks 1, 2 and 3 and the offshore block 4 is 21.6 km from the coast (i.e. all transects in blocks 1, 2 and 3 are 21.6 km long). The 18 m (10 fathom) line forms the boundary between the inshore blocks 6, 8, 10, 11 and 12 and the offshore blocks 7, 9 and 13. (Adapted from Marsh and Saalfeld 1988.). The areas of the survey blocks (km^2) are as follows: Block 1: 1 004; 2: 665; 3: 1 050; 4: 5 233; 5: 7 839; 6: 451; 7: 1 561; 8: 1 194; 9: 4 600; 10: 259; 11: 396; 12: 452; 13: 6 584.

Fig. 2 Frequency histograms showing details of dugong group sizes on each survey and the proportion of dugongs seen in groups of various sizes over all surveys (a) all groups (b) groups containing calves □ groups with one calf; ■ groups with two calves; ◪ one group with one calf, one group with two calves.

Fig. 3 The distribution of dugong density in the survey area from Cape Bedford to Hunter Point in November 1985. The corresponding figure for the survey area from Cape Bedford to Cape Melville in November 1984 is also provided.

Fig. 4 The approximate distribution and density of inshore seagrass beds in the survey area provided for comparison with Fig. 3. The ground-truthed seagrass data are from Coles *et al.* (1985) and adapted from Marsh and Saalfeld (1988).

Fig. 5 Frequency histograms showing the number of dugongs seen in water of various depths on each survey and the proportion of dugongs seen in water of various depths over all surveys. These depths were obtained from marine charts and have not been corrected for tidal levels at the time of the survey. In view of the paucity of information for this area, these data must be regarded as very approximate.

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Table 1 Weather conditions encountered on each survey.

	November 1984	April 1985	November 1985 Blocks 1-7	November 1985 Blocks 8-13
Wind speed ($km\ h^{-1}$)	≤20	≤30	≤28	≤19
Cloud cover (oktas)	0-2	2-7	0.5-5	0-4
Minimum cloud height (m)	650-1000	200-2500	460-1525	305-610
Beaufort Sea State mode (range)	1 (0-3)	2 (1-3.5)	2.5 (0-4)	1 (0-3)
Glare [a,b] mode (range)	1 (0-2)	2 (0-3)	1 (0-2.5)	1 (0-2.5)
Visibility (km)	>10	8->10	8->10	>20->50

a Worse side of aircraft

b Scale 0 = none, 1 = <25% of field of view affected by glare, 2 = 2.5 ≤ 50%, 3>50%.

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

Date of survey	Blocks: lines	Group size mean (s.e./$\bar{x}$)	Number of observers		Perceptual Correction Factor estimate (Cp^{h})		Availability Correction Factor estimate (Ca^{h})
			P[g]	S[g]	P[g]	S[g]	
November 1984	blocks 1-4	1.62 (0.04)	1[a]	1[a]	1.13 (0.01)	1.13 (0.01)	2.48 (0.14)
April 1985	blocks 6-13	1.57 (0.07)	1[b]	2	1.58 (0.07)	1.20 (0.07)	1.95 (0.19)
November 1985[e]	blocks 1-4; 5: 9-23; 6 & 7; 8 & 9: 10-12	1.47 (0.04)	2	2	1.10 (0.02)	1.15 (0.04)	2.62 (0.12)
November 1985[e]	block 5: 1-8	1.47 (0.04)	2	1[c]	1.10 (0.02)	1.53 (0.04)	2.62 (0.12)
November 1985[f]	blocks 8 & 9: 13-32; 10; 11: 39-42; 12: 43-48; 13: 33-48	1.53 (0.09)	2	2	1.06 (0.03)	1.02 (0.01)	1.44 (0.23)
November 1985[f]	blocks 11: 50-57; 12 & 13: 49	1.53 (0.09)	1[d]	2	1.42 (0.03)	1.02 (0.01)	1.44 (0.23)

[a] Based on correction factor for starboard rear seat observer on November 1985 survey blocks 8-13 (who saw a similar number of dugong groups to port observer on this survey), when weather conditions similar to this survey.

[b] Port correction factor based on starboard mid-seat observer this survey (who saw a similar number of dugong groups).

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

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

[e] Blocks flown October 31 - November 8, 1985.

[f] Blocks flown November 17 - 21, 1985.

[g] P = port; S = starboard.

[h] Coefficient of variation of associated correction factor

Table 3: Estimated densities and numbers of dugongs on the various surveys. The values are ± standard error incorporating the errors resulting from sampling, and in estimating mean group size and the correction factors. The numbers in brackets represent the standard errors resulting from sampling only.

Block	Initial Survey		November 1985 Survey	
	Density per km2	Numbers	Density per km2	Numbers
1	0.15 ± 0.06 (0.06)[a]	149 ± 61 (58)[a]	0	0
2	1.22 ± 0.45 (0.43)[a]	812 ± 299 (288)[a]	2.47 ± 0.87 (0.82)	1644 ± 570 (543)
3	0.93 ± 0.23 (0.21)[a]	974 ± 244 (223)[a]	0.26 ± 0.10 (0.10)	272 ± 110 (106)
4	0.18 ± 0.04 (0.04)[a]	964 ± 231 (208)[a]	0.12 ± 0.05 (0.05)	626 ± 256 (248)
sub - total				
blocks 1 - 4	0.36 ± 0.06 (0.06)[a]	2899 ± 454 (423)[a]	0.32 ± 0.08 (0.08)	2542 ± 634 (606)
precision[c]		0.16 (0.15)[a]		0.25 (0.24)
5	N/A	N/A	0.46 ± 0.09 (0.07)	3630 ± 714 (585)
precision[c]				0.20 (0.16)
6	2.07 ± 1.04 (0.99)b	934 ± 471 (448)[b]	1.76 ± 0.94 (0.92)	792 ± 423 (414)
7	0.10 ± 0.05 (0.04)b	151 ± 73 (68)[b]	0	0
8	0.74 ± 0.23 (0.19)[b]	878 ± 271 (226)[b]	0.51 ± 0.16 (0.11)	611 ± 192 (131)
9	0[b]	0[b]	0.03 ± 0.02 (0.02)	134 ± 104 (99)
10	0[b]	0[b]	0.09 ± 0.09 (0.09)	24 ± 23 (22)
11	0.53 ± 0.17 (0.15)[b]	209 ± 68 (59)[b]	0.56 ± 0.20 (0.18)	222 ± 81 (71)
12	0[b]	0[b]	0.06 ± 0.06 (0.06)	27 ± 26 (25)
13	0[b]	0[b]	0.02 ± 0.01 (0.01)	128 ± 83 (76)
sub - total				
blocks 6 - 13	0.13 ± 0.04 (0.03)[b]	2172 ± 552 (510)[b]	0.13 ± 0.03 (0.03)	1938 ± 491 (459)
precision[c]		0.25 (0.24)[b]		0.25 (0.24)
Total for November 1985 survey			0.26 ± 0.03 (0.03)	8110 ± 1073 (959)
precision[c]				0.13 (0.12)

[a] November 1984

[b] April 1985

[c] (s.e./$\bar{x}$)

N/A not available

Table 4: Summary of analysis of variance comparing observed dugong density in the Great Barrier Reef Marine Park between Cape Bedford and Cape Melville by blocks and by years (1) without covariates (roman print) and (2) with Beaufort sea state as a covariate[a] (*italics*).

Sources of variation	Sum of squares[b]		d.f		*F*		Significance of *F*	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Blocks	13.696	*14.176*	2	*2*	18.932	*19.694*	0.000	*0.000*
Years	0.827	*0.134*	1	*1*	2.228	*0.373*	0.134	*0.543*[c]
Blocks by years	2.753	*2.560*	2	*2*	3.806	*3.557*	0.026	*0.033*
Residual	30.383	*29.872*	84	*83*				
Regression		*0.510*		*1*		*1.418*		*0.237*

[a]. Assumption that regression slopes the same for all cells was not violated (*P* = 0.612).

[b]. Data transformed using *ln*(X + 0.33 smallest non-zero density).

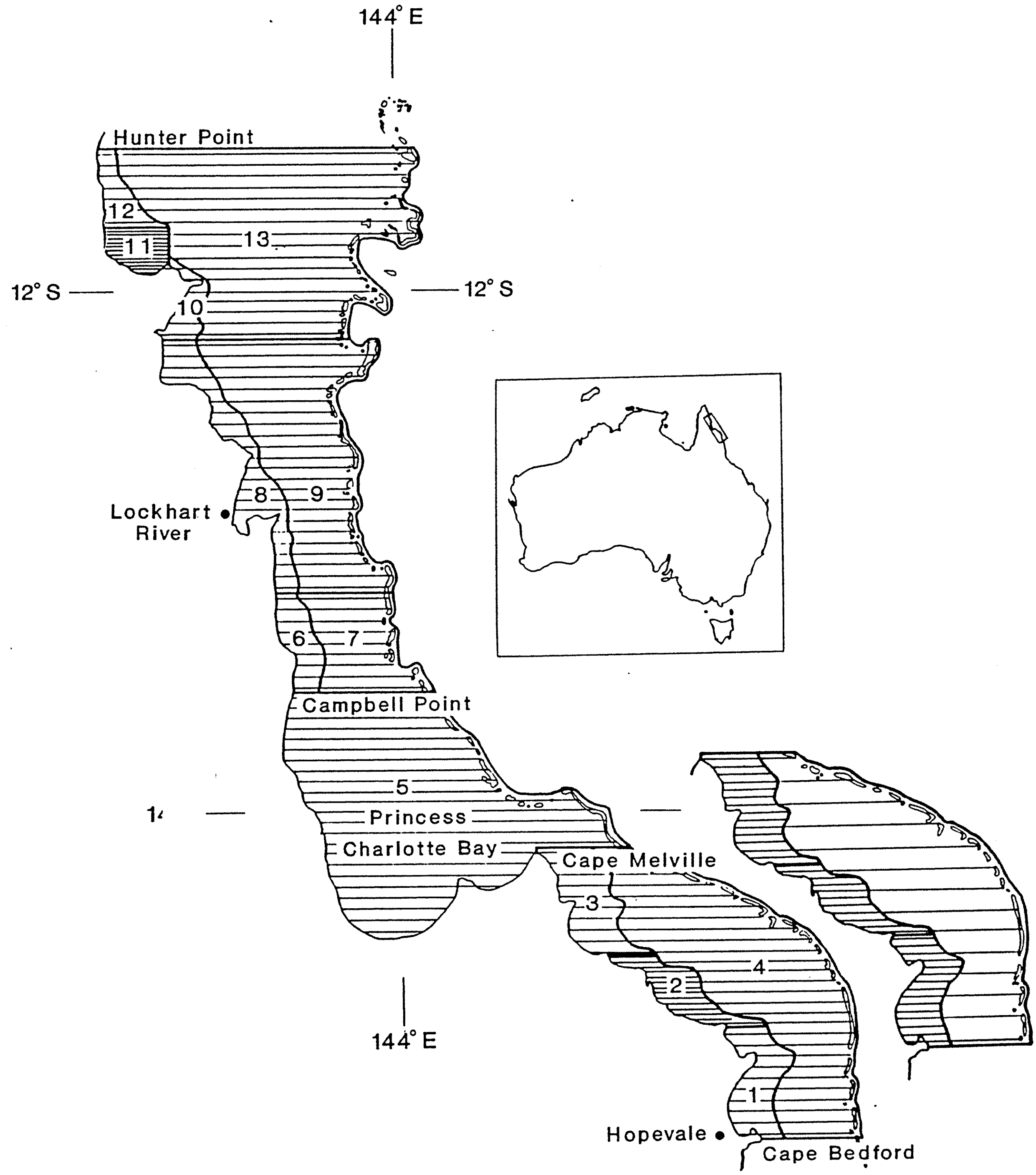
[c]. The probability of no significant difference in dugong density between years was greatest (*P* = 0.543) when Beaufort sea state was used as the only covariate. The corresponding proability with cloud cover as a covariate was *P* = 0.112 and with Beaufort sea state and cloud cover as combined as covariates *P* = 0.328. The assumption that regression slopes are the same for each cell was not violated with cloud cover (*P* = 0.283) as a covariate, but was violated when Beaufort sea state and cloud cover were both used as covariates (*P* = 0.044).

Table 5: Summary of analysis of variance comparing observered dugong density in the Great Barrier Reef Marine Park between Campbell Point and Hunter Point by blocks and by season[a].

Source of variation	Sum of squares[b]	d.f.	*F*	Significance of *F*
Lines	22.053	48	1.532	0.039
Main plot comparisons				
Zones (inshore/offshore)	15.917	1	28.890	0.000
Main plot error	26.445	48		
Sub-plot comparisons				
Season	0.016	1	0.054	0.817
Season by zone	0.001	1	0.004	0.950
Sub-plot error	28.798	96		

[a]. The probability of there being no significant differences in dugong density between seasons was $P = 0.957$ with Beaufort sea state as a covariate, $P = 0.798$ with cloud cover as a covariate, and $P = 0.731$ with both Beaufort sea state and cloud cover as covariates.

[b]. Data transformed using *ln*(X + 0.33 smallest non-zero density).



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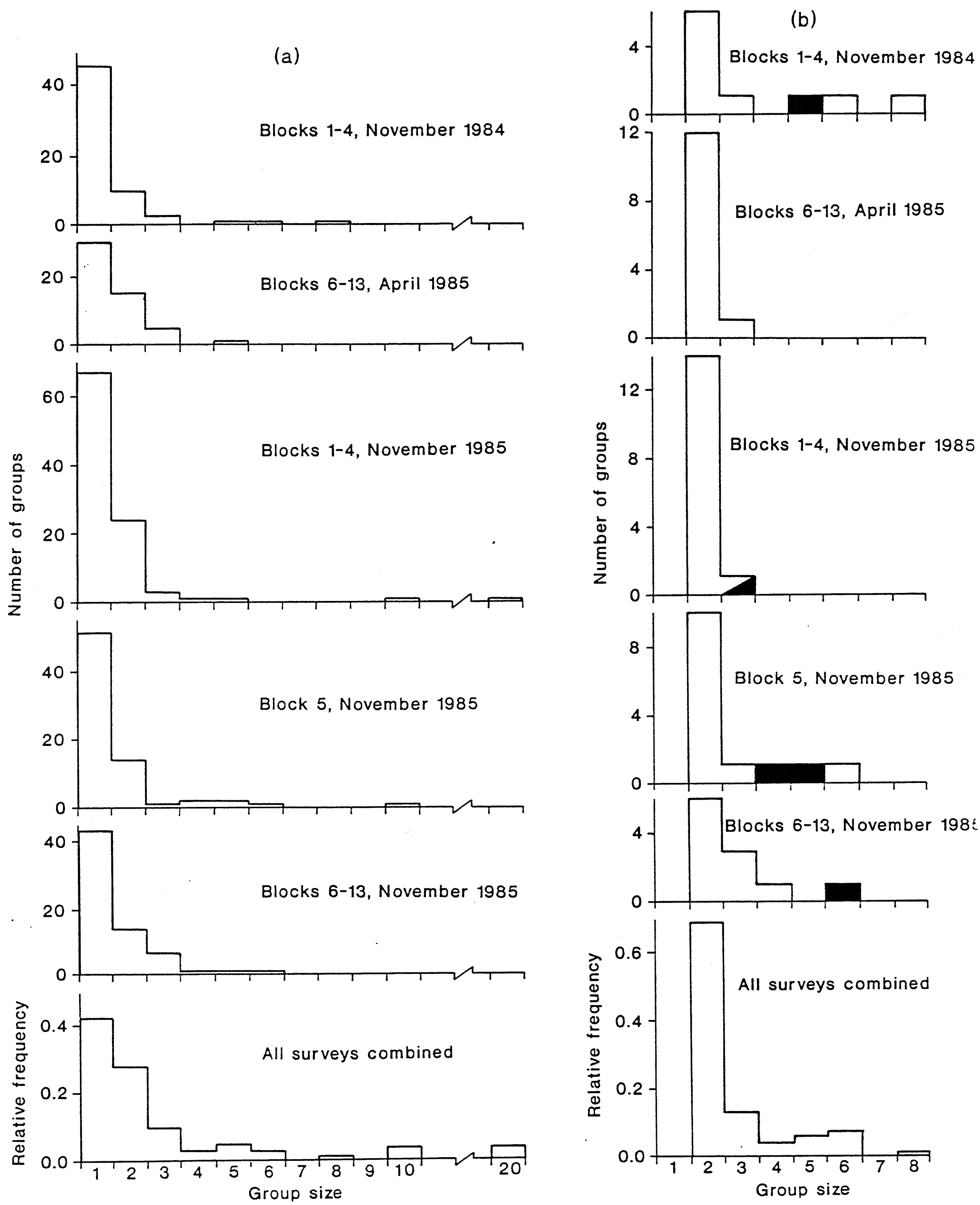
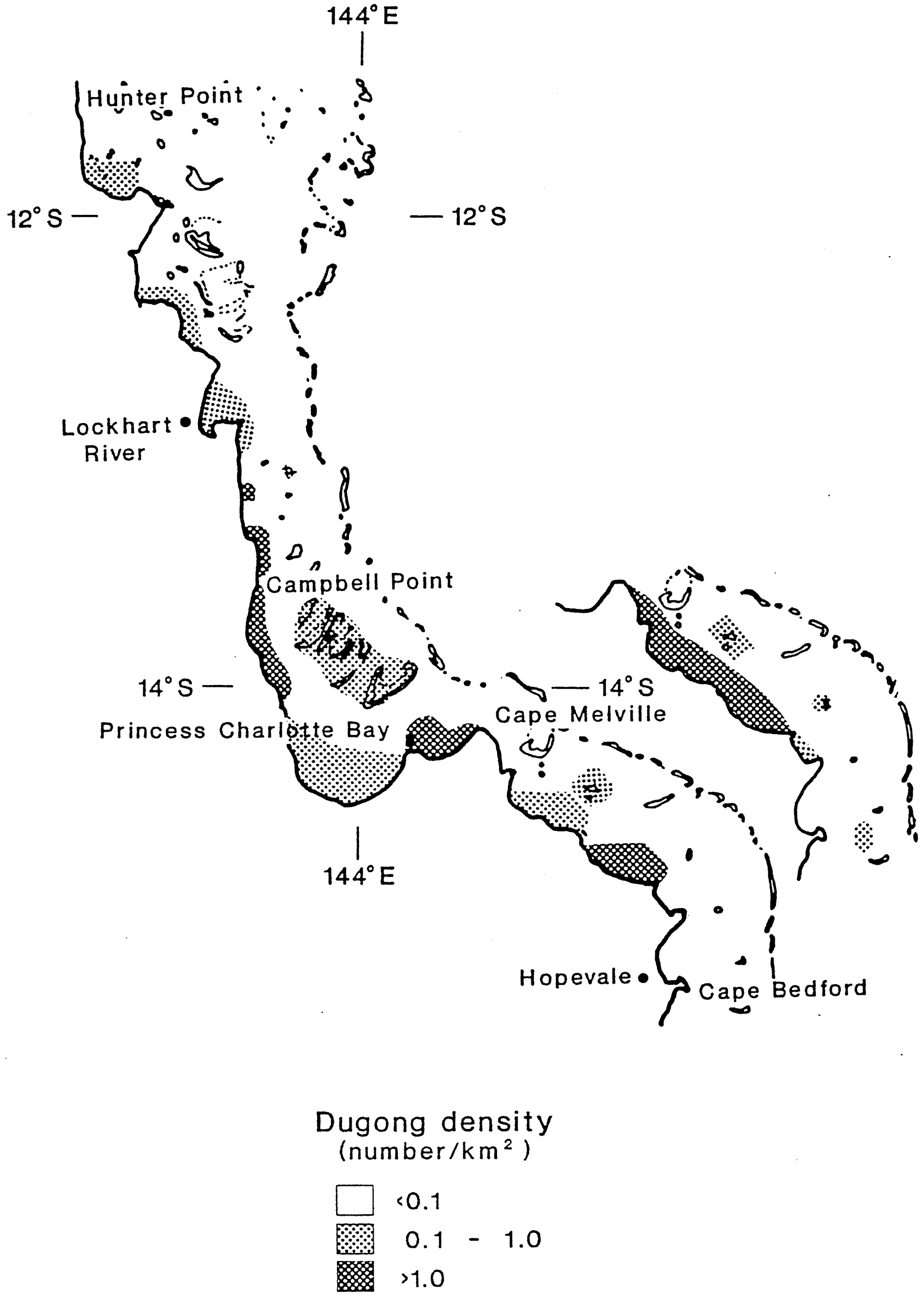


Fig. 2 Frequency histograms showing details of dugong group sizes on each survey and the proportion of dugongs seen in groups of various sizes over all surveys (a) all groups (b) groups containing calves ☐ groups with one calf; ■ groups with two calves; ◪ one group with one calf, one group with two calves.



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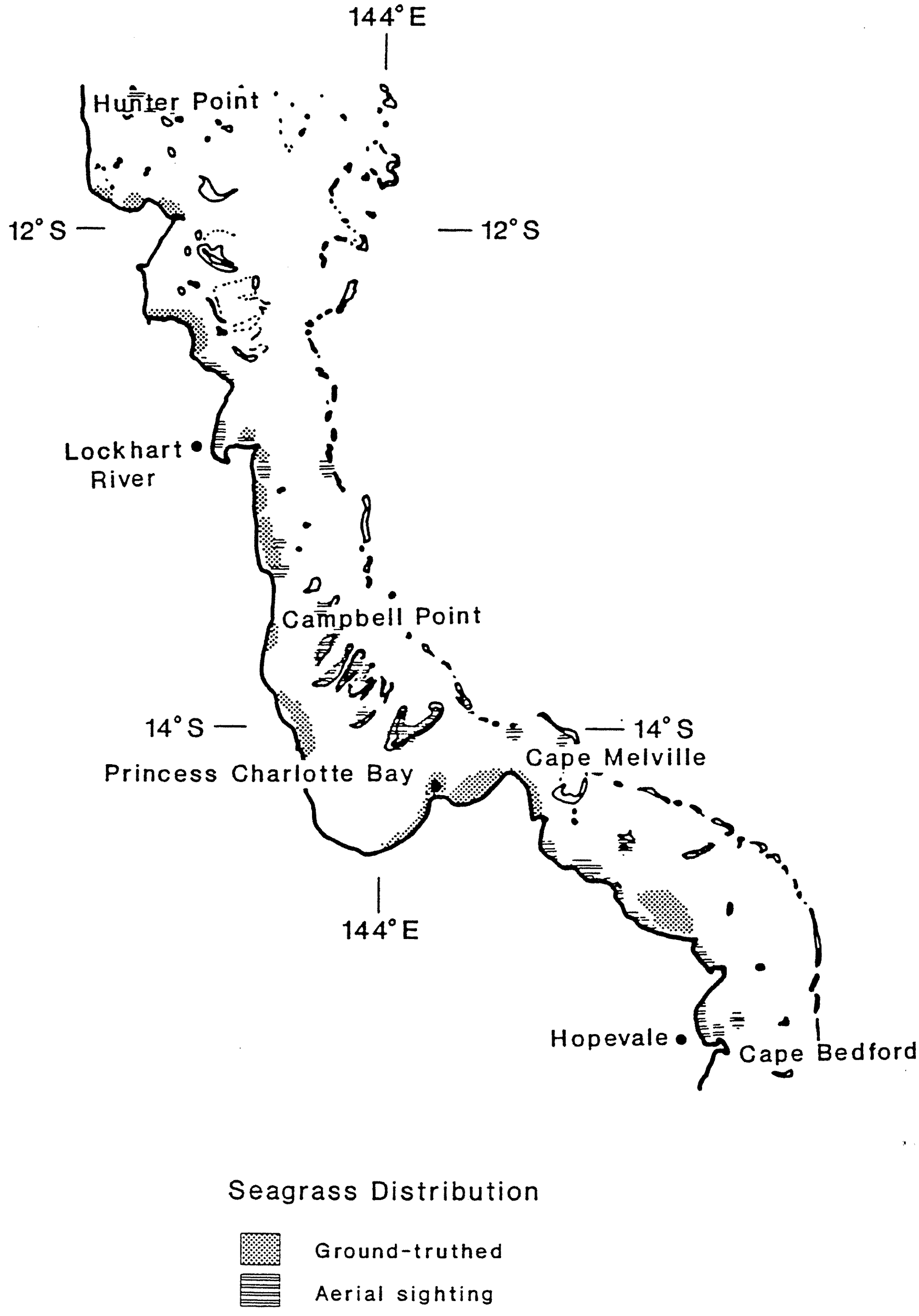

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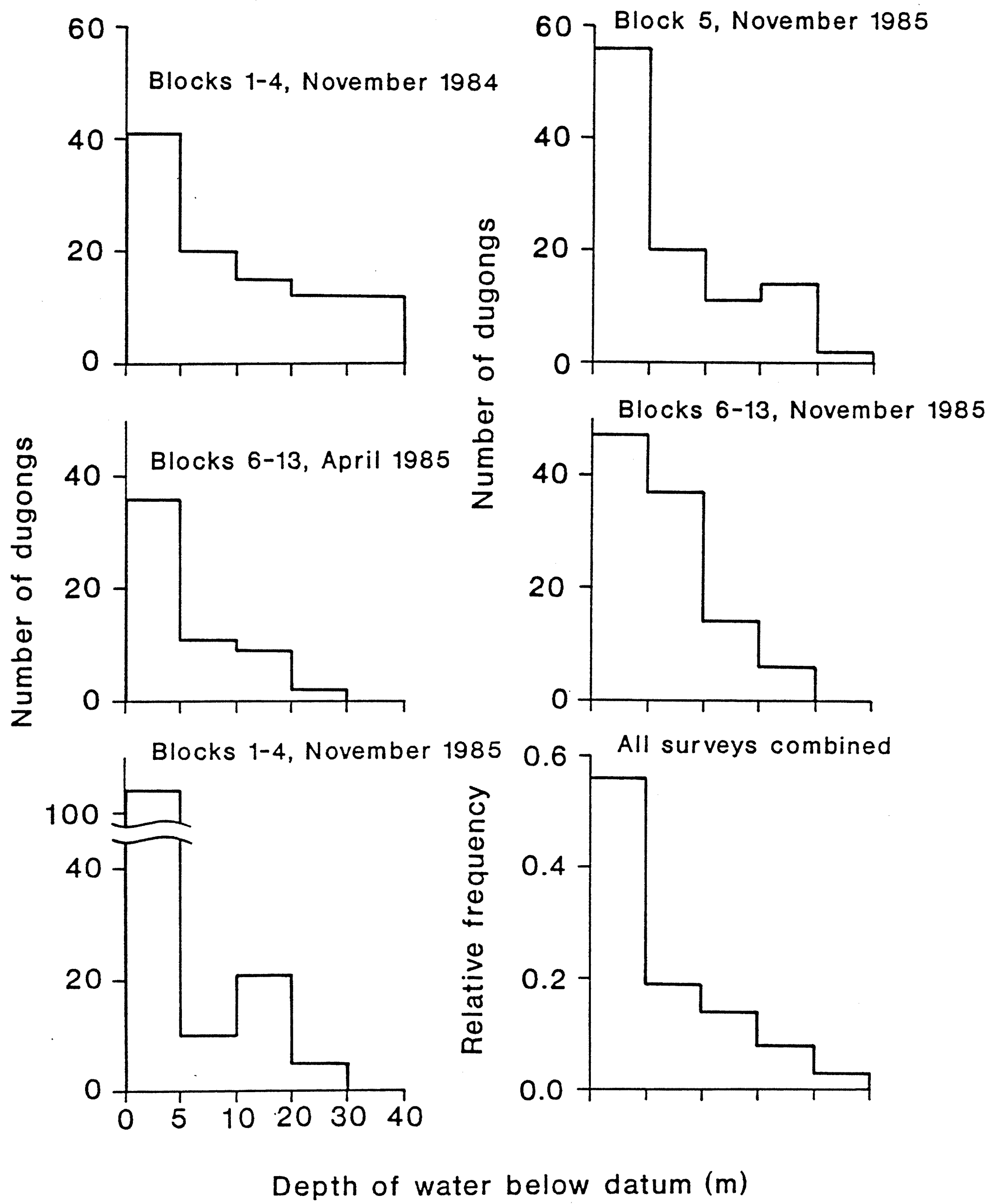

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The distribution and abundance of dugongs in the southern Great Barrier Reef Marine Park

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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 a. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. Submitted to *J.Wildl. Manag.*

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.

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♦ = 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.

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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	$\leq$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 $\leq$ 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	Number of observers Starboard	Perception Correction Factor estimate (C.V.) Port	Perception Correction Factor estimate (C.V.) 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

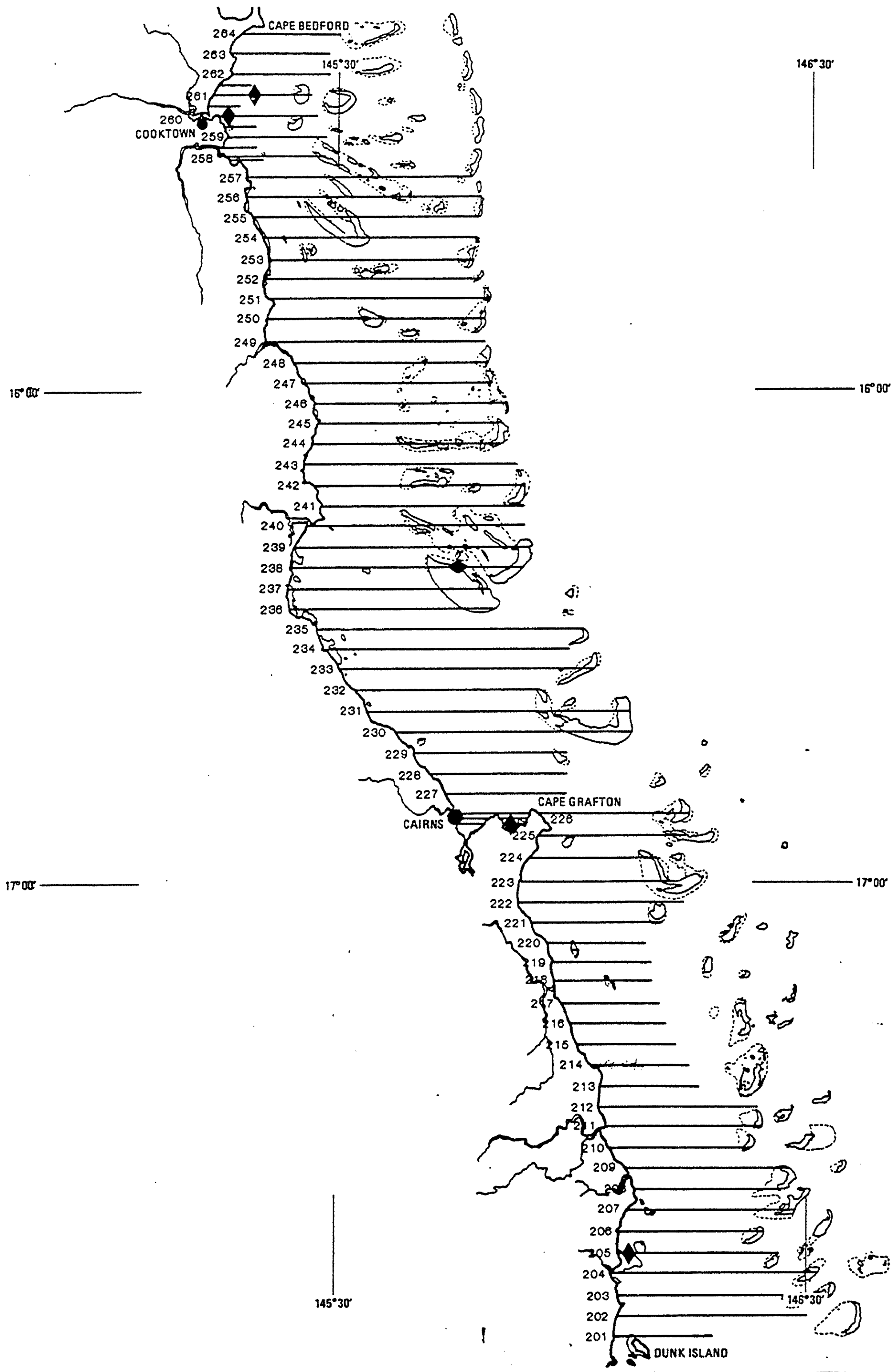


Fig. 1a Cairns survey area, showing the transect lines for the October 1987 survey. Dugong sightings (♦) made during the survey are also shown as the sighting rate for this survey was too low to allow the determination of dugong density in the survey area.

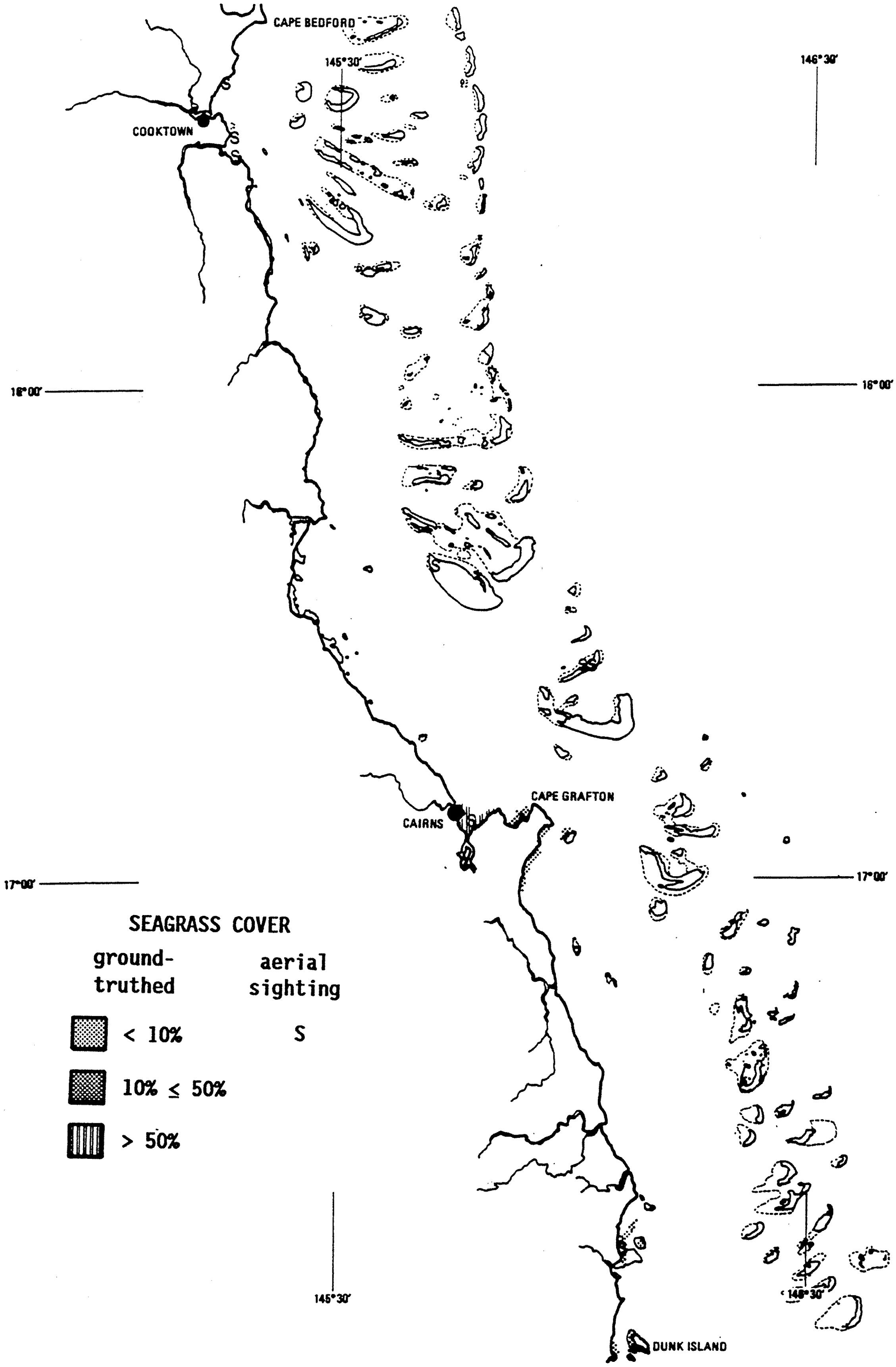


Fig. 1b The distribution and density of inshore seagrass beds in the Cairns Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript).

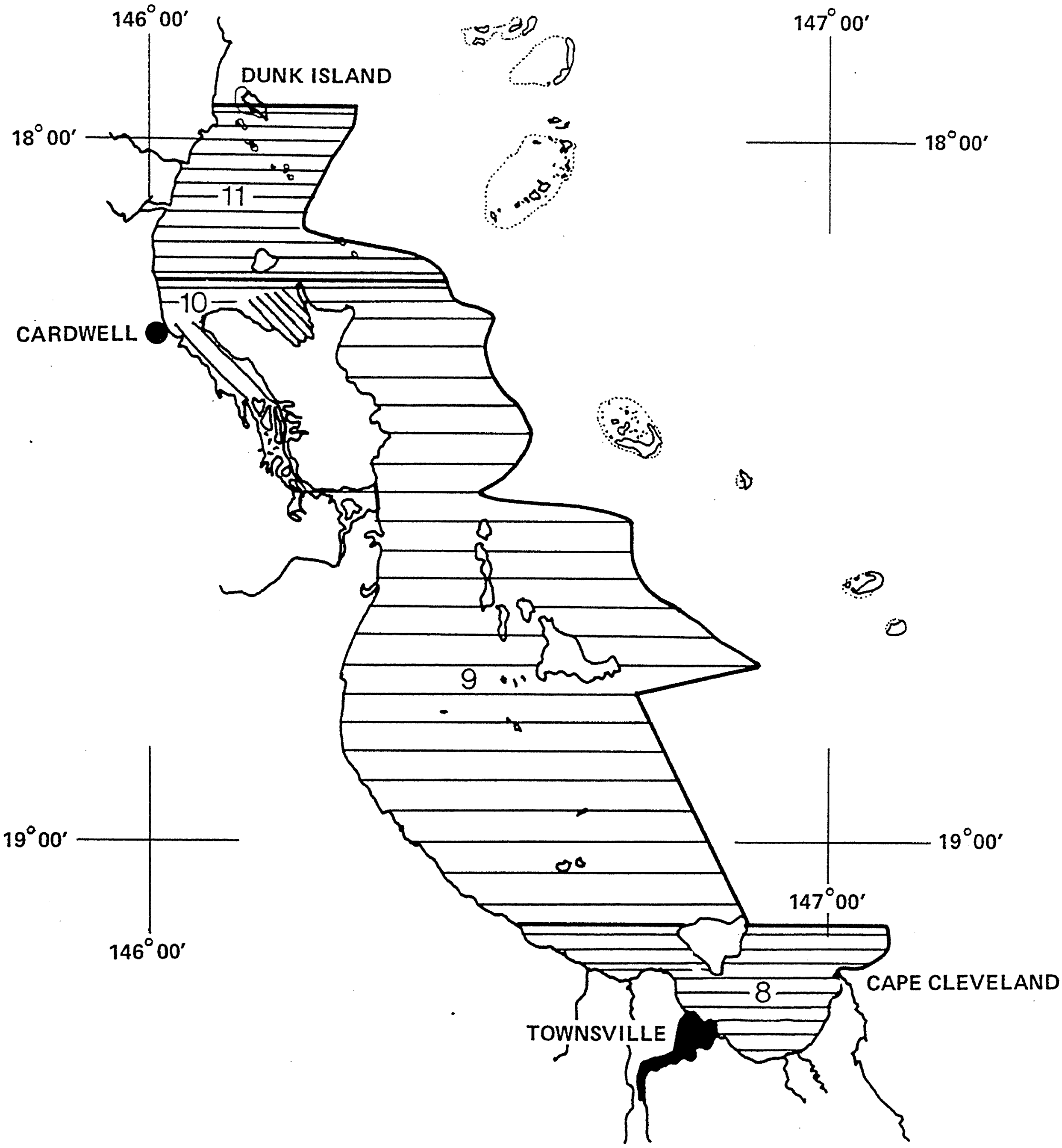


Fig. 2a Northern Central Section survey area, showing the survey blocks (8-11) and transect lines for the September 1986 and October 1987 surveys.

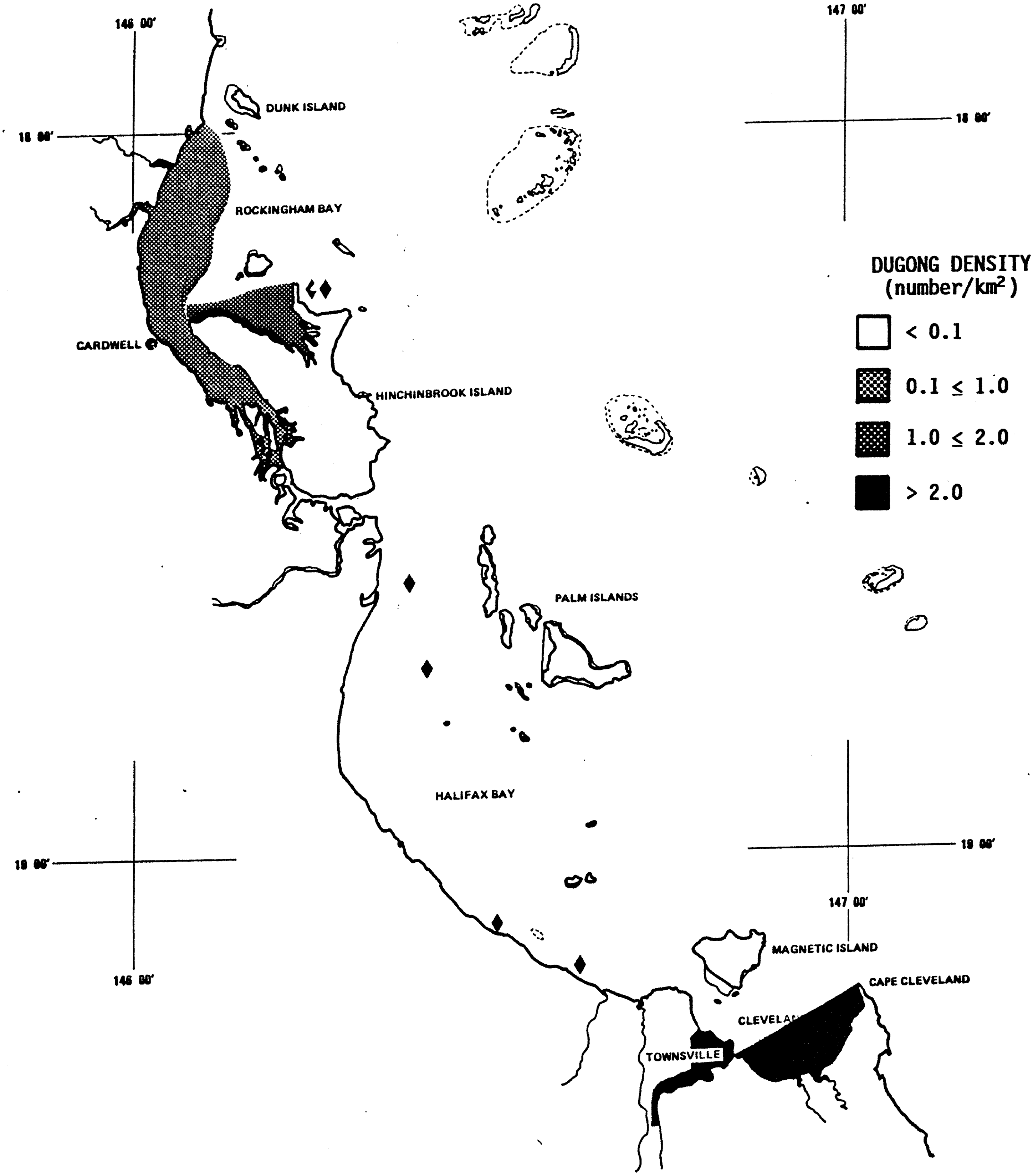


Fig. 2b The distribution of dugong density in the northern Central Section survey area in September 1986.

♦ = individual sightings.

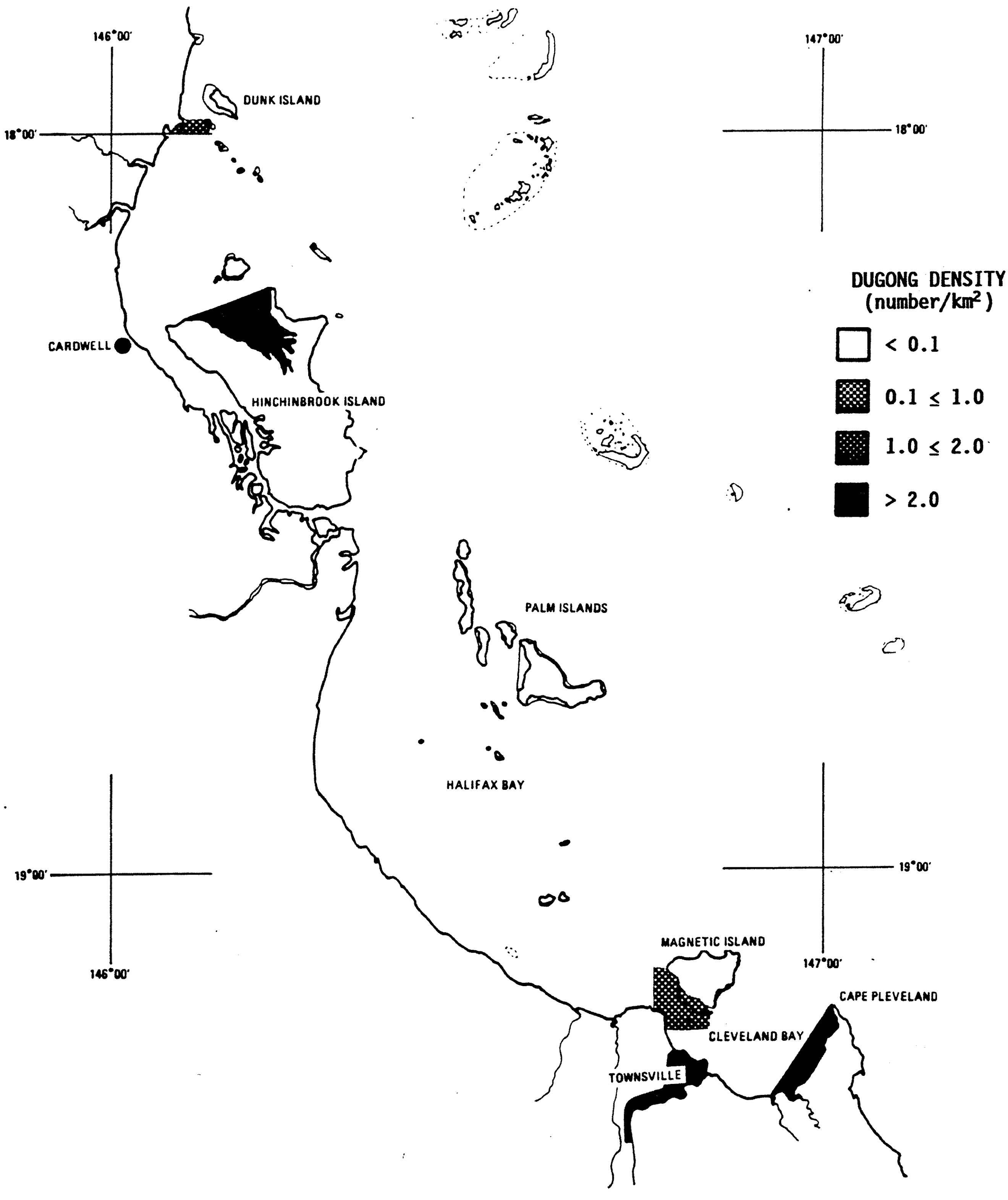


Fig. 2c The distribution of dugong density in the northern Central Section survey area in September - October 1987.

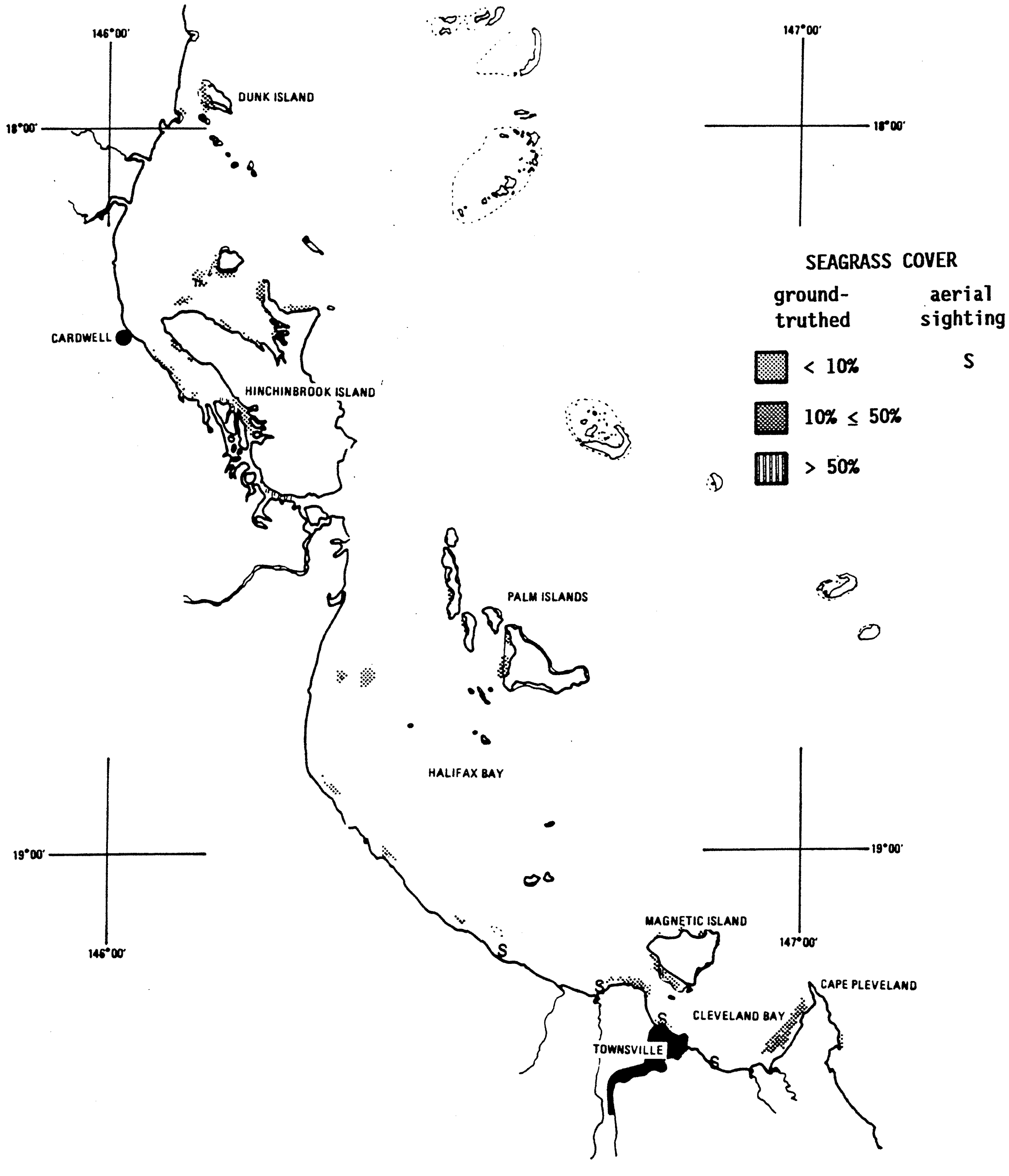


Fig. 2d The distribution and density of inshore seagrass beds in the northern Central Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (manuscript).

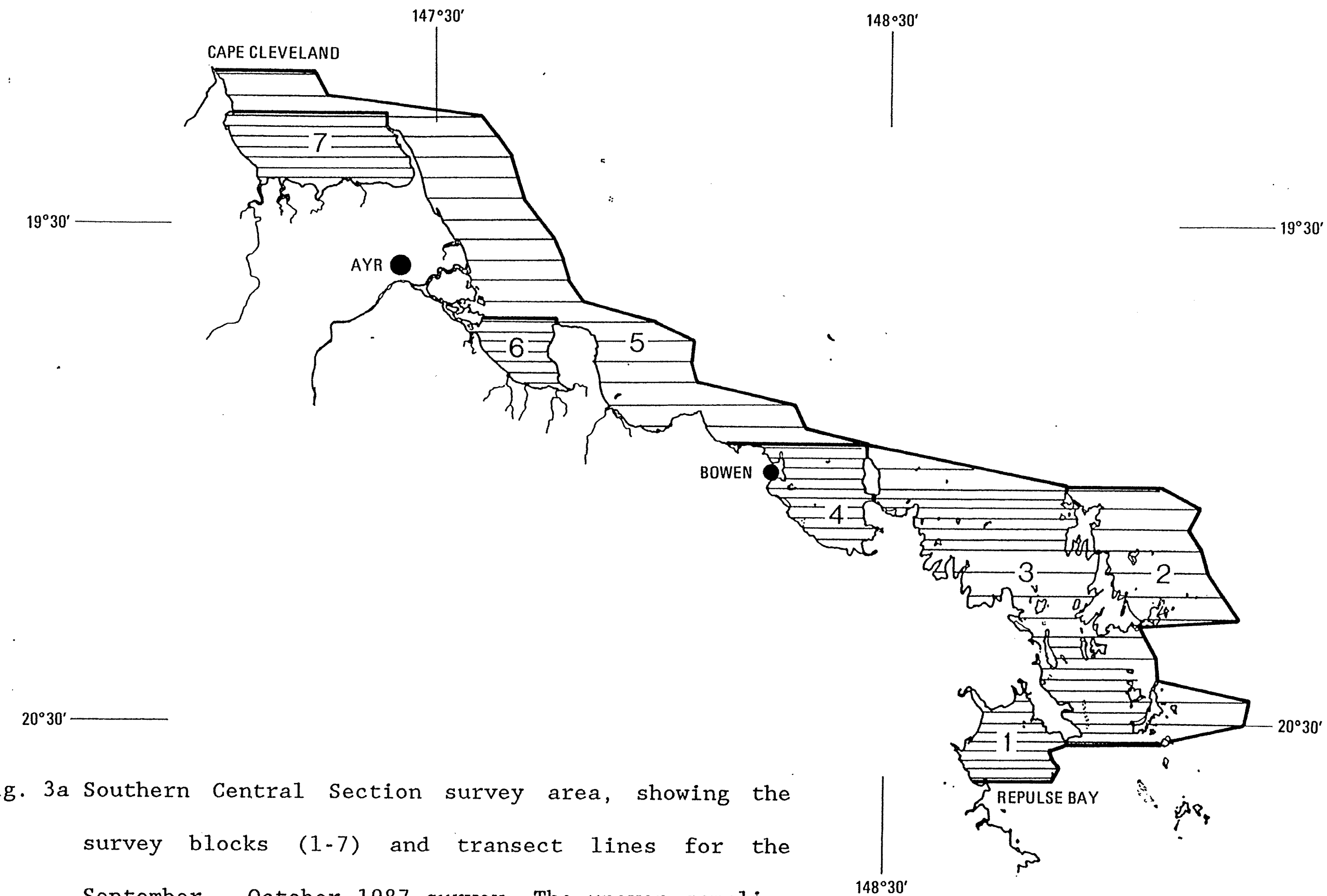


Fig. 3a Southern Central Section survey area, showing the survey blocks (1-7) and transect lines for the September - October 1987 survey. The uneven sampling intensity in Block 3 was the result of logistical problems; no dugongs were seen in this block.

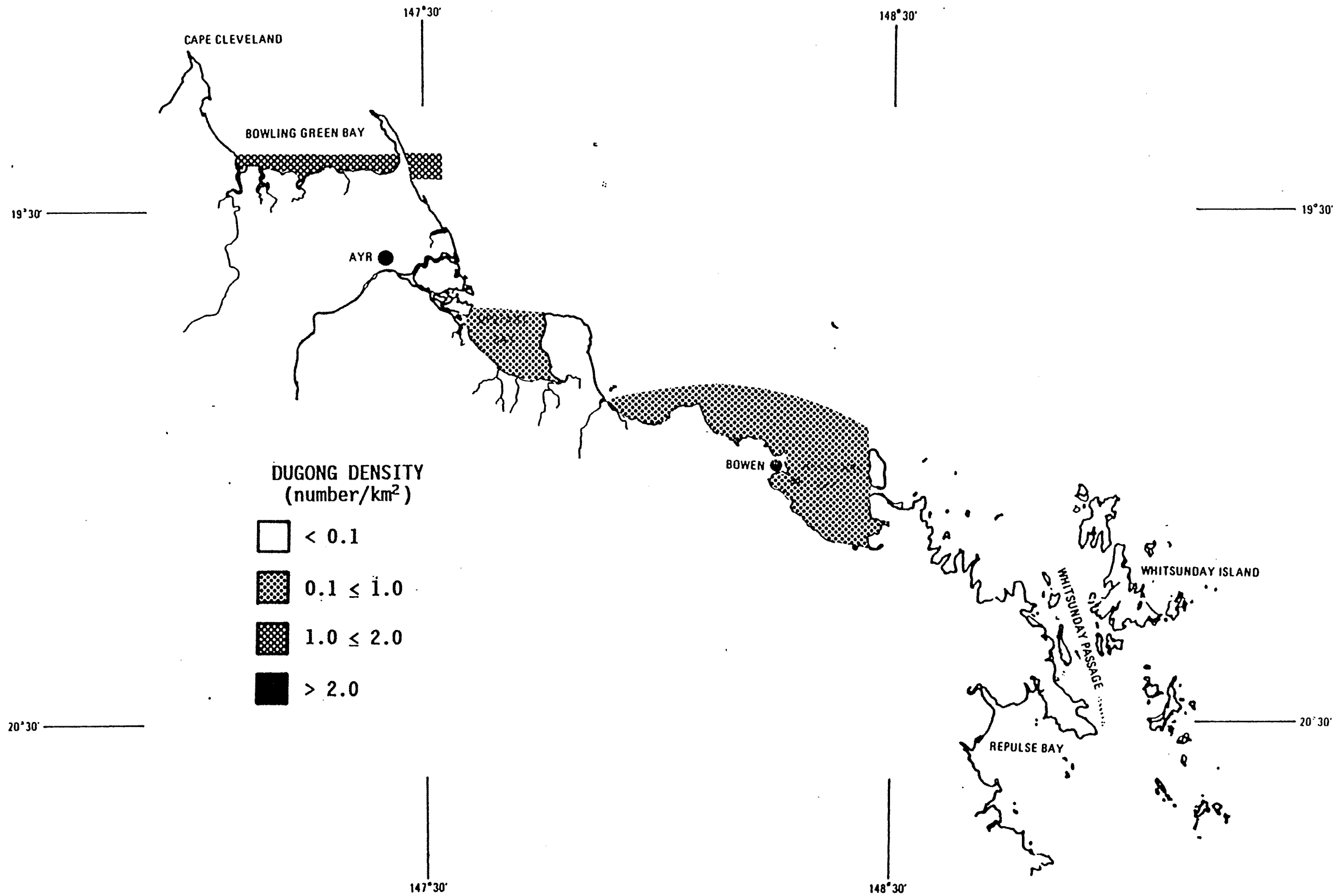
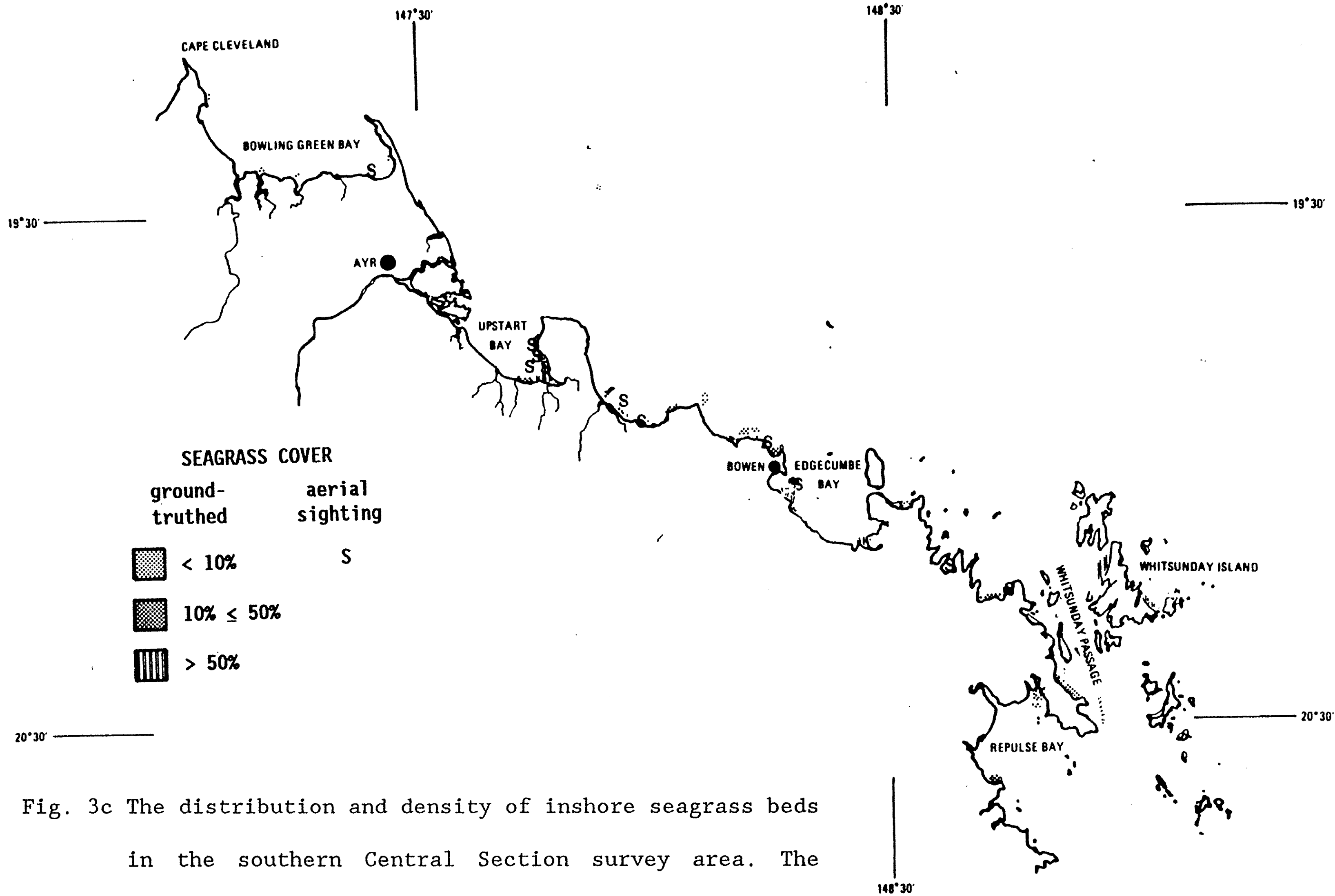


Fig. 3b The distribution of dugong density in the southern Central Section survey area in September - October 1987.



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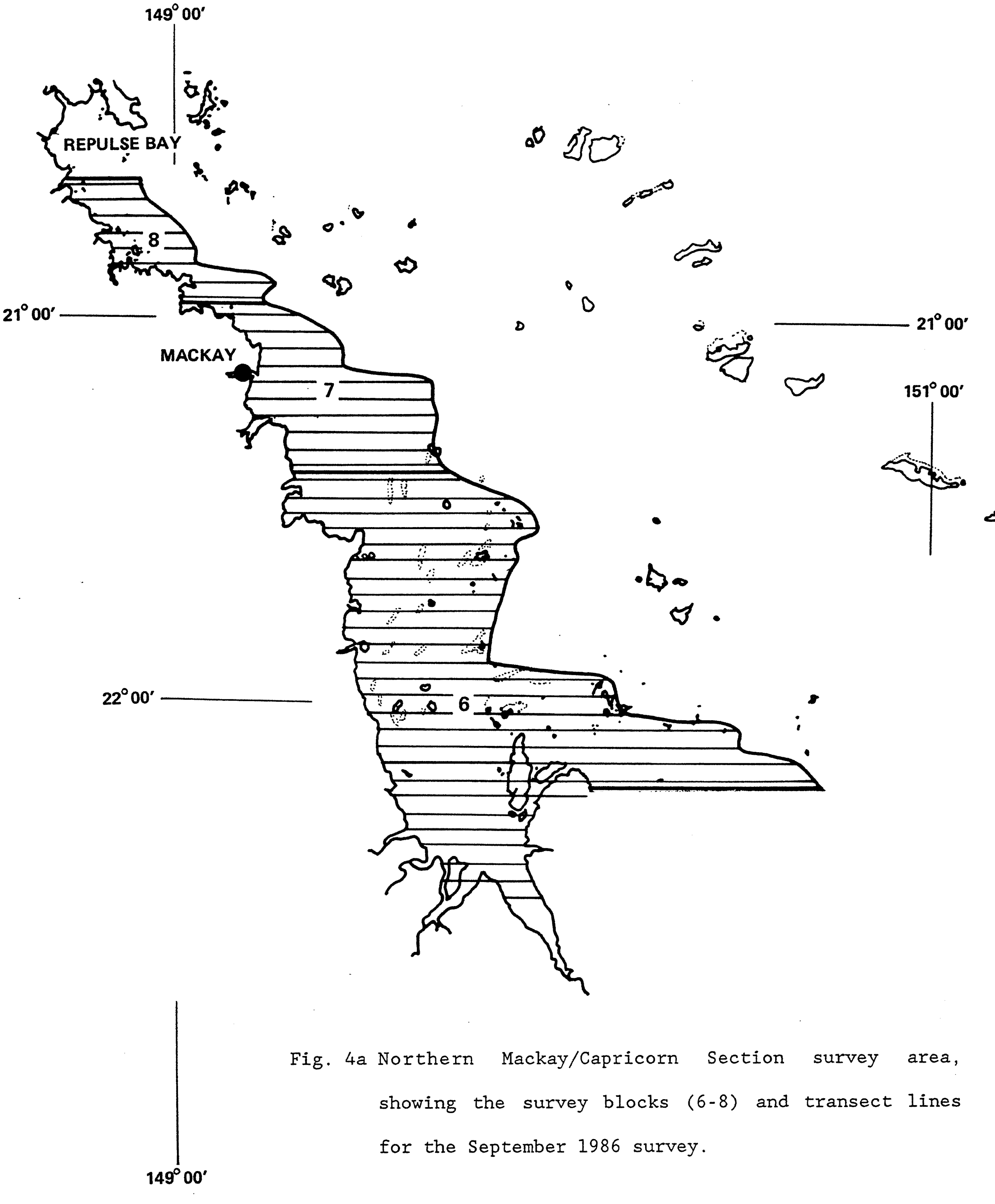

Fig. 4a Northern Mackay/Capricorn Section survey area, showing the survey blocks (6-8) and transect lines for the September 1986 survey.

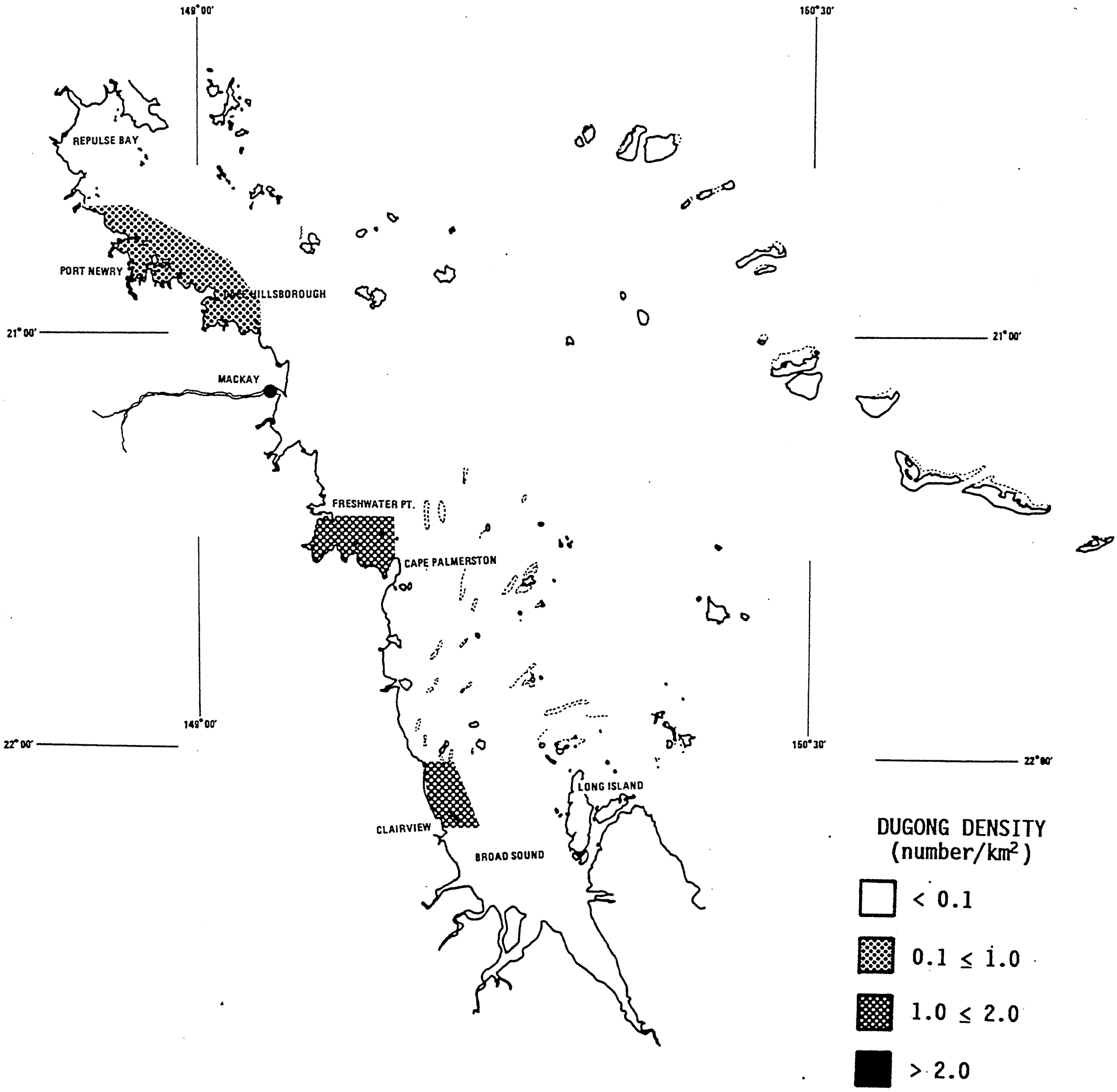

Fig. 4b The distribution of dugong density in the northern Mackay/Capricorn Section survey area in September 1986.

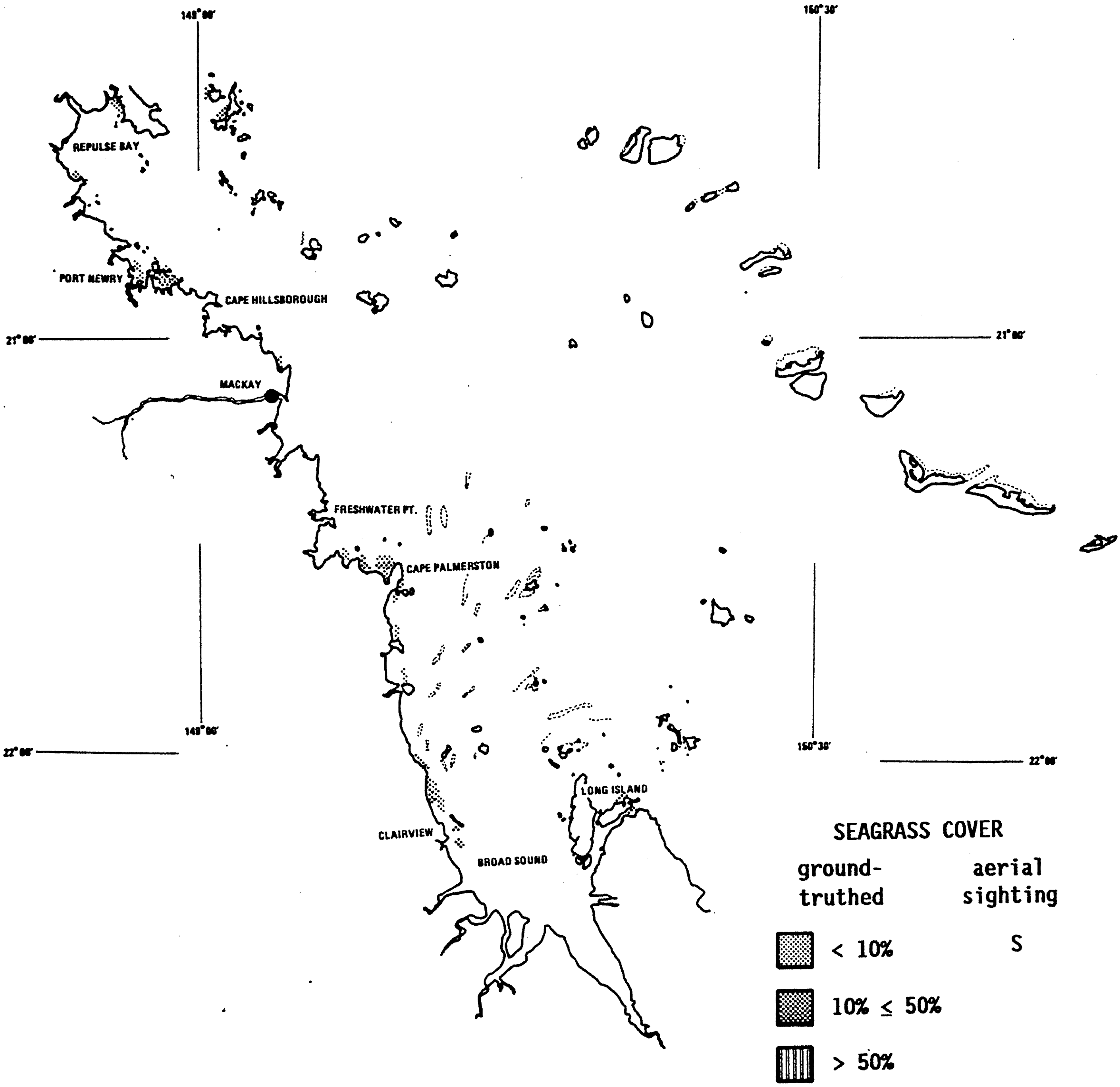

Fig. 4c The distribution and density of inshore seagrass beds in the northern Mackay/Capricorn Section survey area. The ground-truthed seagrass data are from Coles *et al.*, (1987).

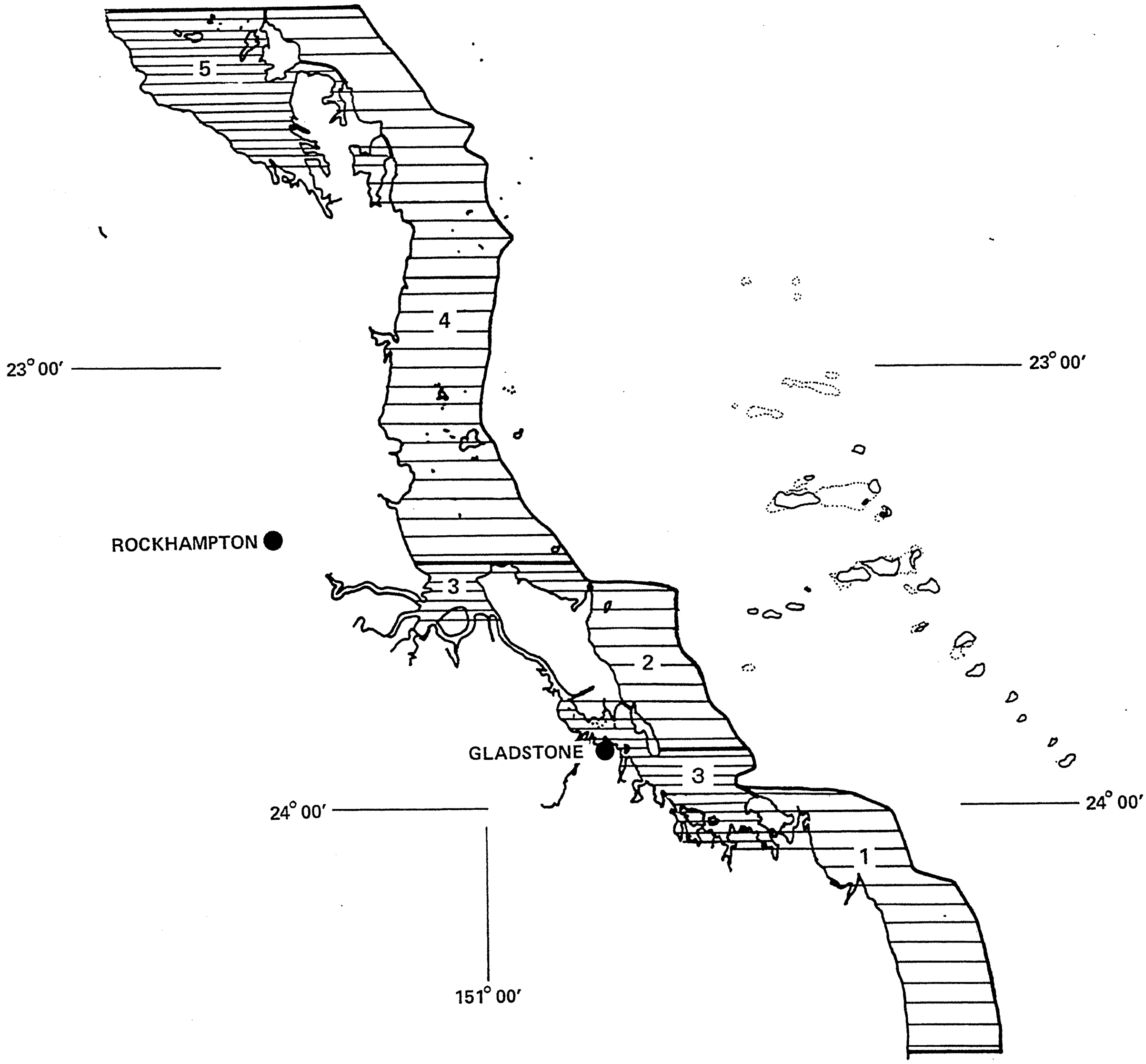

Fig. 5a Southern Mackay/Capricorn Section survey area, showing the survey blocks (1-5) and transect lines for the September 1986 survey.

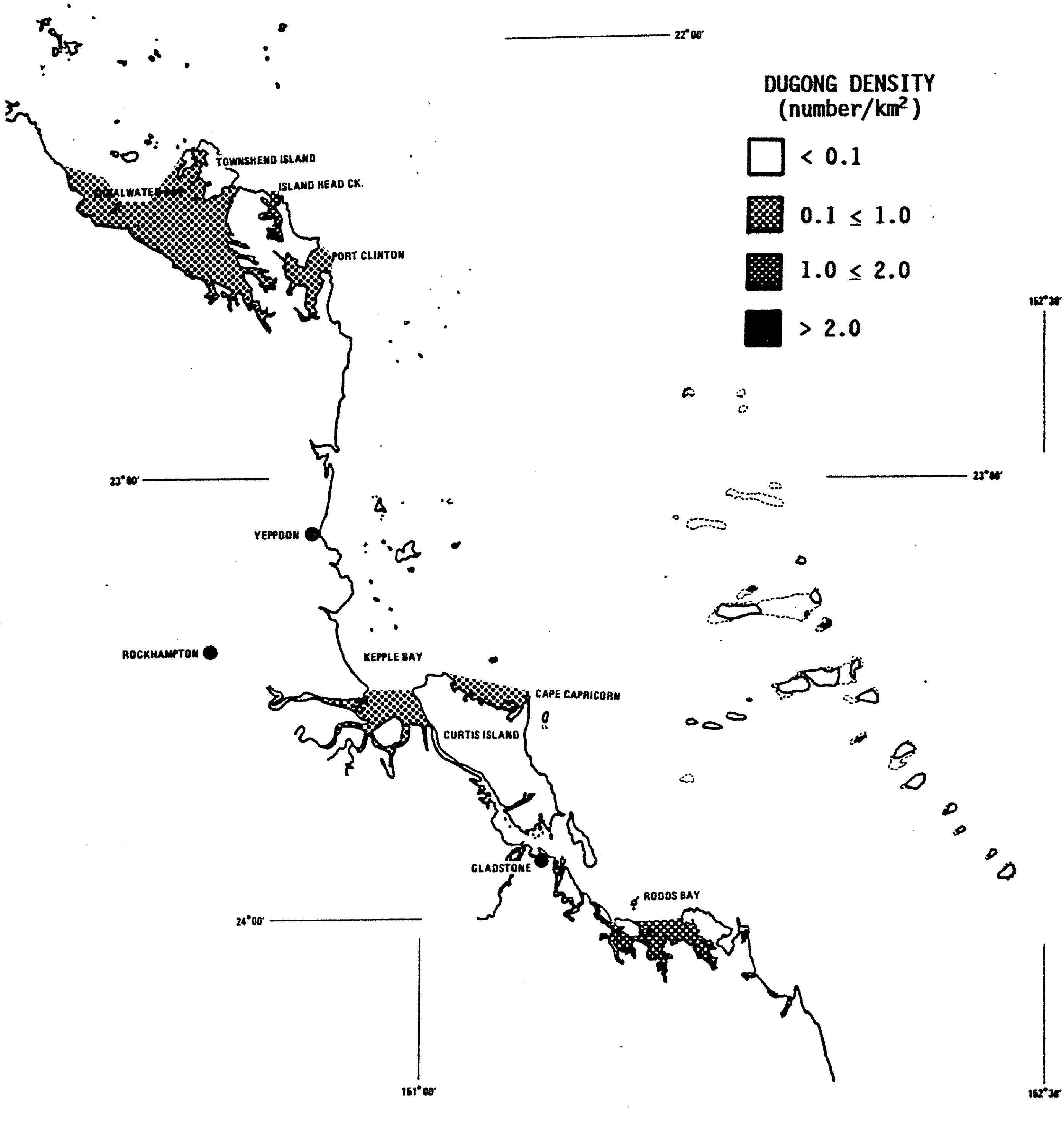

Fig. 5b The distribution of dugong density in the southern Mackay/Capricorn Section survey area in September 1986.

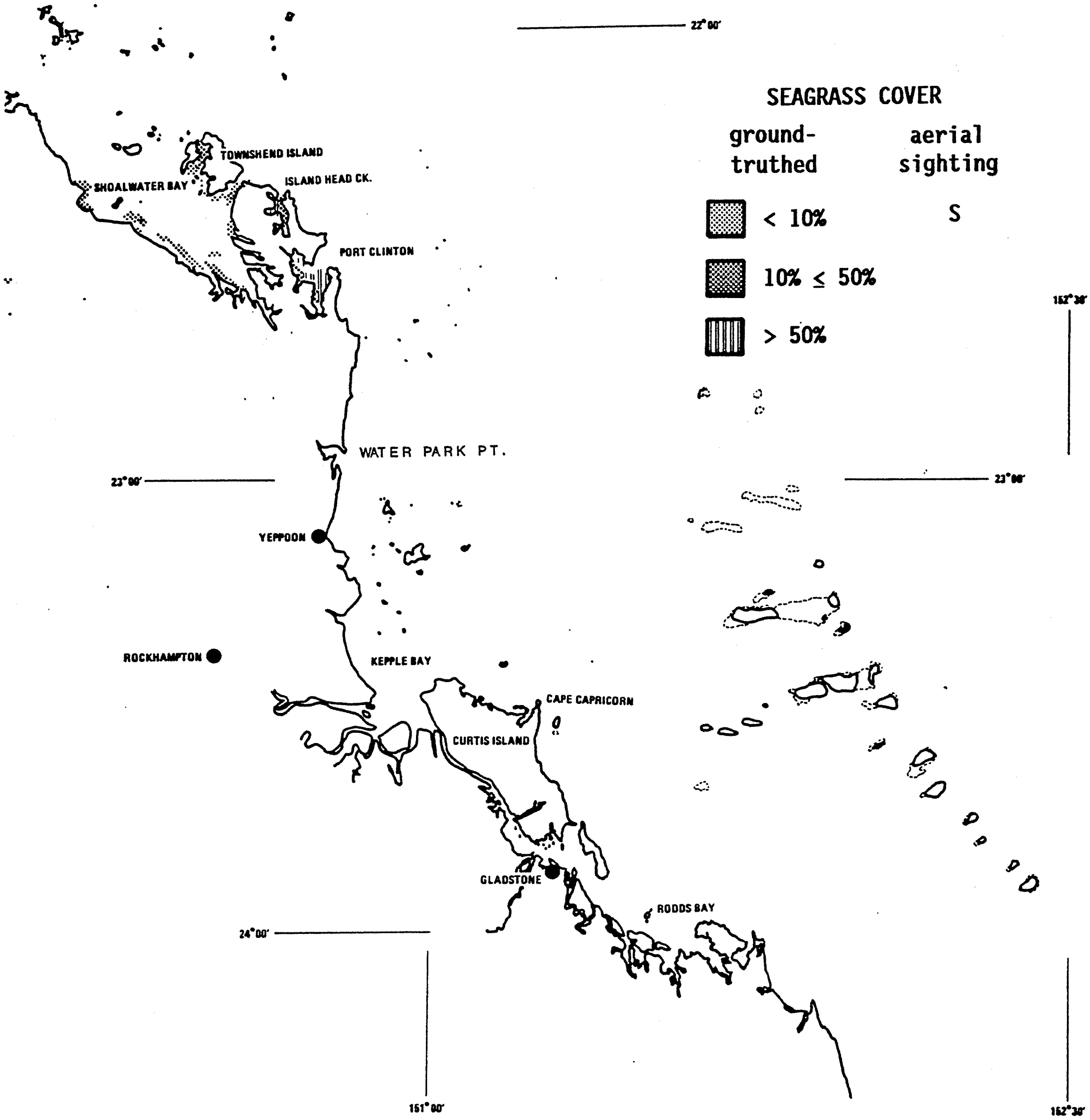

Fig. 5c The distribution and density of inshore seagrass beds in the southern Mackay/Capricorn Section survey area north of Water Park Point. The ground-truthed seagrass data are from Coles *et al.*, (1987).

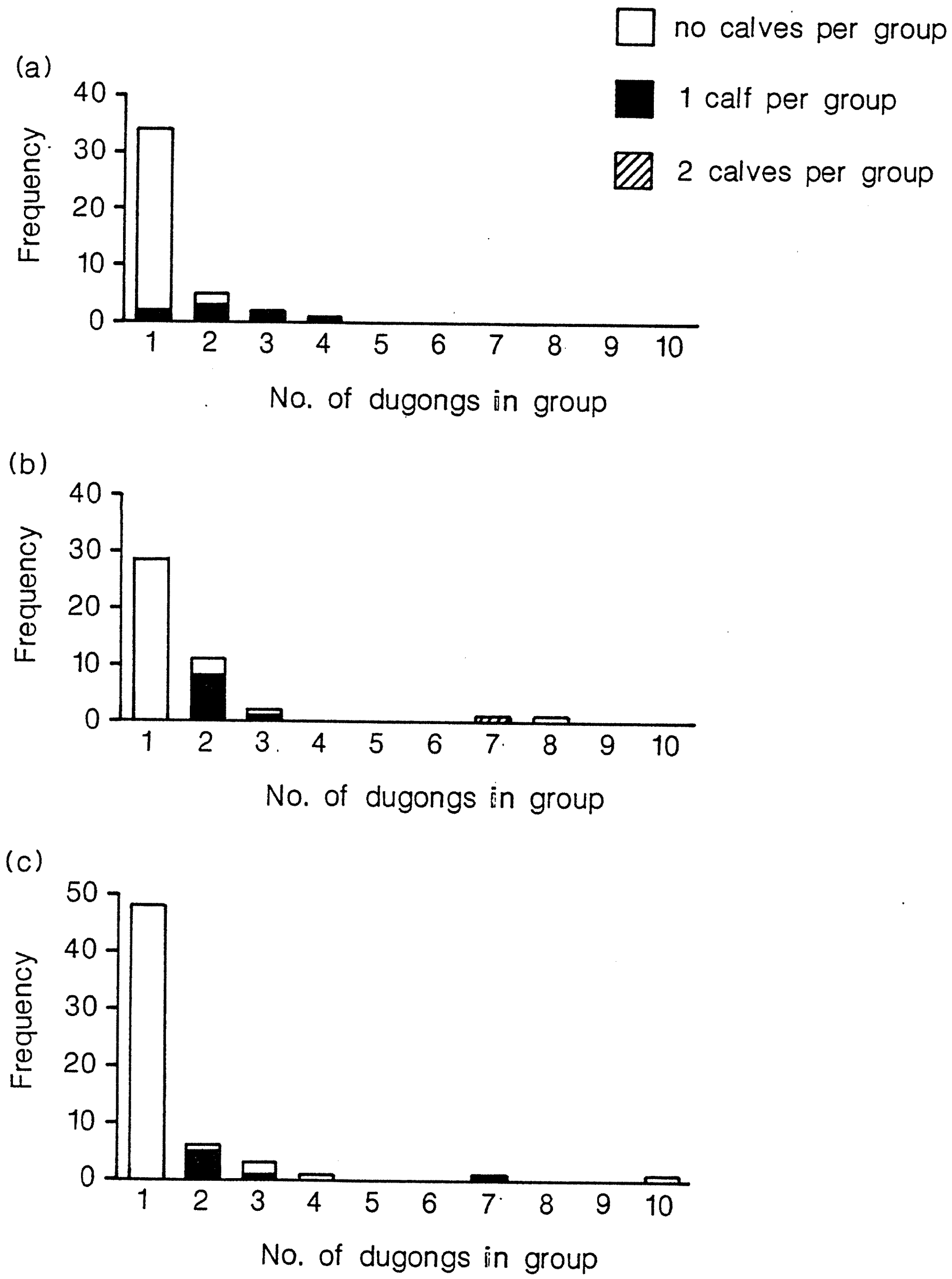

Fig. 6 Frequency histograms showing details of dugong group size and composition for (a) the Northern Central Section in September 1986, (b) the Central Section in September - October 1987 and (c) the Mackay/Capricorn Section in September 1986.

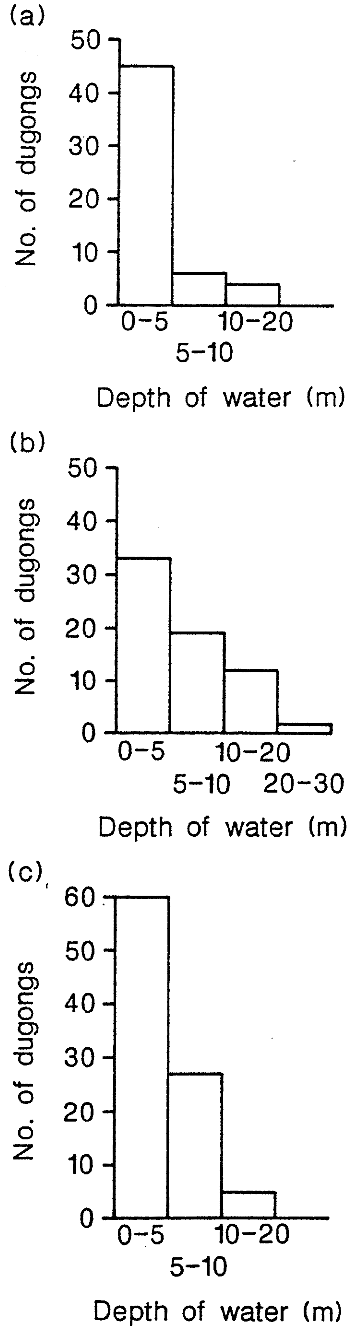

Fig. 7 Frequency histograms showing the depths of water in which dugongs were sighted in (a) the Northern Central Section in September 1986, (b) the Central Section in September - October 1987 and (c) the Mackay/Capricorn Section in September 1986. These depths were obtained from marine charts and have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

Report

to

The Australian Fisheries Service

The Great Barrier Reef Marine Park Authority

and

The Fisheries Management Branch of the Queensland Department of Primary Industries

June 1988

THE DISTRIBUTION AND ABUNDANCE OF THE DUGONG IN THE TORRES STRAIT REGION.

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Townsville, Qld 4811

EXECUTIVE SUMMARY

In November 1987, dugongs were counted from the air at an overall sampling intensity of 7.4% over a total area of 30,533 km^2 in the Torres Strait region and adjacent waters of the Great Barrier Reef Marine Park. About half the survey was repeated in March 1988; persistently bad weather prevented its completion.

We corrected for perception bias (the proportion of animals visible in the transect which are missed by observers), and standardized for availability bias (the proportion of animals that are invisible due to water turbidity) with survey-specific correction factors. The resultant minimum population estimate in November 1987 was 12,522 $\pm$ S.E. 1,644 dugongs at an overall density of 0.41 $\pm$ S.E. 0.05 km^{-2}, a precision of 13%.

Although there were no significant differences between population and density estimates obtained from the repeat surveys of the same areas, relatively more dugongs were sighted close to the major western islands in the March survey.

Our data suggest that if the dugong population were increasing maximally, this region could support an unselective man-induced mortality of 700 dugongs per year at most. If the current rate of increase is similar to that estimated from the Daru dugong catch between 1978 and 1982, the maximum unselective harvest will be of the order of 300 dugongs. If significantly more females than males are being caught, these figures are overestimates.

In the absence of adequate catch statistics and current life history information, it is impossible to confirm whether the current dugong harvest in Torres Strait is likely to be below the sustainable yield. A high priority should therefore be placed on public education in an attempt to pre-empt any increase in catch.

The resultant maps of distribution and density suggest that, if the Torres Strait dugong sanctuary area is to be effective, its boundaries should be renegotiated or an additional protected area established around Buru (Turnagain) Island.

The low number of dugongs seen in the waters of the Great Barrier Reef Marine park adjacent to Torres Strait do not warrant special protection when the zoning plan for this area is revised. However, the Islanders need more information on the restrictions on their hunting within the Great Barrier Reef Marine Park.

RECOMMENDATIONS

1. That the collection of further dugong catch statistics from Torres Strait communities in both Australia and Papua New Guinea be given high priority. At the very least, the harvest of dugongs from Boigu Island should continue to be monitored as an index of hunting activity in the Western Islands. The Islanders should be encouraged to continue sending dugong tusks to James Cook University so that the age-sex composition of the catch can be verified.

2. That the dugong public education program be continued in the Australian communities and extended in collaboration with Papua New Guinea to the Papuan communities. The program should emphasize the vulnerability of the dugong to over-harvesting, the illegality of selling dugong meat and the current restrictions on dugong hunting in the sanctuary area and in the Great Barrier Reef Marine Park.

3. That negotiations be commenced with the Islanders to either extend the boundaries of the present dugong sanctuary to include some high density areas or to establish an additional protected area in the vicinity of Buru (Turnagain) Island. The concept of the Buru Island Sanctuary should be included in the public education program.

4. That the Papua new Guinea Government be encouraged to establish a similar sanctuary in a high density dugong area in Papuan waters.

5. That in order to monitor numbers, this survey be repeated in November 1992 and at five yearly intervals thereafter. (November is the month when favorable weather conditions are most likely and in view of the high cost of transporting a suitable aircraft and survey crew to Torres Strait, it is likely to be a waste of money to attempt a survey at another time of the year).

6. That a copy of this report be made available to each Community Council in Torres Strait. The report should be distributed in association with a personal presentation as part of the public education program and should be accompanied by a summary written for non-scientists.

Introduction

The dugong, Dugong dugon, listed as vulnerable to extinction by the International Union for the Conservation of Nature (IUCN, 1986), has traditionally been important in the culture and diet of the peoples of Torres Strait (see Johannes and MacFarlane, manuscript). In recent years, both some local people (see Johannes and MacFarlane, manuscript) and scientists (e.g. Hudson, 1986; Marsh, 1986) have been concerned by an apparent decline of dugong numbers in the area.

This concern was fueled by the decrease in the number of dugongs passing through the local market at Daru (9° 05'S, 143° 22'E) on the Papuan side of Torres Strait from 208 in 1979 to 81 in 1981, despite an increase in the availability of motorized craft, an extension of the hunting grounds, and an apparently sustained hunting effort (Marsh, 1986). The statistics of Johannes and MacFarlane (in press) suggest a parallel slump in the dugong catch of the Western Islanders; fewer than one fifth as many dugongs were caught in the Western Islands during their study in 1983-84 as were caught during the same months in 1976-78 (Nietschmann, 1982). In addition, a dugong hunter based on Thursday Island who kept records indicating that he had caught 41 dugongs between October 1975 and June 1976, claimed in November 1983 that he had not been able to catch a dugong for four to five years despite that fact that his catch effort remained the same and he continued to catch turtles (Marsh et al., 1984a).

A dedicated aerial survey of the major dugong hunting grounds in Torres Strait in November 1983 produced a minimum population estimate of 1,455 ± S.E. 276 dugongs (Marsh, 1986). It was appreciated that this was 'an underestimate, probably a gross underestimate of the Torres Strait dugong population' because the proportion of dugongs that were sighted under aerial survey conditions had not been calibrated. However, the difference between this estimate and the estimate of 22,000 required to support an annual unselective harvest of 500 dugongs, the lower limit of the estimated annual catch for at least some years between 1975 and 1982 (see Tables 1 and 2) was huge. In view of the decline in catch rates, this discrepancy led to serious doubts about there being enough dugongs in Torres Strait to sustain the level of hunting that had apparently taken place, especially as the estimate of a required population of 22,000 was based on population parameters obtained from the animals harvested by the hunters from Daru (Marsh, 1986).

Some Islanders claimed, however, that more dugongs would have been sighted if the 1983 survey had been carried out during (rather than immediately before) the wet season, and that a substantial proportion of animals occurred west of the 1983 survey area.

In view of recent improvements in aerial survey methodology, it was decided to conduct further surveys in 1987-88 to determine the distribution and abundance of dugongs in Torres Strait. These surveys were designed to take account of the Islanders' criticisms of the design of the previous survey.

Methods

The western and central waters of Torres Strait north of 11°S and the adjacent eastern coastal waters of Cape York south to Hunter Point (11°30′S., 142°50′E.) were surveyed between November 10 and 21 1987 (Fig. 1). About half this region was resurveyed between March 4 and 11 1988 (Fig. 2), before persistently rough weather forced this second survey to be terminated prematurely.

As far as possible, both 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 (sea state Beaufort 3 or less). The weather conditions encountered are summarized in Appendix Table 1; details of weather conditions for each transect for each survey are summarized in Appendix Table 2 (see Volume 4).

Survey Design

For estimation of regional densities of dugongs, the area was divided into 7 blocks (Fig. 1) on the basis of sampling intensity and placement of transects . Block areas (Table 3) were estimated from 1:250,000 maps using a planimeter or a digitizing tablet. The areas of major islands were excluded from the block areas. The areas of small (<3 km^2) islands were included in the block areas.

The Partenavia 68B aircraft was flown at a groundspeed of 185 $km\ h^{-1}$ (100 kn.) and at an altitude of 137 m (450 feet) ASL. The pressure altimeter was calibrated at each takeoff and landing. Transect width (200 m on each side of the aircraft at survey altitude) was demarcated by fibre glass rods attached to artificial wing struts. The actual width of each transect was estimated by calculating the mean survey height for that transect (taking into account the altimeter correction at each landing using appropriate interpolations), assuming a combined transect width of 400 m at an altitude of 137 m.

The transect lines flown in November 1987 are shown in Fig. 1; those flown in March 1988 are shown in Fig. 2. In order to increase precision, all lines were aligned approximately across the ecological axes of the area i.e. east-west south of Buru (Turnagain) Island (9° 34'S, 142° 18'E,) and north-south along the Papua New Guinea coast. Lines were generally spaced at intervals of 5' latitude (9.3 km or 5 nm) in most of Block 3 and in Block 4; and at intervals of 2.5' latitude in the remaining blocks. Additional lines were flown in the Newcastle Bay area (Block 5). Some lines in the northern half of Block 3 were aligned so that their end points coincided with islands or reefs in order to aid navigation. The bias caused by this non-random placement is considered inconsequential in view of the very small size of these islands and reefs.

Counting Procedure

The crew comprised a pilot navigator, a front right survey leader/recorder, and two tandem observing teams, who occupied the middle and rear seats on opposite sides of the aircraft. Only two operational observers were available during the first day of each survey while the other observers were being trained. The observers reported their observations of dugongs, turtles (usually not identified to species), cetaceans, sharks, rays, sea snakes and surface plankton blooms in standard format into an intercom connected to a two track tape recorder. We recorded whether each sighting occurred in the top (furthest from aircraft), middle, or bottom third of the transect in order to increase the probability of distinguishing between different observations reported simultaneously by both members of a tandem team. Operational mid seat observers were visually screened from the rear seat observers and acoustically isolated from the remainder of the crew apart from each other.The rear seat observers and the mid seat observers reported their (independent) observations into separate tracks of the tape recorder. Trainee mid seat observers could hear the reports of the rear seat observers.

Data including aircraft height and position, locations of presumed seagrass beds, weather conditions, the starting and finishing times for each transect, and the sightings of the rear seat observers were recorded by the survey leader using a micro computer programmed as a data logger and timer.

More details on methodology are provided by Marsh and Sinclair (manuscripts a & b).

Post Survey Data Editing

The tape record of each transect was used to check and edit the computer records, so that each sighting could be classified as being made by one (specified) observer or both members of a tandem team. Records of the time of each observation and of the starting and finishing times for each transect enabled the position of each observation to be plotted on a map as a basis for the preparation of the smoothed density distribution maps.

Correction Factors

Correction factors were calculated for each survey for perception bias (groups of dugongs visible on the transect line 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 as outlined in Marsh and Sinclair (manuscript a). The corrections for perception bias were calculated on the basis of the proportion of sightings seen by one (specified) member or both members of each tandem team using the Petersen mark-recapture model; those for availability bias were based on the proportion of dugongs sighted during each survey that were on the surface in comparison to the proportion on the surface in a clear water area where all dugongs were potentially available.

Analysis

Because transects were variable in area, the Ratio Method (Jolly 1969; Caughley and Grigg 1981) was used to estimate density, population size and their associated standard errors for each block for each survey. Any statistical bias resulting from this method is considered inconsequential in view of the high sampling rate (Table 3) (see Caughley and Grigg 1981). Input data were the estimated number of dugongs for each tandem team per transect calculated using the corrections for perception and availability biases. The resultant standard errors were adjusted to incorporate the errors associated with the appropriate estimates of the perception and availability correction factors and the mean group size (Table 4) following the method of Jolly and Watson (1979) (as outlined in Marsh and Sinclair, manuscript a).

The significance of the differences in density between surveys for the areas which were surveyed twice were 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 both analyses were corrected densities per square kilometre based on mean group sizes and the estimates of the correction factors for perception and availability bias, each line 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

Dugong group size and composition

The distribution of dugong group sizes observed on the November 1987 survey did not differ significantly from that observed in March 1988 (Fig. 3) (G with William's Correction = 4.04, P> 0.25, 3 d.f.). The largest group (subjectively distinct clumping) seen in November was five, in March six. These results are comparable with the November 1983 survey where the largest group seen was six also (Marsh, 1986). In all three surveys, more than 75% of the dugongs sighted were alone or in a group of two animals (Fig. 3; Marsh 1986).

The proportion of calves seen was also similar in the three surveys: 14.3% in November 1983; 13.6% in November, 1987; 14.3% in March 1988. This is not surprising. Calving is diffusely seasonal in northern Australia and the calves stay with their mothers for at least 18 months (Marsh et al., 1984b) . On all three surveys (Fig. 3; Marsh, 1986) more than 70% of the cow-calf pairs identified were unaccompanied by any other dugongs.

Population and density estimates

The values of the mean group sizes and correction factors used in obtaining these estimates are summarized in Table 4. The raw data have been listed in the Appendix. Table 5 gives estimates of the density and numbers of dugongs per block for each survey together with the standard errors of these estimates.

The population estimates sum to 12,522 ± S.E. 1,644 dugongs for the whole region in November 1987 at an overall density of 0.41 ± S.E. 0.05 dugongs per km^2, a precision of 13%. This indicates that Torres Strait is a very important area for dugongs with a population comparable to that of the entire Great Barrier Reef Marine Park (Marsh and Saalfeld, unpublished data).

This estimate is, of course, substantially higher than the minimum estimates obtained for part of the same area by Marsh (1986). The difference is due to the improved survey methodology; Marsh's (1986) estimate was uncorrected for the biases inherent in the survey technique.

We consider that the present estimate is more likely to be an underestimate than an overestimate. The correction for availability bias for each survey (Table 4), is based on the ratio of the proportion of dugongs sighted that are at the surface during the survey to the proportion sighted in a clear water area when all dugongs present were potentially available, and assumes that the proportion of dugongs at the surface is the same for all habitats and at all times (Marsh and Sinclair, manuscript a). This assumption may not be valid in Torres Strait, where in contrast to the east coast of Australia where our other dugong surveys have been carried out, significant numbers of animals are seen in relatively deep water (see Fig. 7 and text below). Anderson's (manuscript) observations suggest a trend for dugongs to remain submerged longer in deeper water. A more accurate correction for availability bias in Torres Strait will

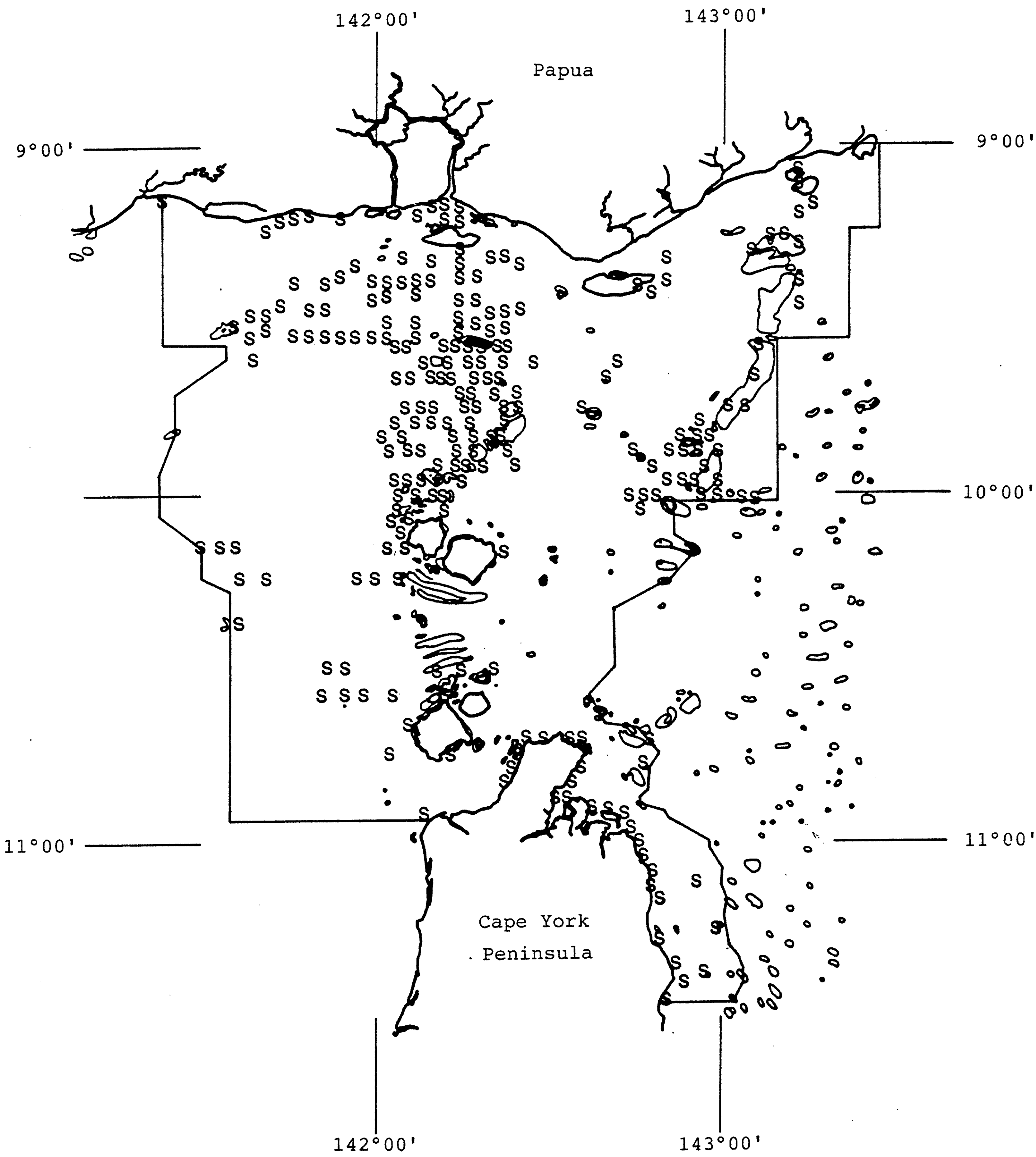

Figure 6: The distribution of presumed seagrass sightings from the air in the survey area. Sightings from the November 1987 and March 1988 surveys have been combined on a single map, with the boundaries of the survey area indicated.

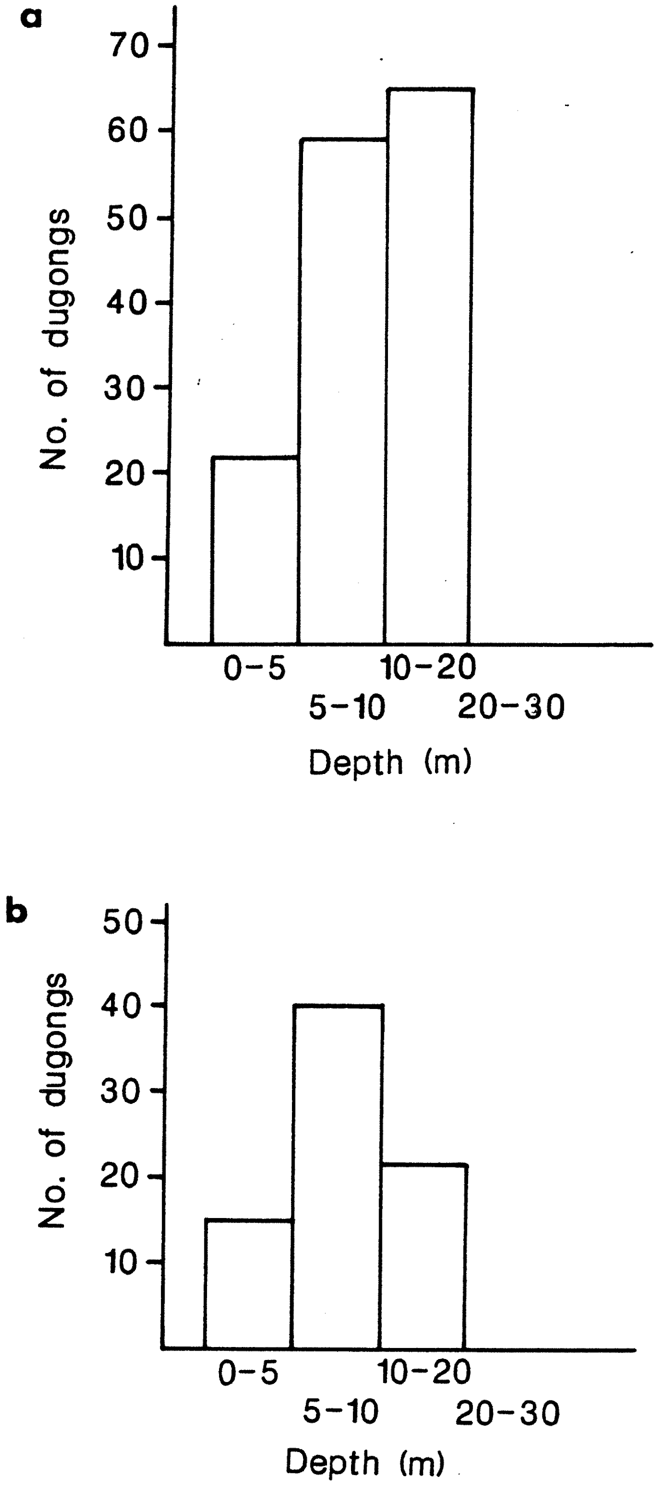

Figure 7: Frequency histograms showing the depths of water in which dugongs were sighted in (a) November 1987 and (b) March 1988. Estimates for depth of water are biased as they were made only for the less than 50% of sightings that occured in charted waters. Most of the uncharted waters are likely to be less than 10m deep.

require further investigation of dugong diving behaviour in this area.

Distribution of Dugongs

Figures 4 and 5 are smoothed density distribution maps based on the results of the November 1987 and March 1988 surveys respectively. Maps of actual sightings are provided in the Appendix. In November 1987, dugong density was highest on the seagrass beds (see Fig.6) around Badu and extending north across Orman Reef around Buru Island and east to Gabba Island (9°46'S, 142°37'E). The next highest density was observed over the Warrior Reef complex. Densities were very low along the coasts of Papua New Guinea and Cape York including the northernmost waters of the Great Barrier Reef Marine Park.

Differences between surveys

There was no significant difference in the number of dugongs observed in the areas covered by both surveys (Table 6). Addition of Beaufort sea state and/or cloud cover for each transect as covariates did not change this result and made little difference to the results.

Because the March survey was not completed, it is not possible to determine if there had been a major change in the distribution of dugongs in Torres Strait between the two surveys. However, a significantly higher proportion of the dugongs sighted in the areas surveyed both in November and March, was close (<10km) to the major western islands in March (47/160 or 29%) than in November (26/251 or 10%) (G with William's correction =23.46, d.f.= 1, $p<0.001$). This is consistent with the Islander's perceptions that dugongs are more abundant in the area from Cape

York to Mabuiag during the North-West monsoon (Johannes and MacFarlane, manuscript).

High densities of dugongs were observed in the Buru Island/ Orman Reef area in both November 1987 and March 1988. This was also the area supporting the highest densities of dugongs in November 1983 (Marsh, 1986). Large numbers of dugongs were also sighted in this area on a Coastwatch flight on June 17 1988 (M. McCarthy, pers. comm). It seems likely that the extensive seagrass beds in this area (Fig. 6) are consistently important dugong habitat, despite the essentially seasonal nature of the dugong catch from this area by Boigu Islanders (Johannes and MacFarlane, manuscript).

As much of the Orman Reef area is uncharted, we were able to estimate the depth of water in which only about 45% of dugongs were sighted in the November 1987 survey (Fig. 7). The figures from March 1988 are, of course, even less representative. The surveys indicate that significant numbers of animals are sighted in relatively deep water (>10m), in contrast to the northern waters of the Great Barrier Reef Marine park where 56% of dugongs are sighted in water less than 5m deep (Marsh and Saalfeld, manuscript). Significant numbers of dugongs are seen more than 10km from land in Torres Strait, in contrast to their essentially inshore distribution in most other areas. Dugong distribution in Torres Strait undoubtedly reflects the extensive beds of both intertidal and subtidal seagrass beds in this area (Fig. 6).

Sustainable annual catch

On the basis of experience in Torres Strait in the late 1970's, Nietschmann (1984), 'guesstimated' an average annual dugong catch in Torres Strait of about 750 animals. We do not know whether this estimate was restricted to the Australian Islands or whether it included dugongs caught by Islanders who operate crayboats. From the limited statistics available (see Tables 1 and 2), Marsh (1986) estimated that the total annual dugong catch for the Torres Strait area for at least some years between 1975 and 1982 was at least 500 to 1000 animals. She then estimated the minimum populations required to support an annual unselective harvest of 500 and 1000 dugongs assuming a population sex ratio of 1:1 on the basis of a simple population model which was constructed to determine the annual rate of increase of stable dugong populations with various combinations of life-history parameters in the range observed for several populations.

Marsh (1986) calculated that, even with the most optimistic combination of life history parameters, a dugong population was unlikely to increase at more than about 5% per year. If the parameters calculated from the dugongs passing through the Daru market in 1978-1982 are operable, the maximum rate of increase is likely to be only about 2%. It is likely, however, that the rate of increase of the Torres Strait dugong population is currently higher than this latter figure which was obtained soon after anecdotal evidence suggests there was a period of extensive seagrass dieback in Torres Strait (Johannes and MacFarlane, manuscript). The mean calving interval (the parameter to which the dugong population model is most sensitive) decreased significantly from nine years in 1978-79 to three years in 1981-82, coincident with the reported recovery of the Torres Strait seagrass beds (Marsh and Hudson, unpublished data).

Marsh's (1986) population model indicates that 12,500 dugongs are likely to be able to sustain an unselective harvest of only 700 animals per year when dugongs are breeding optimally. If the population parameters calculated on the basis of the dugong specimens obtained from the Daru harvest in 1978-82 are currently valid, the maximum sustainable harvest is of the order of 300 per year. Johannes and MacFarlane (in press) reported that adult females outnumbered adult males in the 'unselective' catch of the Boigu Islanders recorded by Mrs Pabai from Boigu by a ratio of 5:2. Dugong tusks are sexually dimorphic and the small sample which has been forwarded to us by Mrs Pabai indicate that her records are correct. Nonetheless, we find this sex ratio surprising, as the (much larger) catches from Mabuiag, Badu and Kubin (Nietschmann, 1984), and from Daru (Hudson, 1986) indicated a ratio close to parity. However, if the Torres Strait dugong catch as a whole is currently biased in favour of females, the sustainable harvest figures of between 300 and 700 dugongs are substantial overestimates.

It is impossible to evaluate whether the dugong is currently being over-exploited in Torres Strait without reliable catch figures from all the major hunting communities in the region, plus an estimate of the number of dugongs killed for illegal sale All the evidence available suggests that the number caught is now much lower than for the period between 1975 and 1983 as summarized in Tables 1 and 2. Johannes and MacFarlane (manuscript) estimate that the total legal harvest of dugongs by members of the Australian communities in Torres Strait in the mid 1980's was of the order of 120-140 animals per year. (In 1985-87, the annual average catch from Boigu, a major hunting community, averaged about 45 animals per year (Johannes and MacFarlane, manuscript)). Johannes and MacFarlane also consider that the illegal harvest of dugongs for cash in the course of crayfishing activities has declined substantially from the 1983 level (Table 2). We have no information about the current dugong catch by the people of the Western Province of Papua New Guinea except that it is believed to have declined substantially since the sale of dugong meat was banned in 1984 (Hudson, 1986).

We believe that there is no cause for complacency about the dugong situation in Torres Strait, despite the apparent decline in catches and the substantially higher population estimate resulting from the November 1987 survey. The situation has the potential to deteriorate rapidly if catches increase. It is clearly important to continue with the public education campaign in an attempt to pre-empt such an increase, and to encourage the Government of Papua New Guinea to do likewise. It would also be desirable to continue monitoring the legal catch by communities on both sides of the border. Given the logistical difficulties of doing this in the Australian communities (Johannes and MacFarlane, manuscript), we suggest that at the very least, the monitoring of the catch at Boigu should be continued as an index of hunting activity in the Western Islands.

Effectiveness of the present sanctuary area

The surveys indicate that dugong density in much of the present sanctuary area is very low (Fig. 4 and 5). We were unable to survey the remainder of the sanctuary because of our inability to hire a suitable survey aircraft with an Omega navigation system, however, the bathymetry of the unsurveyed area suggests that it is unlikely to be good dugong habitat. Our observations suggest that banning dugong hunting from this area (which was not heavily hunted) is likely to have a limited effect on dugong conservation in Torres Strait, except as a means of emphasising the danger of over-exploitation and the need for rational management.

If dugong management in Torres Strait is to be effective, it will be important to protect animals in at least some of the high density areas. To change the boundaries of the present sanctuary so soon after it has been established would be psychologically unsound. We suggest that it would be more appropriate to negotiate with the Islanders about establishing a second sanctuary area in the region of Buru Island, an area of seemingly consistently high dugong numbers. Such a sanctuary would probably meet most opposition from hunters from Boigu, Badu and Mabuiag. However, the records of Johannes and MacFarlane (manuscript) indicate that only about 10% of the catch from Boigu is obtained from the Buru area and that this catch is seasonally limited. The proportion of the catch of hunters from Badu and Mabuiag which is obtained from the vicinity of Buru is unknown; both communities are known to hunt at Orman Reef between their home islands and Buru (Johannes and MacFarlane, manuscript). Even if it is impossible to obtain agreement about such a sanctuary in the near future, we suggest that the idea should be canvassed as part of the public education programme. It would also be timely to suggest to the Papua New Guinea Government that a dugong sanctuary should be established in their waters, perhaps within the Maza Wildlife Management Area (Hudson, 1986).

Timing of future surveys

As discussed above, the dugong's rate of maximum annual population increase is limited by its biology to about 5% a year or less. A rate of decline would be determined by numerous factors including the harvest regime. Given the evidence of declining catches in Torres Strait, the annual rate of change of the population is expected to be relatively low.

When designing a monitoring program for a vulnerable species such as the dugong, the consequences of failing to pick up a declining trend are more serious than the consequences of deciding that a declining trend is occurring when it is not. Thus it is particularly important to consider Type 2 statistical errors. If this expected low rate of dugong population change is to be monitored within an acceptable range of statistical error, the precision of the population estimates will have to be high. Under a constant intensity of sampling, the precision of a population estimate improves as the size of the survey area is increased as evidenced by Table 5. Thus future surveys for dugongs in Torres Strait should cover the whole area of important dugong habitat (Fig. 3)..

November is the time of year when weather conditions are most likely to be optimal for a period long enough to survey such a large area adequately, making it unrealistic to plan more than one survey in any one year.

Gerrodette (1987) outlines procedures for estimating the minimum number of samples required to detect a trend in numbers using linear regression. His technique has been used to investigate how long it would take to detect with acceptable levels of confidence that a dugong population which was decreasing at say 5% or 10% per year was in fact declining i.e. that the slope of the regression line was significantly less than 0. The following assumptions were made:

(1) that the population estimate would have a precision of 13% (as for the November 1987 survey);

(2) that the coefficient of variation is inversely related to the square root of abundance as predicted for strip transects by Seber (1982).

The probability of both a Type I error α and a Type II β error was set at 0.05.

It is estimated that if surveys were held every year, it would take 9 years i.e. ten surveys to be able to detect a 5% decline with 95% confidence; six years to detect a 10% decline. After nine years a dugong population declining at 5% per year would have been reduced to 63% of its size at the time of the first survey, whereas a population declining at 10% per year would have been reduced to 53% of its initial level after six years. A preliminary indication of such trends could be obtained more quickly by allowing α and/or β to assume larger values. Of course, a decline more rapid than these would be detected more quickly with the same frequency of surveys.

As Gerrodette (1987) points out, annual surveys are probably not the optimum frequency of sampling for a population that is changing relatively slowly. As the interval between surveys increases, the effective rate of change per interval increases, and the required number of surveys therefore decreases (see Gerrodette, Table 2). For example, we have calculated that two dugong surveys 10 years apart could establish with 95% confidence that a population decreasing at 5% per year is declining. Such a low survey frequency would obviously provide substantially less information than annual surveys.

Any sampling strategy will be a compromise between information and cost. The Great Barrier Reef Marine Park Authority is required by law to revise zoning plans every five years, and we have recommended that dugong surveys be repeated in the Park at five-yearly intervals. Given the expense, time and personnel needed to conduct large-scale surveys in remote areas, we suggest that this would also be an appropriate interval between dugong surveys in Torres Strait.

Acknowledgments

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TABLE 1: Dugong catch statistics from five Torres Strait communities 1975-82.

Collection period	Location	Number caught Total	Average per month	Source
October 1975 - June 1976	Thursday Island	41	4.6	Personal records kept by one hunter for Dr G.E. Heinsohn
Sept 1976 - August 1978	Mabuiag	227	9.5	Records collected by Nietschmann during his stay on Mabuiag
January 1977 - December 1977	Kubin	50	4.2	plus records kept for him by an Islander in Kubin
October 1976 - 1979	Badu	227	7.8	and Badu - March (Nietschmann 1984)
July 1978 - March 1982	Daru	454	10.1	Records of dugongs sold in the Daru market collected by PNG Division of Wildlife (Hudson, 1986)

TABLE 2: Estimates of the dugong catch of Islanders on crayboats in 1983 on the basis of interviews conducted in late 1983 by Marsh et al., (1984) and MacFarlane (see Johannes and MacFarlane, manuscript).

Informant	Interviewer	Estimate	Basis of estimate
Island leader not involved with fishery	Marsh	>100	discussions with other Islanders
Islanders who owned and operated crayboats	Marsh	~500[a]	30 taken one week from several boats; maximum of 11 per day; last week (November 12-18 1984) four taken from one boat
Crayboat crews + personal involvement with cray industry 1980-81	MacFarlane	~240	Assumed 2 dugongs / per week per boat, 4 boats, 30 week season[b]

[a] Probably an overestimate; the Islanders wished to emphasise their prowess as hunters.

[b] This is probably an overestimate of the length of the crayfishing season and of the weekly catch. Peter Channells (pers. comm. 1988) reports that the average number of days per year worked by a freezer boat in 1981-86 was 109 and that vessels do not work continuously in areas where dugongs occur.

TABLE 3: Areas of survey blocks and sampling intensities.

Block	Area (km^2)	Sampling %
(a) November 1987		
0	2202.0	9.1
1	6420.0	9.5
2	7148.0	9.1
3	9287.0	4.2
4	3108.0	5.1
5	1221.0	12.2
6	1167.0	7.9
	30533.0	7.4
(b) March 1988		
2[a]	5477.0	9.5
3[a]	5904.0	4.9
4	3108.0	5.1
5[a]	829.0	10.0
6[a]	1070.0	8.5
	16388.0	7.0

[a] these blocks were incompletely sampled in the March 1988 survey (see Figure 2 for details of transects not flown).

TABLE 4: Details of group size estimates and correction factors used in the population estimates.

Blocks : lines	Group size mean (C.V.)	Number of observers Port	Number of observers Starboard	Perception Correction Factor estimate (C.V.) Port	Perception Correction Factor estimate (C.V.) Starboard	Availability Correction Factor estimate (C.V.)
(a) November 1987						
5: 9-13	1.3863(0.0470)	1[a]	1[b]	1.3538(0.0087)	1.3913(0.0188)	2.7203(0.1196)
2: 1-8; 3: 13-16	1.3863(0.0470)	2	1[b]	1.0425(0.0087)	1.3913(0.0188)	2.7203(0.1196)
0; 1; 2: 9-28; 3: 1-12; 4; 5: 1-8, 14-16; 6	1.3863(0.0470)	2	2	1.0425(0.0087)	1.0896(0.0188)	2.7203(0.1196)
(b) March 1988						
2: 1-5	1.4375(0.0505)	1[a]	1[b]	1.5238(0.0422)	1.5000(0.0568)	2.5714(0.1367)
2: 6-8	1.4375(0.0505)	2	1[b]	1.1513(0.0422)	1.5000(0.0568)	2.5714(0.1367)
2: 9-28; 3: 3-13; 4; 5: 1-4, 9-13; 6: 2-11	1.4375(0.0505)	2	2	1.1513(0.0422)	1.1538(0.0568)	2.5714(0.1367)

[a] training transects for port rear-seat observer. Port correction factor based on correction factor of the port mid-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 5: 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.

Block	Density per km^2	Numbers
(a) November 1987		
0	0.00 ± 0.00	0 ± 0
1	0.18 ± 0.04	1140 ± 280
2	1.11 ± 0.17	7925 ± 1204
3	0.29 ± 0.11	2673 ± 1041
4	0.23 ± 0.10	717 ± 300
5	0.06 ± 0.02	67 ± 27
6	0	0
Total	0.41 ± 0.05	12522 ± 1644
precision		0.13
(b) March 1988		
2[a]	0.84 ± 0.15	4596 ± 839
3[a]	0.31 ± 0.14	1832 ± 840
4	0.03 ± 0.03	84 ± 85
5[a]	0	0
6[a]	0	0
Total	0.40 ± 0.07	6511 ± 1190
precision		0.18

[a] these blocks incompletely surveyed due to bad weather preventing completion of survey.

TABLE 6: Summary of the analysis of variance comparing dugong density in Torres Strait in November 1987 and March 1988 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	1.90169	0.024	1.14217	0.292
Beaufort sea state	1.77641	0.040	1.03702	0.315
cloud cover	1.83974	0.031	1.00269	0.323
Beaufort sea state + cloud cover	1.72316	0.050	0.93619	0.340

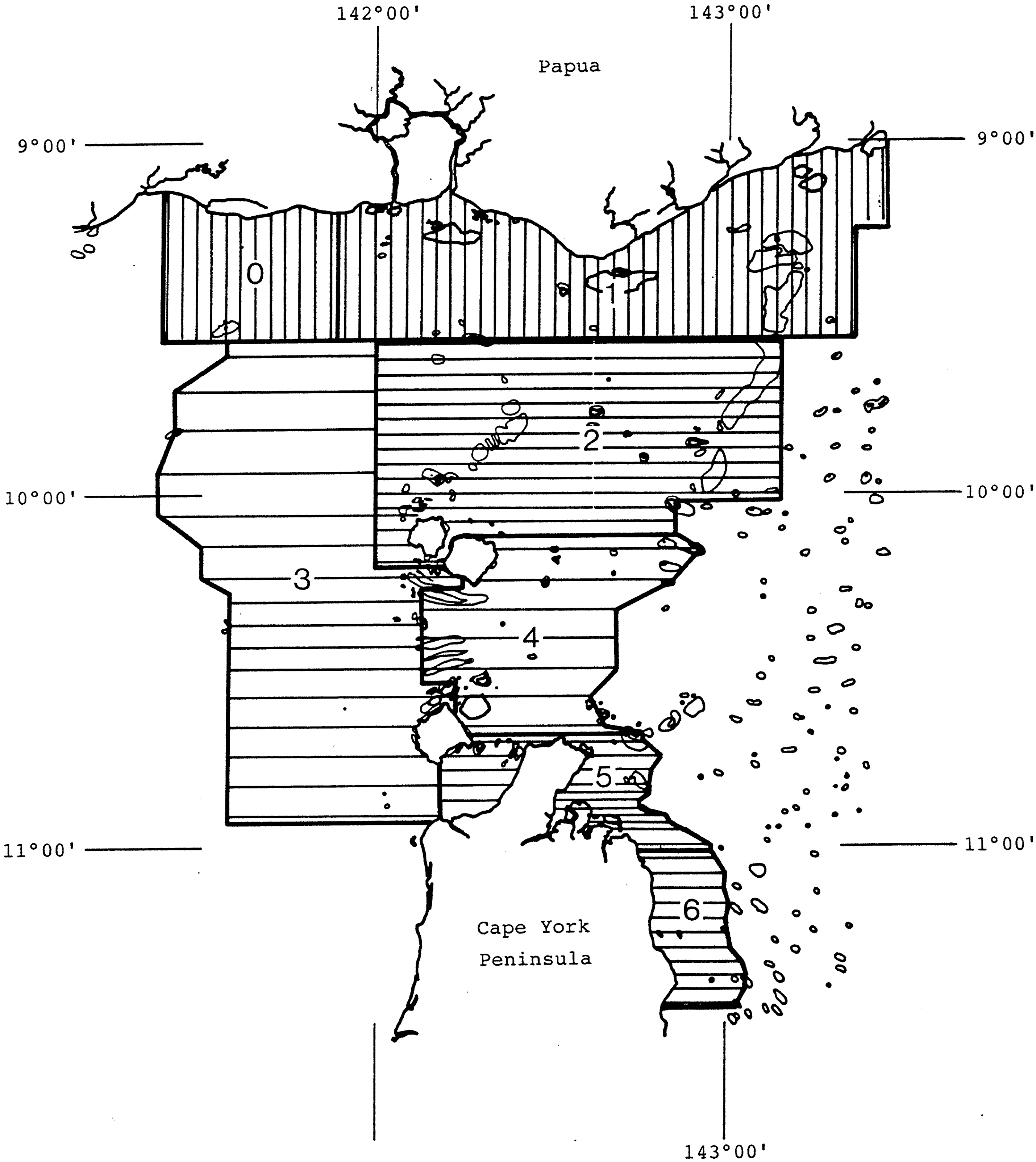


Figure 1: Survey area, showing the survey blocks (0-6) and transect lines for the November 1987 survey.

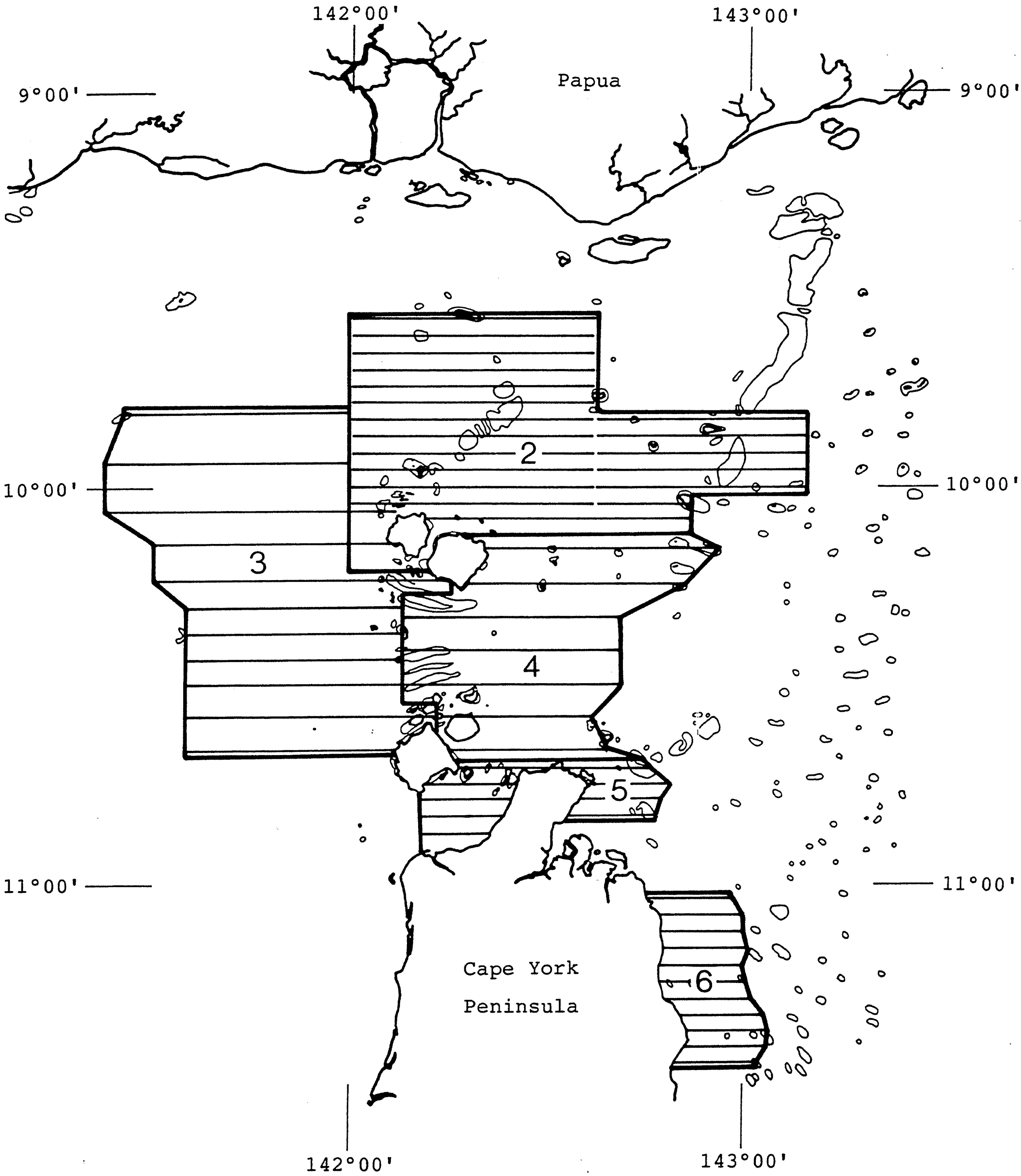


Figure 2: Survey area, showing the survey blocks (2-6) and transect lines for the March 1988 survey. Note that blocks 2, 3, 5 and 6 were incompletely surveyed with respect to the same blocks in the November 1987 survey, and that blocks 0 and 1 were not surveyed.

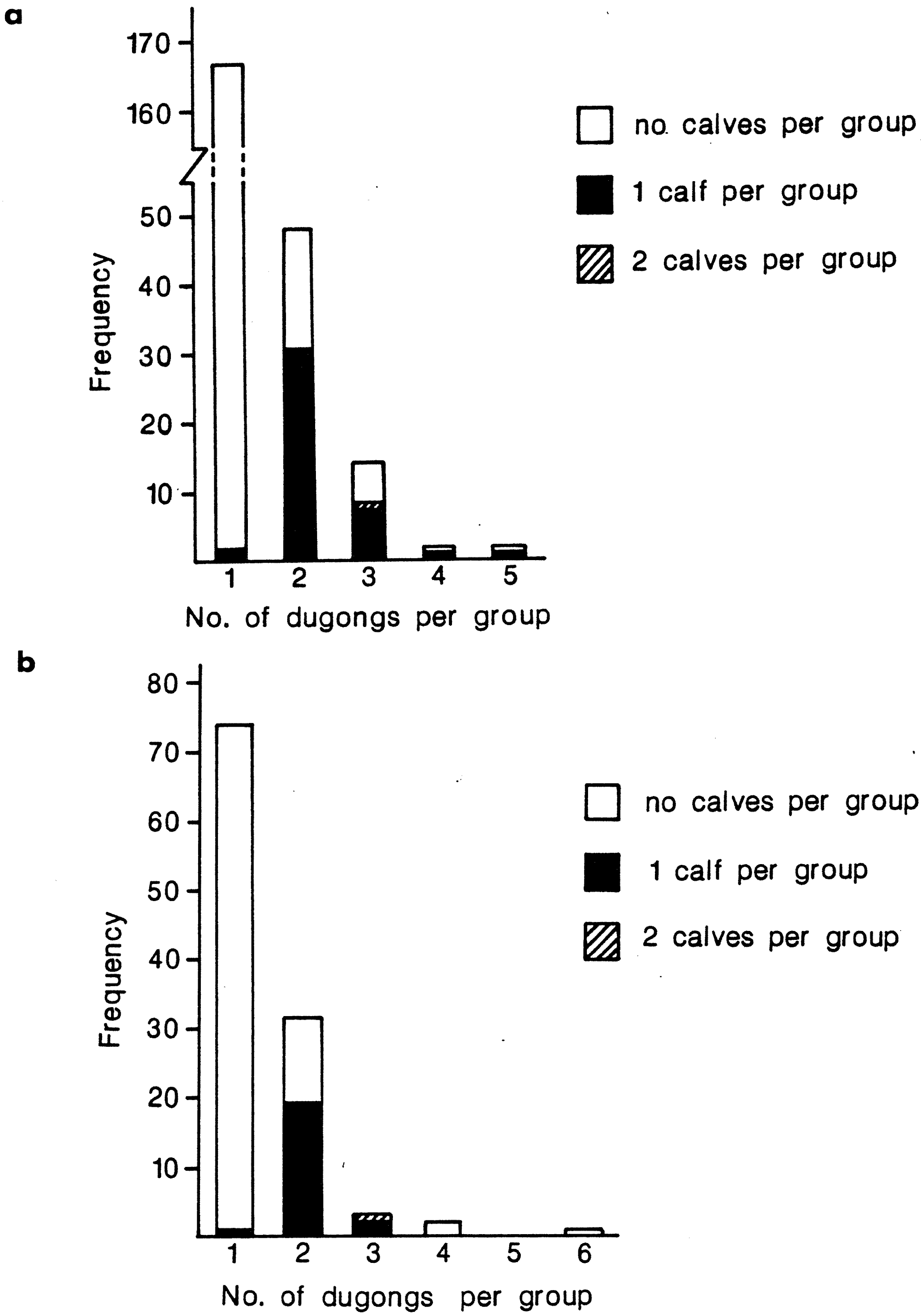
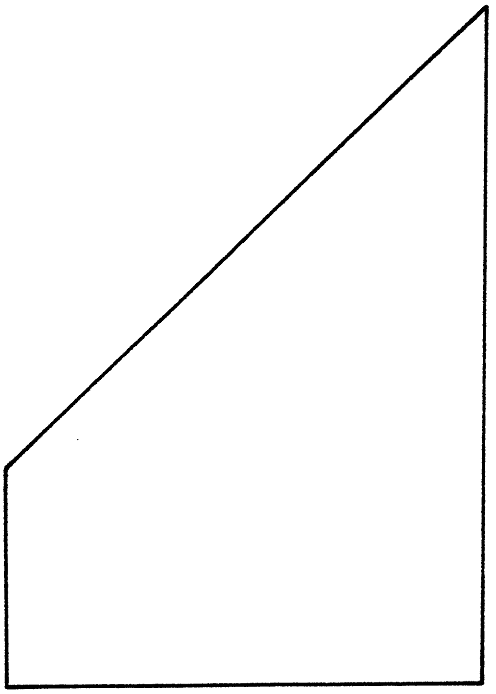


Figure 3: Frequency histograms showing details of dugong group size and composition for (a) November 1987 and (b) March 1988 surveys.



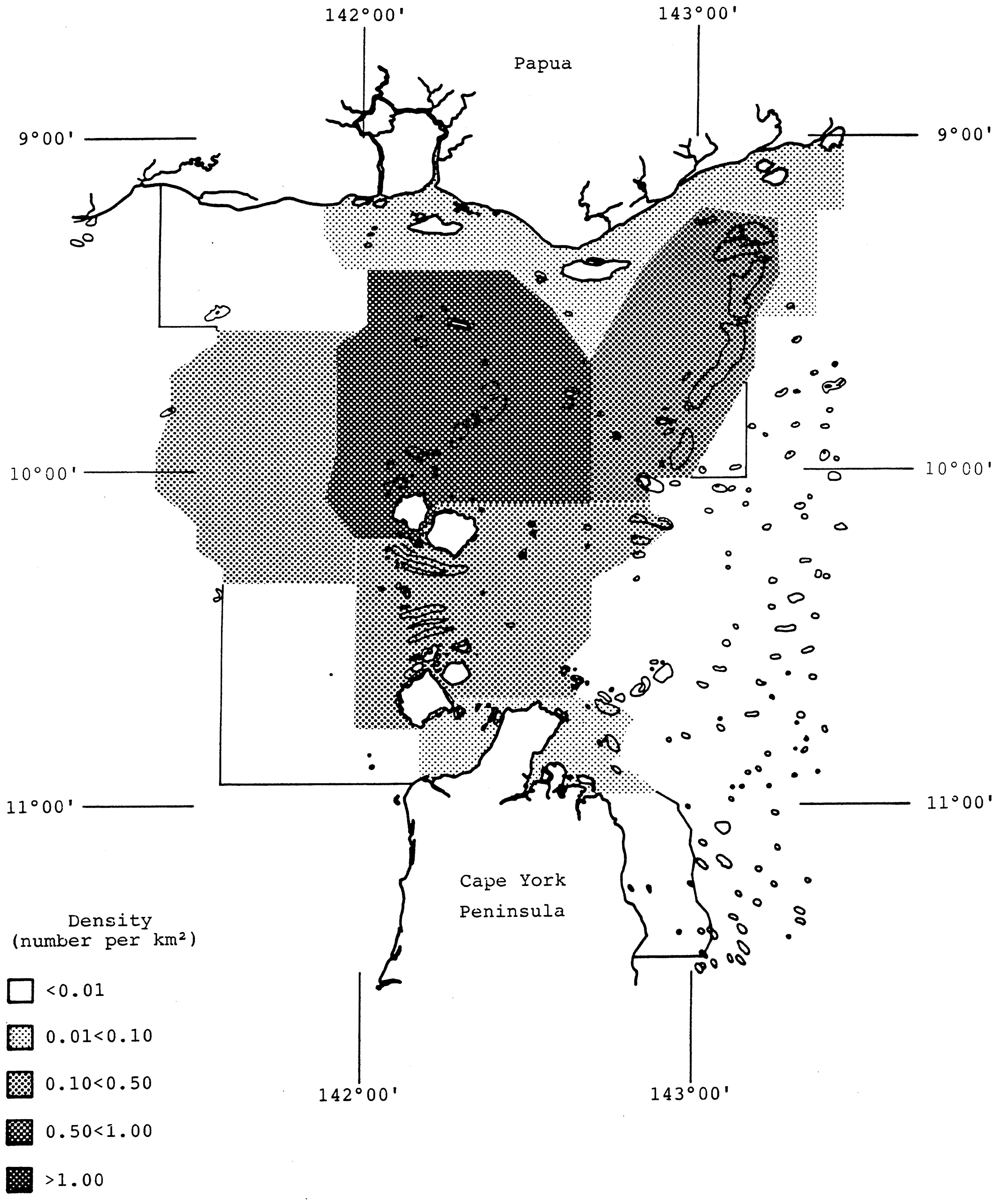
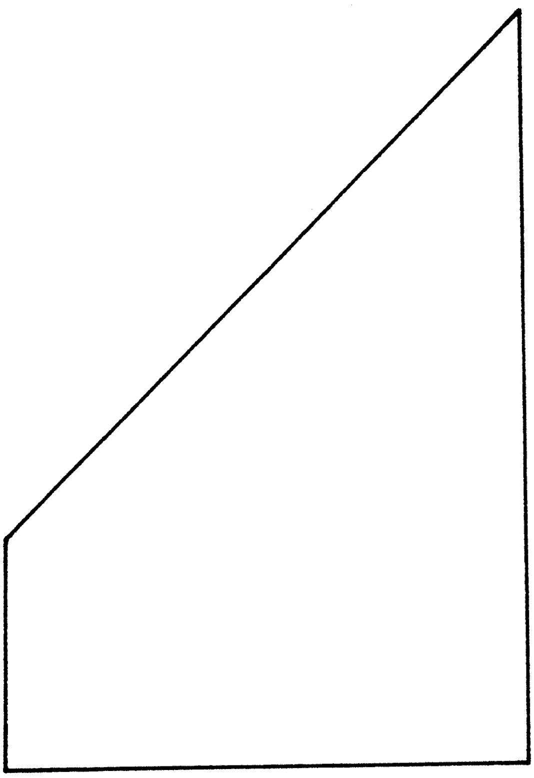


Figure 4: The distribution of dugong density in the survey area in November 1987. Overlay shows the boundaries of the Protected Zone Joint Authority Dugong Sanctuary Area.



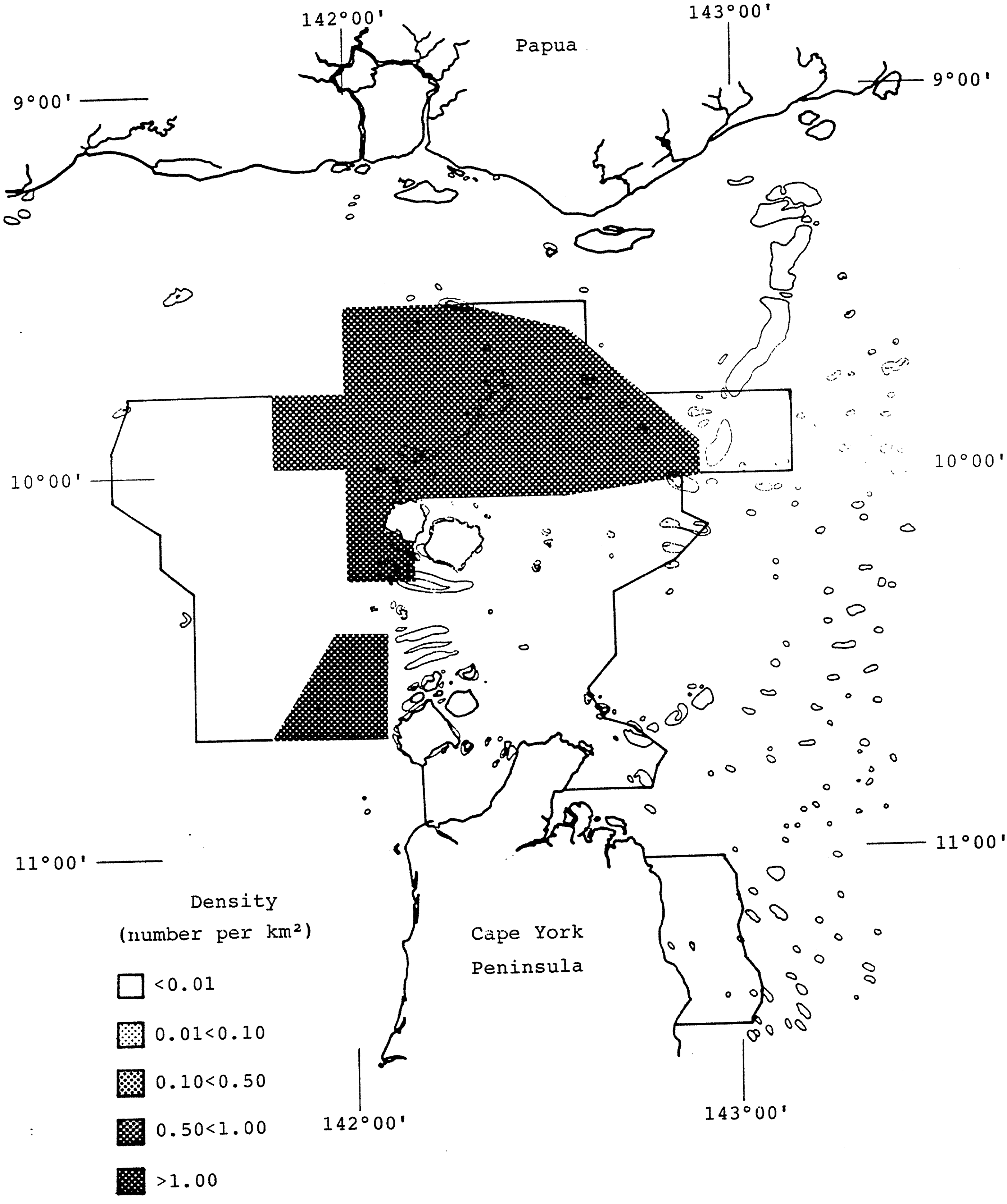


Figure 5: The distribution of dugong density in the survey area in March 1988. Overlay shows the boundaries of the Protected Zone Joint Authority Dugong Sanctuary Area.

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Aerial Surveys of Sea Turtles in the Northern Great Barrier Reef Marine Park

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Running Head: Turtle aerial surveys

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

Abstract

In 1984 and 1985, sea turtles were counted from the air at an overall sampling intensity of 9% over a total area of 31,288 km^2 within the northern sections of the Great Barrier Reef Marine Park during surveys designed primarily to census dugongs. The sea turtles were not identified to species. We attempted to correct sightings for perception bias (the proportion of animals visible in the transect which are missed by observers), and to standardize for availability bias (the proportion of animals that are invisible due to water turbidity) with survey-specific correction factors. The resultant minimum population estimate in November 1985 was 32,300 ± S.E. 2,753 sea turtles at an overall density of 1.03 ± S.E. 0.09 km^{-2}, a precision of 9%. We consider this to be a gross underestimate of numbers actually present. Significant differences between population and density estimates obtained from repeat surveys of the same areas were accounted for by differences in Beaufort sea state and cloud cover using analysis of covariance suggesting that we had not been successful in standardizing all biases. Turtles were widely distributed throughout the Great Barrier Reef lagoon from inshore seagrass beds to mid- and outer-shelf reefs. Highest densities were observed on inshore seagrass beds and on mid-shelf reefs, particularly between Murdoch Island and Cape Melville, and in Princess Charlotte Bay. Maps of density and distribution are given. The value and limitations of this survey regime for censusing sea turtles are discussed.

Introduction

Sea species of sea turtles occur in the Great Barrier Reef Region: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), flatback (*Natattor (Chelonia) depressa*), Pacific Ridley (*Lepidochelys olivacae*), and leatherback (*Dermochelys coriacea*) (Cogger, 1984). Green and hawksbill turtles are the most common species found on the reefs of the northern Great Barrier Reef (Limpus, 1978); green turtles are also common on inshore seagrass beds in this region. The flatback turtle is encountered only rarely in reef situations and yet, like the Pacific Ridley, it may be abundant in coastal areas inshore from the main coral reefs and in the vicinity of continental islands (Limpus, 1978). The flatback is the species most commonly caught in trawls in northern Great Barrier Reef waters (Y. Beuteaux, unpublished data). The leatherback is an oceanic species rather than a resident of coral reefs, but is occasionally sighted in this region (see Limpus and McLachlan, 1979).

Sea turtles (especially large animals) can often be seen clearly from the air during low-level surveys particularly in calm seas and in clear water. However, with the exception of the leatherback, they are difficult for the non-specialist observer to identify to species.

Admitting the limitations of this method in the absence of specific identifications, this paper aims to generate distribution maps for sea turtles in the northern Great Barrier Reef Marine Park and to provide a minimum estimate for sea turtles in the area on the basis of sightings recorded during aerial censuses of dugongs, *Dugong dugon*, in 1984 and 1985.

Methods

The coastal zone between Cape Bedford (15°15'S., 145°21'E.), Cape Melville (14°10'S., 144°30'E.) and the outer barrier reef was surveyed between November 13 and 15 1984, and again between November 1 and 5 1985. The corresponding area between Campbell Point (13°32'S., 143°35'E.) and Hunter Point (11°30'S., 142°50'E.) was surveyed between April 21 and 26 1985, and again between November 7 and 8 and November 17 and 21 1985. The intervening Princess Charlotte Bay area was surveyed once between October 31 and November 7 1985.

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 1.

Survey Design

For estimation of regional densities of turtles, the area was divided into 13 blocks (Fig. 1) on the basis of sampling intensity, depth contours, and/or Aboriginal hunting activity. Block areas (Table 2) were estimated from 1:250,000 maps using a planimeter or a digitizing tablet. The areas of major islands were excluded from the block areas. The areas of small (<3 km^2) islands were included in the block areas.

The Partenavia 68B aircraft was flown at a groundspeed of 185 km h^{-1} (100 kn.) at a altitude of 137 m (450 feet) ASL. The pressure altimeter was calibrated at each takeoff and landing. Transect width (200 m on each side of the aircraft at survey altitude) was demarcated by fibre glass rods attached to artificial wing struts. The actual width of each transect was estimated by calculating the mean survey height for that transect (taking into account the altimeter correction at each landing using appropriate interpolations), assuming a combined transect width of 400 m at an altitude of 137 m.

The transect lines flown on the various surveys are shown in Figure 1. In order to increase precision, all lines were aligned east west i.e. approximately perpendicular to the depth contours. For the 1984 survey of blocks 1 through 4, 14 lines spaced at intervals of 5′ latitude (9.3 km or 5 nm) extended to the outer Barrier Reef. Each pair of these long lines was interspersed with two shorter lines 3.1 km (1.7 nm) apart and extending 21.6 km from the coast. (The latter is the distance flown in seven minutes at 185 km h^{-1} [100 kn.]). This survey design was developed on the assumption that almost all dugongs would be seen close to the coast. This assumption proved incorrect. As a result, in subsequent surveys lines were flown between the coast and the outer Barrier Reef at intervals of 2.5′ latitude, an arrangement which also aided navigation by providing definite start and end points for each transect. Additional lines were flown in two areas of particular interest to the Great Barrier Reef Marine Park Authority (blocks 2 and 11). The intensity with which each block was sampled is summarized in Table 2.

Counting Procedure

The usual crew comprised a pilot navigator, a front right survey leader/recorder, and two tandem observing teams who occupied the middle and rear seats on opposite sides of the aircraft. Four operational observers were not always available especially during the first two surveys. During the November 1984 survey, the crew included one operational (rear seat) observer on each side of the aircraft and a trainee observer in the port mid-seat. On the April 1985 survey and when training a second mid-seat observer in the November 1985 surveys, only one tandem team and the rear-seat observer on the other side of the aircraft were operational as the trainee observer did not report his sightings. A complete crew was available at other times.

The observers reported their observations of dugongs, turtles (usually not identified to species), cetaceans, sharks, rays, seasnakes and surface plankton blooms in standard format into an intercom connected to a two track tape recorder. We recorded whether each sighting occurred in the top (furthest from aircraft), middle, or bottom third of the transect in order to increase the probability of distinguishing between different observations reported simultaneously by both members of a tandem team. Operational mid seat observers were visually screened from the rear seat observers with a curtain and acoustically isolated from the remainder of the crew (apart from each other). The rear seat observers and the mid seat observers reported their (independent) observations into separate tracks of the tape recorder. Trainee mid seat observers could hear the reports of the rear seat observers.

Data including aircraft height and position, locations of presumed seagrass beds, weather conditions, the starting and finishing times for each transect, and the sightings of the rear seat observers were recorded by the survey leader using a micro computer programmed as a data logger and timer.

More details on methodology are provided by Marsh and Sinclair (manuscripts a & b).

Post Survey Data Editing

The tape record of each transect was used to check and edit the computer records, so that each sighting could be classified as being made by one (specified) observer or both members of a tandem team. Records of the time of each observation and of the starting and finishing times for each transect enabled the position of each observation to be plotted on a map as a basis for the preparation of the smoothed density distribution maps.

Correction Factors

Correction factors for perception bias (groups of turtles visible on the transect line that were missed by observers) and their associated coefficients of variation were calculated as outlined in Marsh and Sinclair (manuscript a). It was not possible to correct for availability bias (groups of turtles that were unavailable to observers because of water turbidity) because of the lack of data from an aerial survey of turtles in clear water (when all animals are potentially visible) to use as a standard. Instead, we used the data from the November 1985 survey of blocks 8 to 13 as the standard as this survey had the lowest proportion of turtles sighted at the surface. We corrected all the other surveys against this (see Table 3) in order to calculate the various correction factors for availability bias and their associated coefficients of variation (see Marsh and Sinclair, manuscript a). Thus this paper provides standardized minimum population estimates only.

Analysis

Because transects were variable in area, the Ratio Method (Jolly 1969; Caughley and Grigg 1981) was used to estimate density, population size and their associated standard errors for each block for each survey. Any statistical bias resulting from this method is considered inconsequential in view of the high sampling rate (Table 2) (see Caughley and Grigg 1981). Input data were the estimated number of turtles for each tandem team per transect calculated using the corrections for perception and availability biases. The resultant standard errors were adjusted to incorporate the errors associated with the appropriate estimates of the perception and availability correction factors and the mean group size (Table 3) following the method of Jolly and Watson (1979) as outlined in Marsh and Sinclair (manuscript a).

The significance of differences in density between years and between blocks for the Cape Bedford-Cape Melville area (blocks 1 through 4), were tested using analysis of variance with and without measures of cloud cover (oktas) and/or sea state (Beaufort scale) as covariates. Input data for both analyses were corrected densities per square kilometer based on mean group sizes and the estimates of the correction factors for perception and availability bias, each line within a block (or zone) 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.

There were two fixed factors (blocks and years) in the analysis of the survey results for blocks 1 through 4. Lines within blocks could not be used as a factor because of the differences between years in the survey design (Fig. 1). An unweighted means analysis was used because the number of transects varied by block.

The same lines were flown during the two surveys of blocks 6 through 13 enabling line to be used as a (random) factor in the analysis. Each line was divided into an inshore and an offshore zone at the 10 fathom (18m) depth contour. Zone and season were treated as fixed factors. A split plot design (Snedecor and Cochran 1967 p.369 - 372) was used for the analysis which was performed with and without measures of cloud cover and/or sea state as covariates.

Distribution maps

Prior to the preparation of the smoothed density distribution maps, the entire survey area was divided into the following habitats without reference to the turtle data:

(1) Inshore waters to the 10m line. (This region was further subdivided on the basis of the presence/absence of seagrass beds; see Figure 3).

(2) Mid-shelf reef complexes with associated shoals.

(3) Outer-shelf reefs and associated shoals. (When habitats (2) and (3) were continuous they were combined i.e. between Murdoch Point (14°37′S., 144°55′E.) and Cape Melville).

(4) Continental island complexes and associated reefs e.g. Lizard Island (14°42′S., 145°30′E.), Flinders Group (14°11′S., 144°15′E.).

(5) The shallow coastal plane between the 10m and 20m depth contours between Cape Flattery (14°58′S., 145°21′E.) and Barrow Point (14°20′S., 144°40′E.).

(6) The remaining areas, chiefly the deep channels.

The distribution maps were based on corrected densities.

Results

Reliability of Observers

A total of 768 groups of turtles were categorized as being seen by both members of a tandem team. We investigated observer reliability by comparing the reports of team members.

There was very little disagreement between tandem observers. Team members differed over specific identity on 18 occasions (2.3%) compared with 4.7% for dugongs on the same surveys. The difference is not significant (G with William′s correction = 1.877; 1 d.f.; $P>0.1$). Twelve of the discrepancies occurred when one observer classified an animal as a turtle while the other was unsure; on four occasions one observer classified apparently the same animal as a ray when the other thought it was a turtle; once apparently the same animal was called a turtle by one observer, a dugong by the other; on another occasion there was disagreement as to whether an animal was a dolphin or a turtle.

Animals are often seen in the process of surfacing or diving as an observer scans the sea surface, so it is possible for one observer to see an animal at the surface while it is below the surface when sighted by the other observer. Not surprisingly, one team member described a turtle as being on the surface when his counterpart reported it as beneath the surface on 16 occasions (2.1%). This compares with 8.6% for dugongs on the same surveys (Marsh and Saalfeld, manuscript). The difference is significant (G with William's correction = 11.223; 1 d.f.; $P<0.001$).

Minimum 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 have been listed in Marsh (1987). Table 4 gives estimates of the density and numbers of turtles per block on the various surveys together with the standard errors of these estimates. Two standard errors have been listed for each estimate: (1) based on the difference in corrected turtle counts between transects only, (2) incorporating the errors in estimating the appropriate correction factors and mean group size as well.

The minimum population estimates sum to 32,300 ± S.E. 2,753 turtles for the whole region in November 1985 at an overall density of 1.03 ± S.E. 0.09 turtles per km^2, a precision of 9%. This is likely to be a gross underestimate of the number of turtles present as we attempted merely to standardize availability bias rather than to correct for it in absolute terms.

Difference between surveys

The results of the analysis of variance used to investigate the differences between the surveys of blocks 1 through 4 held in November in both 1984 and 1985 (Table 5) indicated that densities differed significantly between blocks ($P<0.001$). There was no significant interaction between years and blocks ($p=0.6$) indicating that the turtles were dispersed similarly on both surveys. Although the difference between years in the minimum population estimate was substantial (13,875 ± S.E. 2,235 in 1984, 7,918 ± 1,318 in 1985), the probability of rejecting the null hypothesis was only 0.062 when the analysis was performed without using weather conditions as covariates. When Beaufort sea state for each transect was used as a covariate the probability of the observed turtle density being the same for each survey increased to 0.755, indicating that the lower observed density in 1985 could be explained by the rougher seas (Table 1).

Comparison of the results of the April (post wet season) and November (pre wet season) surveys of blocks 6 through 13 in 1985 without using weather conditions as covariates (Table 6) indicated that observed densities differed significantly between lines and between seasons, with the observed density significantly higher in November than in April 1985. However, there was no significant difference in density between the inshore and the offshore zone, nor was there any significant season by zone interaction indicating that the pattern of dispersion was similar for both surveys. When Beaufort Sea State and cloud cover for each transect were used as covariates the difference in observed density between seasons was no longer significant ($P=0.422$) indicating that this difference could also be explained by changes in the sighting conditions due to weather.

These results suggest that our attempts to standardize the biases had had only limited success.

Distribution of Sea Turtles

Figure 2 consists of smoothed density distribution maps based on the results of the November 1984 and November 1985 surveys. More detailed maps are provided in Marsh (1987). Turtle densities were highest in the following habitats:

(1) inshore seagrass beds (Fig. 3), particularly in Bathurst Bay and in the area between Claremont Point and the mouth of the Chester River in Princess Charlotte Bay;

(2) mid-shelf reef complexes, particularly the large planar reefs in Princess Charlotte Bay which are believed to support significant stands of the sea grass Thalassia hemprichii (see Hopley, 1982);

(3) the large mid-shelf/outer-shelf complex between Murdoch Point and Cape Melville and extending up to 14°55'S.

Overall, Princess Charlotte Bay stood out as an area supporting particularly high densities of turtles. Throughout the survey area, densities tended to be lowest in the deep channels and on some outer shelf reefs.

A large nesting aggregation of turtles was observed in the area immediately surrounding Raine Island on November 17 1985. The density of animals was too great to estimate using visual counting techniques. The only leatherback sighted was in the channel just west of Martha Ridgway reef (12°8'S., 143°47'E.) on 20 November 1985.

Discussion

The results of this survey need to be interpreted in the context of the complex life history of sea turtles which typically live in widely dispersed feeding grounds from which they travel often long distances to aggregate to breed in a small number of traditional rookeries (Limpus and Nicholls, 1988). The green turtle rookeries on Raine Island - Pandora Cay are the only major sea turtle rookeries in the survey area. Small rookeries also occur at No.7/No.8 Sandbanks (13°27'S., 143°59'E./13°22'S., 143°28'E.) (Limpus 1982a). The nesting aggregation observed in the Raine Island area was not included in the smoothed density map as it was off the transect (Fig. 2); and the density in the region of No.7/No.8 Sandbanks was not exceptional (Fig. 2). We saw no courting aggregations. We conclude that most of the turtles sighted on these surveys were on their feeding grounds.

Previous observations (Limpus 1978, 1982b; Limpus and Reed, 1985a; Limpus personal communication) indicate that most of the turtles seen on reefs and inshore seagrass beds (the areas of highest density see Fig. 2) are green turtles. It is therefore likely that most of the turtles sighted belonged to this species. Unlike the other species, the annual numbers of nesting green turtles fluctuate dramatically (Limpus and Nicholls, 1988). The nesting season which peaked in December 1984-January 1985 was much better than that a year later. Sea turtles are believed to return to their feeding grounds at the end of the nesting season. On this basis, we predict that there should have been more sea turtles on the feeding grounds in (1) November 1985 than November 1984 (2) April 1985 than November 1985.

This is the reverse of what was observed (Tables 4,5,6,). The population estimate for the Cape Bedford - Cape Melville area (blocks 1-4) was nearly twice as high in November 1984 (13,875 ± S.E. 2,235) than in November 1985 (7,918 ± S.E. 1,318) (Tables 4 and 5). Similarly, the population estimate for blocks 6-13 was significantly higher in November 1985 (11,778 ± S.E. 1,047) than in April 1985 (7,192 ± S.E. 920) (Tables 4 and 6). We believe that these results are unlikely to reflect the true situation.

Problems with the Survey Technique

Aerial censuses of turtles present a number of major difficulties. As a result, this survey technique is much less satisfactory for turtles than for dugongs (see Marsh and Saalfeld, manuscript).

In contrast to the major and unexpected differences between surveys in the population estimates for turtles (Tables 4,5,6), there were no significant differences between the population estimates for dugongs obtained as a result of the 1984 and 1985 surveys of blocks 1 to 4, and the April and November 1985 surveys of blocks 6 through 13 even when weather conditions were not used as covariates (Marsh and Saalfeld, manuscript). As discussed above, the observed differences in turtle densities are unlikely to be real. As shown in Tables 5 and 6, they can be explained by differences in sighting conditions which were better on the surveys on which the higher densities were observed (modal sea state Beaufort 1; maximum cloud cover 4 oktas; Table 1) than on the others (modal sea state Beaufort 2; maximum cloud cover 7 oktas; Table 1). Marsh and Sinclair (manuscript b) showed that, even over a relatively small range of conditions, the observed density of turtles depended on the sea state; fewer turtles were seen in rougher seas. In contrast, dugong sightings were much less affected by changes in sea state, making it is easier to correct for perception and availability biases.

Specific identification of turtles is clearly another major problem which could probably be at least partially overcome by additional training of observers (C J Limpus, pers comm). A much more difficult problem is the unknown proportion of turtles which are too small to be seen from the air. For example, Heron Island Reef (Capricorn Group, southern Great Barrier Reef) supports green turtles as small as 36cm curved carapace length (Limpus and Reed, 1985b). It is difficult to correct for such turtles as they comprise a different (and usually unknown) proportion of the population in different habitats. Green turtles which live in the deep water off-the reef front at Heron Island are mainly immature while more than half those in the lagoons are adults (Limpus, 1978). We also lack the data to correct for the proportion of large turtles which are unavailable to observers due to water turbidity. Thus the population estimates presented here although precise (e.g. C.V. 9%) are gross underestimates.

Value of the Surveys

The chief value of these aerial surveys for sea turtles is their ability to provide data for use as a basis for preparing large scale relative density distribution maps as an aid to preparing and revising zoning plans for the Great Barrier Reef Marine Park. (The pattern of dispersion remained constant in our limited repeat surveys of the same areas (Tables 5 and 6)). The minimum population estimates, although undoubtedly gross underestimates also serve to put the Aboriginal harvest of turtles in some perspective. For example, the data of Smith (1987) indicate that the people of Hopevale caught approximately 125 turtles (mostly greens) over a 17 month period between in 1984-1985 when the minimum population estimate for blocks 1 and 2 in November 1984 was 1,984 $\pm$ S.E. 317, while the people of Lockhart River community caught at least 31 turtles (30 greens) in three months in 1985 when the minimum population estimate for block 8 in November 1985 was 1,040 $\pm$ S.E. 171.

It is also notable that the areas close to Hopevale and Lockhart River Communities (Fig. 2) have a comparatively low density of turtles compared with other inshore seagrass areas. This is not surprising as green turtles, the major target species, tend to be resident on their feeding ground (Limpus and Reed, 1985b), and thus, over a period of years, are susceptible to over-hunting at a local level. This supports the recommendation of Smith (1987) (see also Smith and Marsh, in press) for limiting Aboriginal hunting to defined hunting areas.

We conclude that although dedicated aerial surveys for sea turtles in Great Barrier Reef waters would probably not be cost-effective, the data obtained are a useful by-product of dugong surveys.

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LEGEND TO FIGURES

Fig. 1. Survey areas, showing the survey blocks (1-13) and transect lines used in the 1985 surveys. The transects flown in November 1984 are shown in the adjacent map. The boundary between the inshore blocks 1,2, and 3 and the offshore block 4 is 21.6 km from the coast i.e. all transects in blocks 1,2, and 3 are 21.6 km long. The 18 m (10 fathom) line forms the boundary between the inshore blocks 6, 8, 10, 11, and 12 and the offshore blocks 7, 9, and 13.

Fig. 2. The distribution of turtle density in the survey area from Cape Bedford to Hunter Point in November 1985. The distribution from Cape Bedford to Cape Melville in November 1984 is shown in the adjacent map.

Fig. 3. The distribution and density of inshore seagrass beds in the survey area provided for comparison with Fig. 2. The ground-truthed seagrass data are from Coles *et al*., (1985).

Table 1 Weather conditions encountered on each survey.

	November 1984	April 1985	November 1985 Blocks 1-7	November 1985 Blocks 8-13
Wind speed (km h^{-1})	≤20	≤30	≤28	≤19
Cloud cover (oktas)	0-2	2-7	0.5-5	0-4
Minimum cloud height (m)	650-1000	200-2500	460-1525	305-610
Beaufort Sea State mode (range)	1 (0-3)	2 (1-3.5)	2.5 (0-4)	1 (0-3)
Glare [a,b] mode (range)	1 (0-2)	2 (0-3)	1 (0-2.5)	1 (0-2.5)
Visibility (km)	>10	8->10	8->10	>20->50

a Worse side of aircraft

b Scale 0 = none, 1 = <25% of field of view affected by glare, 2 = 2.5 ≤ 50%, 3>50%.

TABLE 2: Areas of the survey blocks and sampling intensities

Block	Area (km^2)	Sampling %	Block	Area (km^2)	Sampling %
1	1004.0	13.8[a]	5	7839.0	8.5[b,c]
		8.3[c]	6	450.8	8.1[b,c]
2	665.0	13.0[a]	7	1561.2	7.9[b,c]
		16.3[c]	8	1193.7	7.9[b,c]
3	1050.0	13.0[a]	9	4600.4	8.2[b,c]
		7.8[b]	10	258.7	9.5[b,c]
4	5233.0	4.7[a]	11	396.4	25.9[b,c]
		8.9[b]	12	451.9	8.2[b,c]
			13	6583.6	9.1[b,c]

a	November 1984	Area surveyed 7952 km^2	Sampling % 7.6
b	April 1985	Area surveyed 15497 km^2	Sampling % 9.0
c	November 1985	Area surveyed 31288 km^2	Sampling % 9.0

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

Date of survey	Blocks:lines	Group size mean (c.v.)	Number of observers	Starboard	Perception Correction Factor estimate (c.v.) Port	Starboard	Availability Correction Factor estimate (c.v.)
November 1984	blocks 1-4	1.17 (0.03)	1[a]	1[a]	1.28 (0.03)	1.28 (0.03)	2.18 (0.09)
April 1985	blocks 6-13	1.39 (0.09)	1[b]	2	1.58 (0.06)	1.20 (0.04)	1.58 (0.11)
November 1985[e]	blocks 1-4; 5:9-23; 6; 7; 8 and 9:10-12	1.56 (0.06)	2	2	1.18 (0.02)	1.25 (0.02)	1.32 (0.07)
November 1985[e]	block 5:1-8	1.56 (0.06)	2	1[c]	1.18 (0.02)	2.07 (0.05)	1.32 (0.07)
November 1985[f]	blocks 8 & 9:13-32; 10; 11:39-42; 12:43-48; 13:33-48	1.16 (0.03)	2	2	1.07 (0.01)	1.07 (0.01)	1.00 (0.00)
November 1985[f]	blocks 11:50-57; 12 & 13:49	1.16 (0.03)	1[d]	2	1.40 (0.03)	1.07 (0.01)	1.00 (0.00)

a. Based on correction factor for observer B.B.-H. on Nov. 1985 survey Blocks 6-13, when weather conditions similar to this survey. B.B.-H. (starboard rear-seat observer both surveys) saw similar number of dugong groups to port observer on this survey.

b. Port correction factor based on correction factor starboard mid-seat observer this survey (who saw similar number of dugong groups).

c. Training transects for starboard mid-seat observer. Starboard correction factor based on correction factor starboard rear-seat observer for remainder this survey.

d. Training transects for port mid-seat observer. Port correction factor based on correction factor port rear-seat observer for remainder this survey.

e. Blocks flown October 31 - November 8, 1985.

f. Blocks flown November 17 - 21, 1985.

TABLE 4: Estimated densities and numbers of turtles on the various surveys. The values are ± standard error incorporating the errors resulting from sampling, and in estimating mean group size and the correction factors. The numbers in brackets represent the standard errors resulting from sampling only.

Block	Initial Survey		November 1985 Survey	
	Density per km^2	Numbers	Density per km^2	Numbers
1	0.56 ± 0.18 (0.17)[a]	565 ± 177 (168)[a]	0.39 ± 0.11 (0.10)	390 ± 108 (101)
2	2.09 ± 0.40 (0.34)[a]	1 389 ± 263 (226)[a]	1.21 ± 0.25 (0.22)	803 ± 167 (147)
3	2.79 ± 0.60 (0.53)[a]	2 929 ± 630 (561)[a]	1.66 ± 0.37 (0.34)	1 742 ± 393 (353)
4	1.72 ± 0.41 (0.37)[a]	8 992 ± 2 121 (1 931)[a]	0.95 ± 0.24 (0.22)	4 983 ± 1 242 (1 140)
sub-total blocks 1-4	1.74 ± 0.28 (0.26)[a]	13 875 ± 2 235 (2 030)[a]	1.00 ± 0.17 (0.15)	7 918 ± 1 318 (1 206)
coefficient of variation		0.16 (0.15)[a]		0.17 (0.15)
5	N/A	N/A	1.61 ± 0.28 (0.23)	12 604 ± 2 179 (1 775)
coefficient of variation				0.17 (0.14)
6	3.19 ± 1.08 (0.97)[b]	1 440 ± 485 (438)[b]	1.92 ± 0.71 (0.68)	865 ± 319 (307)
7	0.91 ± 0.33 (0.30)[b]	1 424 ± 508 (464)[b]	0.96 ± 0.33 (0.31)	1 495 ± 509 (487)
8	1.05 ± 0.26 (0.21)[b]	1 254 ± 312 (254)[b]	0.87 ± 0.14 (0.14)	1 040 ± 171 (166)
9	0.17 ± 0.04 (0.03)[b]	784 ± 194 (157)[b]	0.52 ± 0.09 (0.09)	2 389 ± 408 (398)
10	0 [b]	0 [b]	0.90 ± 0.12 (0.12)	234 ± 31 (30)
11	1.09 ± 0.61 (0.59)[b]	431 ± 241 (233)[b]	1.05 ± 0.26 (0.26)	417 ± 104 (103)
12	0.57 ± 0.33 (0.31)[b]	258 ± 147 (142)[b]	0.64 ± 0.23 (0.23)	287 ± 106 (106)
13	0.24 ± 0.06 (0.04)[b]	1 601 ± 372 (290)[b]	0.77 ± 0.11 (0.11)	5 051 ± 720 (701)
sub-total blocks 6-13	0.46 ± 0.06 (0.05)[b]	7 192 ± 920 (809)[b]	0.76 ± 0.07 (0.07)	11 778 ± 1 047 (1 016)
precision[c]		0.13 (0.11)[b]		0.09 (0.09)
Total for November 1985 survey			1.03 ± 0.09 (0.08)	32 300 ± 2 753 (2 374)
precision[c]				0.09 (0.07)

[a] November 1984

[b] April 1985

[c] (standard error/mean)%

N/A not available

Table 5. Summary of analysis of variance comparing observed turtle density in the Great Barrier Reef Marine Park between Cape Bedford and Cape Melville by blocks and by years (1) without covariates (roman print) (2) with Beaufort sea state as a covariate[1] (italics).

Sources of variation	Sum of squares[2]		D.F.		F.		Significance of F	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Blocks	7.855	*7.573*	3	*3*	9.385	*9.335*	0.000	*0.000*
Years	0.996	*0.027*	1	*1*	3.569	*0.098*	0.062	*0.755*[3]
Block by years	0.524	*0.518*	3	*3*	0.626	*0.639*	0.600	*0.592*
Residual	29.851	*28.664*	107	*106*				
Regression		*1.187*		*1*		*4.390*		*0.039*

1. Assumption that regression slopes the same for all cells was not violated (p=0.25)

2. Data transformed using ln(X + 0.33 smallest non-zero density)

3. Probability of no significant difference in turtle density between years was greatest (P=0.755) when Beaufort sea state used as the only covariate. Corresponding probability for cloud cover alone was P=0.448, and for Beaufort sea state and cloud cover combined P=0.069. Assumption that regression slopes are the same for each cell was violated for cloud cover (P=0.000) and for Beaufort sea state and cloud cover (P=0.031).

Table 6. Summary of analysis of variance comparing observed turtle density in the Great Barrier Reef Marine Park between Campbell Point and Hunter Point by zones and by seasons. (1) without covariates (roman print) (2) with cloud cover and Beaufort sea state as covariates[1] (italics).

Sources of variation	Sum of squares[2]		D.F.		F.		Significance of F	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Lines	41.964	*46.936*	48	*48*	2.362	*3.509*	0.000	*0.000*
Main plot comparisons								
Zones (inshore/offshore)	0.154	*0.295*	1	*1*	0.267	*0.517*	0.608	*0.476*
Main plot error	27.687	*26.825*	48	*47*[3]				
Regression		*0.862*		*1*		*1.511*		*0.225*
Sub-plot comparisons								
Season	10.334	*0.181*	1	*1*	31.112	*0.651*	0.000	*0.422*[4]
Season by zone	0.016	*0.026*	1	*1*	0.049	*0.095*	0.826	*0.759*
Sub-plot error	31.889	*26.192*	96	*94*				
Regression		*5.69*		*2*		*10.221*		*0.000*

1. Assumption that regression slopes are the same for all cells is not violated for covariates cloud cover in oktas (P=0.625) or Beaufort sea state (P=0.963) when each is considered separately. However, there is a suggestion that this may not be valid when they are taken together (P=0.047).
2. Data transformed using ln(X + 0.33 smallest non-zero density)
3. 1 degree of freedom returned to main plot error term as covariate cloud cover linearly dependent on year.
4. The probability of there being no significant difference in turtle density between seasons was greatest (P=0.422) when cloud cover and Beaufort sea state were both used as covariates. The corresponding probability for cloud cover cover alone was P=0.14112 and for Beaufort sea state alone P=0.002.

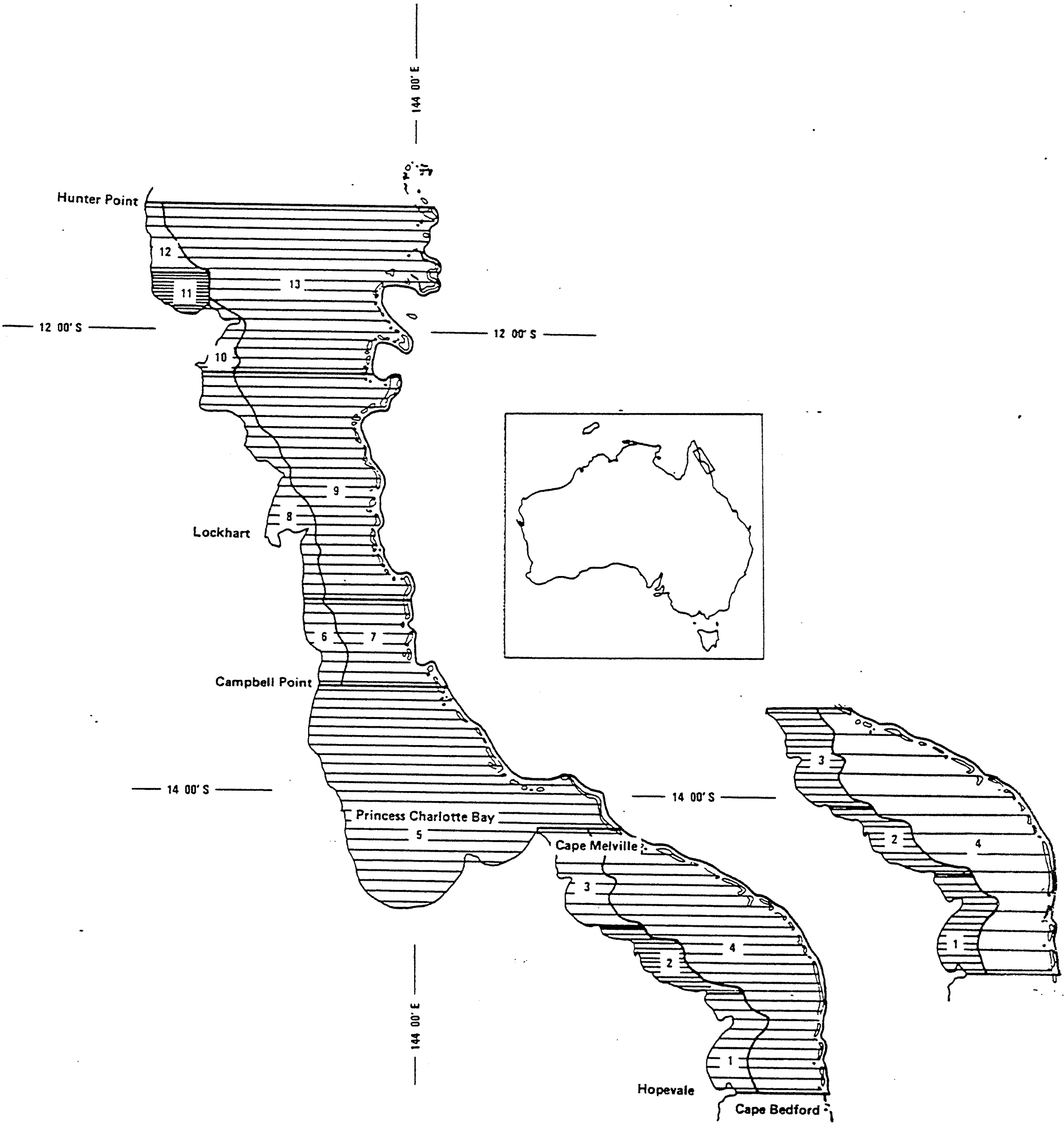

Fig. 1. Survey areas, showing the survey blocks (1-13) and transect lines used in the 1985 surveys. The transects flown in November 1984 are shown in the adjacent map. The boundary between the inshore blocks 1,2, and 3 and the offshore block 4 is 21.6 km from the coast i.e. all transects in blocks 1,2, and 3 are 21.6 km long. The 18 m (10 fathom) line forms the boundary between the inshore blocks 6, 8, 10, 11, and 12 and the offshore blocks 7, 9, and 13.

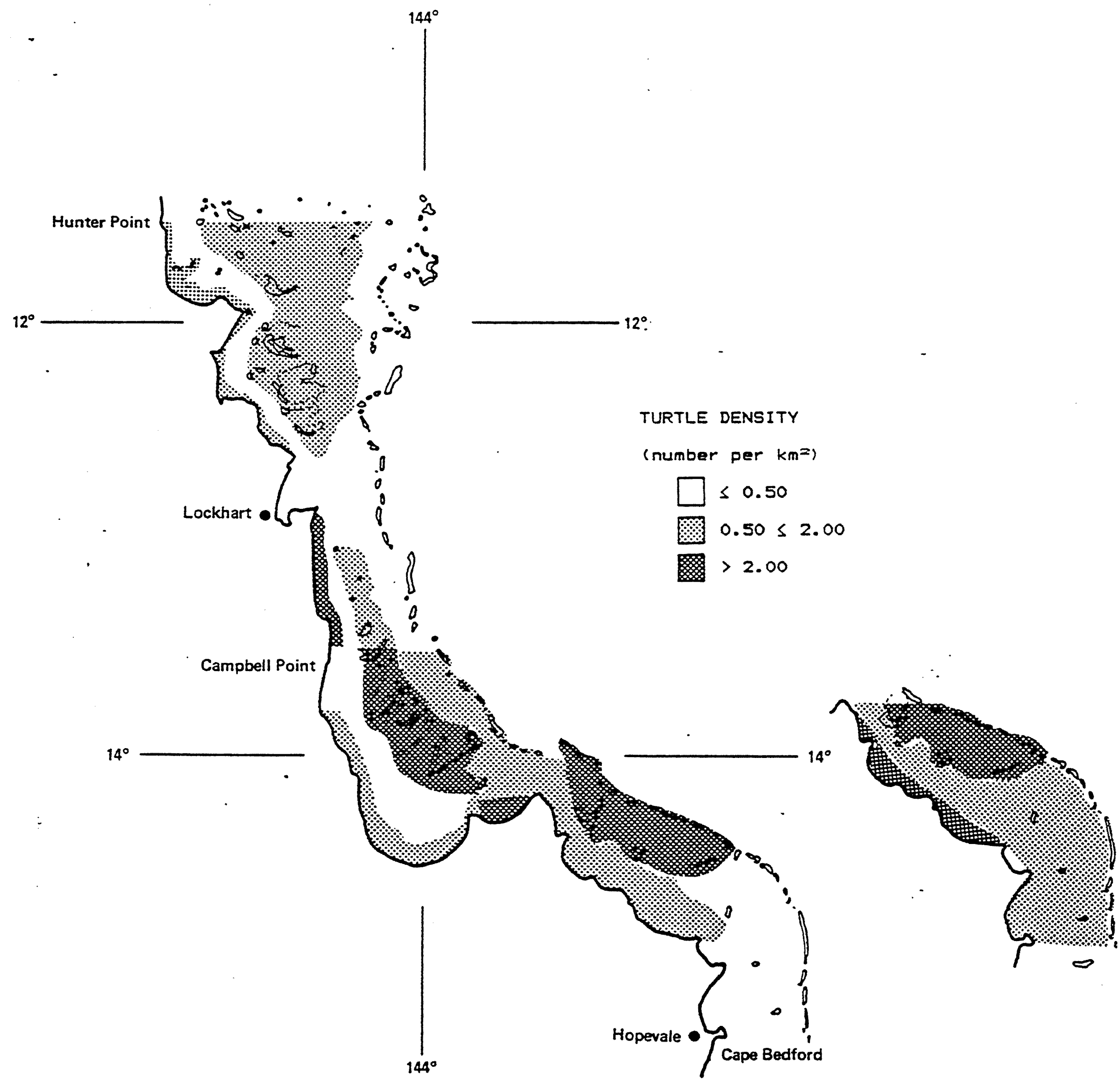

Fig. 2. The distribution of turtle density in the survey area from Cape Bedford to Hunter Point in November 1985. The distribution from Cape Bedford to Cape Melville in November 1984 is shown in the adjacent map.

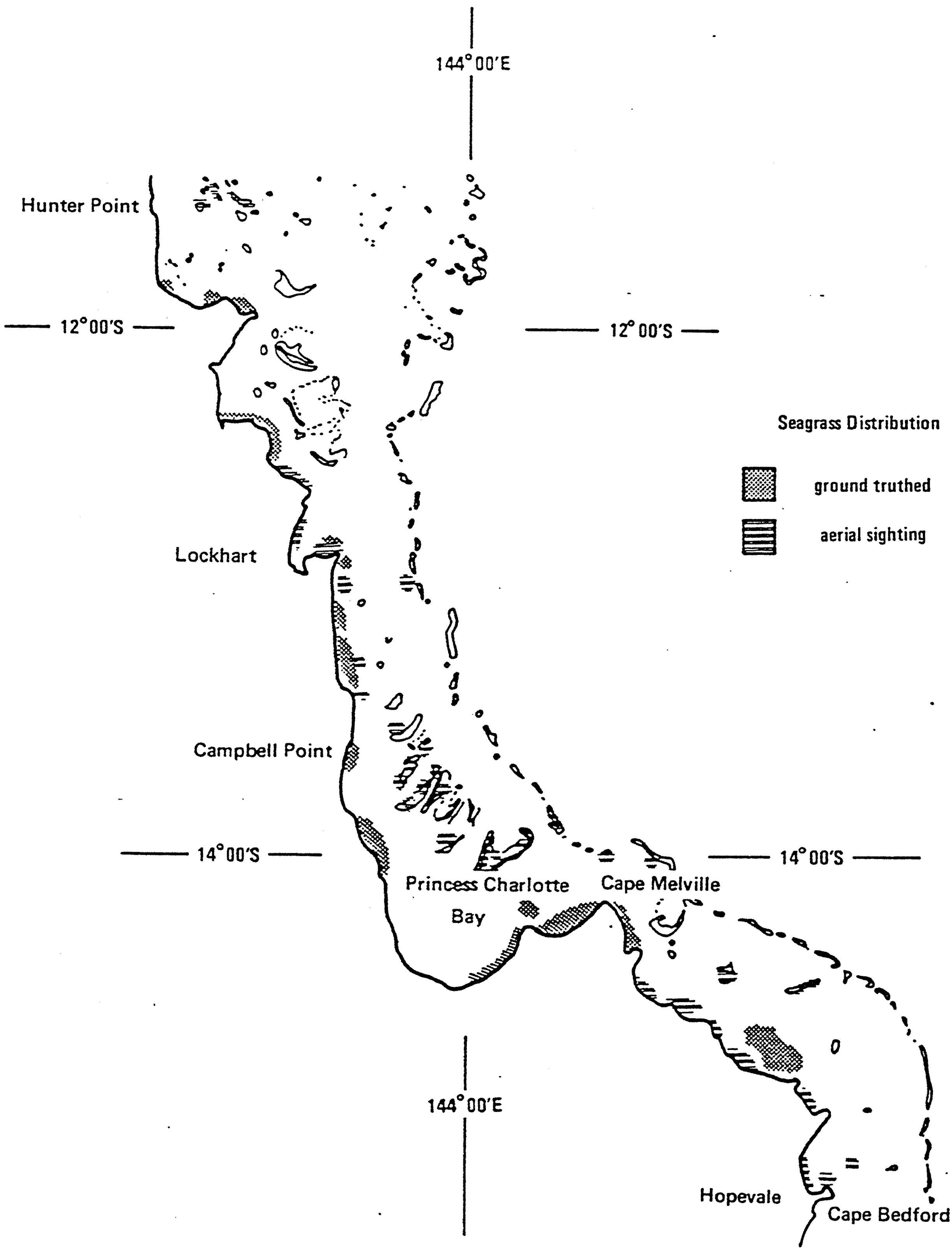

Fig. 3. The distribution and density of inshore seagrass beds in the survey area provided for comparison with Fig. 2. The ground-truthed seagrass data are from Coles *et al.*, (1985).

Part 3

Papers on movements and habitat usage, traditional hunting, and incidental sightings

This volume includes the following papers and report that have resulted from this project:

Marsh, H. and G.B. Rathbun. manuscript. Development and application of conventional and satellite radio-tracking techniques for studying dugong movements and habitat usage. Submitted to Aust. Wildl. Res

Smith, A.J. and Marsh, H. (in press). Management of the traditional hunting of dugongs (*Dugong dugon* (Muller, 1776)) in the Great Barrier Reef Marine Park. *Environ. Manage*.

Spencer, P. (manuscript). Incidental sightings of dugongs in the Great Barrier Reef Marine Park.

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Development and application of conventional and satellite radio-tracking techniques for studying dugong movements and habitat usage.

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Running Head: Conventional and satellite radio-tracking of dugongs

Key words: Dugongs, satellite telemetry, radio-tracking, Great Barrier Reef Marine Park, movements, habitat usage.

Abstract

Techniques have been developed for tracking individual dugongs using buoyant, tethered, conventional and satellite radio transmitters, and applied to six dugongs caught off the North Queensland coast. The dugongs (one immature, one pubertal and four mature males) were caught by bull-dogging or hoop-netting and tracked for between one and 16 months. All spent most of their time in the vicinity of inshore seagrass beds using overlapping home ranges (MAP 0.95) of 4 to 23 km^2. The only dugong to undertake long-distance movements was the pubertal male which journeyed between core areas in two bays about 140 km apart three times in nine weeks, completing the journey in as little as two days. One of the adult animals made several journeys about 10 km up the tidal reaches of a creek. These results support the Great Barrier Reef Marine Park Authority's policy of conserving dugongs by giving a high level of protection to some inshore seagrass beds that support large numbers of animals. The relative merits of conventional and satellite telemetry for tracking dugongs are discussed.

Introduction

The large numbers of dugongs (*Dugong dugon*) within the Great Barrier Reef Marine Park was one of the features of "outstanding universal value" that enabled the region to obtain World Heritage Listing (GBRMPA, 1981). Although dugongs are protected in Australia except for traditional hunting by some Aboriginal peoples, animals are thought to be at risk in some parts of the Park from Aboriginal hunting and from accidental drowning in gill nets (Marsh, in press).

The Great Barrier Reef Marine Park Authority (GBRMPA) has given very high levels of protection to some important inshore seagrass areas where large numbers of dugongs feed (see GBRMPA, 1983, 1985). This method of zonal management relies on dugongs spending a high proportion of their time in these protected inshore areas, an assumption which was questioned as a result of an aerial survey of parts of the Cairns and Far Northern sections of the Park in November 1984. It was estimated that about one quarter of the dugongs in the area were more than 20 km from the coast during this survey (Marsh and Saalfeld, in review). As the establishment of protected areas is very unpopular with fisherman because of the resultant reduction in their fishing grounds, it is important to obtain information on the movements and habitat usage of individual dugongs in order to assess the likely effectiveness of a zonal management strategy for dugong conservation.

The only information on movements of individual dugongs is from P.K. Anderson (1982), who observed dugongs in Shark Bay, Western Australia. On the basis of photographs and sketches, 15 dugongs were recognised more than once by divers. The time between resightings ranged from less than one hour to 15 days; the maximum distance between resightings was 19 km. Another dugong was marked with a paint stick and resighted 4.8 km away the following day.

Because of the impracticality of using natural or artificial marks to identify dugongs visually in the extensive, remote and often turbid waters that characterize their habitats in the Great Barrier Reef Region, it was decided to fit some with radio-transmitters in order to obtain information on their movements and habitat usage. This was a considerable logistical and technological challenge as new equipment and techniques had to be developed. In this paper, we present the results of a pilot study using conventional and satellite telemetry to study dugongs.

Equipment

Harness attachment

Manatees (*Trichechus manatus*) in Florida have been radio-tracked for several years using an attachment composed of a belt around the caudal peduncle, a semi-rigid tether, and a floating transmitter housing (Rathbun *et al.*, in press). This assembly overcomes the problem caused by radio signals attenuating in salt water (which has a high electrolyte content). The floating transmitter housing is at the surface for substantial amounts of time except when the animal is swimming or diving to depths greater than the length of the tether. Because dugong movements and behaviours are thought to be grossly similar to those of manatees, we decided to develop an attachment assembly for dugongs based on the successful manatee model (Rathbun, *et al.*, 1987). The principal challenge was to redesign the peduncle belt for the much smaller tail stock and more delicate skin of the dugong. This was done using a cast of a dugong tail.

In June 1986, we spent three weeks at the Jaya Ancol Oceanarium in Jakarta, Indonesia, testing a prototype attachment assembly on two captive dugongs, a 2.05 m-long immature male weighing 147 kg, and a 1.86 m immature female weighing 114 kg. Each was fitted with a belt, tether and dummy transmitter housing assembly (Figure 1), and closely monitored for 16 days. The original belts caused some minor skin abrasions. These problems were overcome by design modifications (Rathbun, *et al.*, 1987).

Each peduncle belt incorporated a corrodible link (Figure 1) made of either brass nuts and normal steel bolts with an expected life of 3-6 months, or of normal steel nuts and bolts with an expected life of 24 months (Rathbun, *et al.*, 1987).

Conventional radio-tracking

Each 4mW very high frequency (VHF) transmitter (Telonics, Mesa, Arizona), battery and magnetic on-off switch were enclosed in a housing made of 3.8 cm diameter PVC pipe. One end was capped with a 7 cm long PVC nose cone and the other with a PVC plate that included a 0.25 wavelength whip antenna. An assembled unit weighed approximately 530 g and was 42 cm, long excluding the antenna which was 39.5 cm long. The radio frequency was in the 151.5-151.8 MHz range with a pulse duration in the 11.7 - 14 msec range, and a pulse interval of about 1 sec. The expected battery life was one year. Transmissions were received using a Telonics TR-2 receiver and a 4-element Yagi beam antenna or a Telonics RS-2AK "H" antenna (land or boat tracking), or a pair of Telonics H antennae (aircraft tracking).

During trials in September 1986, signals from these transmitters were detected over a line-of-sight range of at least 24 km from an altitude of 286 m with both the H or the 4-element Yagi antennae. Thus a transmitter at the surface of most of Cleveland Bay (Figure 9) was detectable from elevated locations in suburban Townsville.

Satellite telemetry

Each satellite-monitored platform transmitter terminal (PTT) (Telonics), its three lithium D-cell batteries and a magnetic switch, were enclosed in a housing constructed from 7.6 cm diameter PVC pipe capped at one end with a 9 cm long PVC nose cone. The other end was capped with a PVC plate through which protruded a whip antenna which was 15.5 cm long. An assembled unit weighed approximately 2.4 kg and was 50 cm long excluding the antenna. Each PTT transmitted a 401.650 MHz signal at regular intervals (45 sec, PTT 5517; or 60 sec, PTT's 5534, 5535, 5536) throughout its duty cycle. Duty cycles turned the PTT's on and off on a schedule corresponding to the optimal satellite passes, thereby conserving battery life. PTT 5517 operated between 0100 and 0900 hours, and between 1300 and 2000 hours each day for an expected operational life of 4 months; the other PTT's operated between 0100 and 0900 hours, and between 1300 and 2100 hours on every second day, and had an expected operational life of eight months. Motion and temperature sensors were incorporated in the

PTT. Sensor data were encoded as 16 bits following the individual PTT identifier signal. The motion data related to mercury switch closures when the housing tipped more than 90° from the normal vertical position. Transmissions from PTT 5517 included summaries of the number of seconds in the previous minute and in the previous 24 hours that the switches closed; those from the other three PTT's accumulated the number of minutes in which the PTT had tipped through more than 90° in the previous hour, and the number of actual tips (to a maximum of 1023) in the previous 12 hours. We hoped to relate the motion sensor data to dugong activity.

Methods

Capture and deployment

The first dugong we captured (D-1, Table 1) was located using a Cessna 172 aircraft, herded into shallow water using a 4.3 m aluminum boat equipped with a 40-HP outboard motor, and then caught using a rodeo technique developed for catching sea turtles (Limpus, 1978). The animal was supported by an inflatable stretcher (Figure 2) while being fitted with a PTT assembly. The other five animals (Table 1) were caught using a hoop-netting technique similar to that used by oceanaria to catch dolphins and small whales from a 5.5 m aluminum boat with two 60-H.P. outboard motors (Marsh, 1987). The only animal tagged with a conventional transmitter (D-2) was recaptured 29 weeks after initial capture, after being located by homing onto the transmitter from a boat (see below). A rope connected to a 20-cm diameter torpedo buoy was then attached to the tether under the transmitter using a pole with a detachable hook. The float enabled us to follow and to hoop-net the dugong. The transmitter, tether and peduncle belt were then replaced with a new assembly. Four attempts between September 1987 and January 1988 to capture this animal a third time using this technique were unsuccessful.

Conventional radio-tracking

Triangulation from land and outboard-powered boats (5.5 m and 4.3 m long) was used to estimate the position of the dugong tagged with the VHF-radio. Weather permitting, we tracked D-2 from the land during each high and low tide period (usually two tides per day) between 14 and 31 October 1986; once per day (1 November-12 December 1986), three times per week (13 December-3 May 1987), and twice per week (5 May - 4 February 1988). From 1 November 1986, most tracking was done in the evening (usually between 2000 and 2400 hours). The location of D-2 was estimated on 214 occasions by triangulating its position over a 2 to 3-hour period from three elevated locations in suburban Townsville (Figure 9). The three sites were visited sequentially by a single person. In a blind trial to evaluate this technique, two independent observers estimated the positions of two VHF transmitters that were anchored at known sites in the area frequented by D-2 in the southeastern corner of Cleveland Bay (Figure 9). This indicated that the position of a floating transmitter estimated by triangulating from land could be up to 4 km from its true position.

Every three hours for 48 hours from 10 to 12 December 1987, we estimated D-2's position by triangulating sequentially from three fixed buoys in the southeastern corner of Cleveland Bay from a 4.3 m boat. This procedure also proved rather inaccurate because of the difficulty in determining directions in a pitching boat, especially at night. It is also likely that the dugong moved during the time taken by one person to obtain three sequential fixes from either land or boat. Thus when compared to the data from the satellite-monitiored dugongs, the results of such triangulations provided only crude quantitative evidence of the dugong's whereabouts.

More accurate positions were obtained by homing (Mech, 1983) from either the 4.3 m or the 5.5 m outboard-powered aluminum boat (12 days) or from a Cessna 172 aircraft (5 days). However, homing required considerably more effort to determine each location than land-based triangulation. When the dugong was sighted from a boat, its position was calculated by triangulation on three terrestrial landmarks. Despite the extremely turbid water, we also made limited observations on the animal's behaviour, and timed surfacing and diving intervals using two digital stopwatches.

We measured the time that the antenna of the VHF transmitter was above the surface (i.e. the signal was audible) as an index of the activity of D-2, by timing the cumulative duration of the signal for 30 min (14-31 October 1986) or 15 min (from 1 November 1986) using a stopwatch.

Satellite telemetry

Service Argos (Toulouse, France) calculated the locations for each PTT by measuring the Doppler effect on the carrier frequency transmitted by the PTT on the basis of messages received by either one or two polar orbiting NOAA Tiros-N weather satellites (Nos. 9 and 10) travelling 820 km above the earth at 28,000 km/hour, as detailed in Fancy *et al.* (1988). Prior to February 1987, Service Argos required a minimum of five Doppler measurements for a particular PTT to calculate a location from a single overpass with at least a 420-sec interval between the first and last measurement.

We tested the accuracy of Argos-determined locations by anchoring a PTT at the surface of a swimming pool in Townsville for 4.5 days. Twenty-three locations were calculated by Service Argos during this period. The estimated mean location was 200 m ± s.e. 100 m from the location determined from a 1:25,000 parish map. The 35 concurrent temperature records were within the range of a maximum and minimum thermometer in the pool.

In February 1987, Service Argos upgraded their location algorithms, and the following categories of location estimation became available:

Quality 1: 4 messages over 240 < 420 sec interval or only 1 test to determine the correct solution; good internal consistency (1.5 Hz); geometric conditions 1.5° < distance from ground track < 24°; Argos claims 68% of results within 1 km radius circle of true latitude and longitude;

Quality 2: > 4 messages ; good internal consistency (1.5 Hz); geometric conditions 1.5° < distance from ground track < 24°; quality control on oscillator drift and unambiguous solution; Argos claims 68% of results within a 350 m radius circle of true latitude and longitude;

Quality 3: $\geq$ 5 messages over $\geq$ 420 sec; very good internal consistency (<0.15 Hz) and favorable geometric conditions (5° < distance from ground track < 18°; quality control on oscillator drift and unambiguous solution; Argos claims 68% of results within a 150 m radius circle of true latitude and longitude.

Temperature and activity sensor information were received by the satellite(s) on some passes when insufficient signals were received to calculate a location. We refer to such messages as non-location messages.

During the period that each transmitter assembly was attached to a dugong (Table 1), data were accessed by personal computer linked to the Service Argos computer in Toulouse via one of the main frame computers at James Cook University and the Midas and Transpac Telecommunication networks. The Lotus 1,2,3 spreadsheet and the Statistix package were used to process the data.

Home range estimates

Home ranges during the monitoring periods were calculated for all the dugongs using D.J. Anderson's (1982) non-parametric method, which describes home range in a probabilistic sense. The home range is then the smallest area which accounts for 95% (or some other percentage) of the animal's space utilization. We calculated and mapped the areas in which each satellite-tagged dugong spent 95% (MAP 0.95) and 50% (MAP 0.50) of his time on the basis of (1) guaranteed locations only (all locations for D-1; locations of Quality 2 and 3 only for D-3, D-4, D-5, and D-6), and (2) all locations. Similarly, estimates of the home range of D-2 were calculated based on (1) visual sightings only and (2) triangulated positions which were not on land and for which the error triangle was less than $2km^2$. In view of the errors associated with these triangulated fixes (see above), the resultant home range estimate for D-2 should be regarded as approximate. All home ranges were mapped using the Golden Graphics package.

Results

Effectiveness of the attachment assembly

Removal of the VHF transmitter assembly from D-2 allowed us to assess the condition of his caudal peduncle and the assembly itself 29 weeks after initial capture and deployment. Apart from a slight bend in the buckle, which may have occurred during recapture, and some wear at the apex of the wishbone from the ring attached to the proximal joiner (Figure 1), the peduncle belt, tether and transmitter were in good condition. Some electrolysis of the brass/normal steel corrodible link had occurred, however, we estimated that the link would have lasted several more weeks, substantially more than the anticipated 3-6 months. The transmitter bore a heavy coating of algae, but was still functioning normally. Large acorn barnacles had grown on the exposed surfaces of the peduncle belt, and on the tether just distal to the proximal end.

The belt was not causing any obvious damage to the dugong at the time of recapture. Superficial pressure marks, similar to those left by a ring on a human finger, were visible on the skin on both the sides and the ventral ridge of the peduncle. However, there was a deeper (several mm deep) indentation associated with a healed white scar on the dorsal ridge, presumably from a former wound caused by abrasion from the apex of the belt where the tether was attached.

Forty weeks after the recapture, the replacement attachment assembly on D-2 was recovered from a Townsville beach. The peduncle belt had come undone at the buckle, the belt was frayed, and the latex cover was missing. The brass/normal steel corrodible link was more corroded than the one which was deployed for 29 weeks, but was not in imminent danger of collapse. The nylon wishbone was worn at the apex as in the assembly recovered after 29 weeks. The nylon rod of the tether was bent and tapered near the distal end. The transmitter was still functioning. The shoreline adjacent to D-2's home range is lined with mangroves, and if the tether became tangled around a mangrove trunk, the belt may have pulled through the buckle due to the frayed state of the webbing as D-2 fought to get free.

PTT 5517 detached from D-1 after 63 days due to a mechanical failure in the tether/peduncle belt connection, and ceased functioning about 14 hours later. It was found on the beach in Upstart Bay (Figure 7) by a local amateur fisherman and returned to James Cook University. This PTT was returned to Telonics for repair, and redeployed on D-6 in November 1987 (Table 1). It ceased to function 32 days later and has not been recovered.

The absence of tips on the activity counters and/or the pattern of their movements as determined by the PTT locations, indicated that PTT's 5534, 5535 and 5536 detached from Dugongs 3, 4 and 5, respectively, between 47 and 94 days after these animals were tagged in the Starcke River area (Table 1). All three PTT's were washed up on beaches between 65 and 200 km to the north after up to 67 days at sea, and recovered on the basis of locations obtained from Service Argos. PTT 5534 was recovered with its housing intact, but without the belt or tether. The chain connector joining the housing to the tether was missing. As undoing this connector requires a shifting spanner, we suspect human interference. In contrast, PTT's 5535 and 5536 were attached to their respective tethers when recovered, although each peduncle belt was missing. This suggests mechanical failure of the peduncle belt. On the basis of the wear observed in the wishbone of each of the belts recovered from D-2, we suspect that the nylon wishbone was not strong enough to sustain the wear caused by a PTT (which is substantially heavier than a VHF transmitter). We now make wishbones from stainless steel rather than nylon.

Efficiency of the PTT's

The NOAA 9 and 10 satellites made an average total of about nine passes per day over the north-east Queensland coast during the times that the PTT's were operational. On average, a satellite was above the horizon for sufficient time to receive a location record during seven passes per day in 1986 (when the minimum interval required between the first and last of a series of messages was 420 sec) and eight passes per day in 1987-1988 (minimum interval 240 sec). Each dugong was located between zero and seven times per day that the PTT's were operational (Table 2). There was a significant difference between all PTT's in the mean number of locations per day (1-way ANOVA; 4/178 .d.f; $p=0.005$).

The means ranged from 2.5 locations per day for PTT 5517 in 1987 to 3.9 for PTT 5534 (Table 2) indicating that the change in the transmission interval from 45 sec in PTT 5517 to 60 sec in the others did not reduce the number of locations per day. In addition, non-location messages were received on between zero and eight passes per PTT per day (Table 2).

The motion sensors yielded little substantive information. The 24- hour activity sensor in PTT 5517 reflected the distance travelled by D-1 in the corresponding period (1-way ANOVA, $F=8.699$; 2/59 d.f.,$p<0.001$). The highest mean value was obtained on days when the dugong was journeying between Cleveland and Upstart Bays (Figure 5); the next when the dugong was travelling between one of the two parts of its home range in Upstart Bay (Figure 7); and the lowest when the animals apparently remained within one part of its home range in Upstart Bay. The other dugongs tagged with a PTT undertook local movements only, so we were unable to carry out similar analyses on the results from their long-term tip counters. However, there were marked fluctuations in the counts of the 24 hour activity sensor in PTT 5517, and the 1 hour and 12 hour sensors in the other PTT's, when the location records indicated that the animals were moving very little. In the absence of concomitant observations on the animals, these results were virtually impossible to interpret, particularly for PTT's 5534, 5535 and 5536 which operated only every second day (but see below for PTT 5517). The most useful function of the long term activity sensors was to indicate when the PTT's had detached; the tip counters in detached PTT's usually consistently registered zero. The short-term sensor in PTT 5517, which measured the number of seconds in the previous minute that the PTT had tipped through

90°, yielded no useful information as the modal number of tips for all but two records was zero. This is presumably because locations were generally obtained when the animal was relatively inactive at the surface.

The temperatures recorded by the PTT's (Table 2) suggest that the temperature sensor in PTT 5517 was reading significantly higher than those in the other PTT's when they were deployed in the Starcke River area.

Behaviour

We spent up to two hours in an outboard powered boat within a few metres of D-2 on 10 occasions between December 1986 and January 1988. The animal showed no adverse behaviour due to the attachment assembly. It did, however, become increasingly difficult to approach after being recaptured on May 2 1987. By January 1988, it had become impossible to approach the dugong in either a motorized or rowed boat. Consequently, our four attempts to recapture this animal a second time failed because we could not approach it closely enough.

The transmitter was usually pulled under water when D-2 swam fast or moved to surface. The housing was at the surface when D-2 was resting or possibly feeding in shallow water.

The surfacing and diving times obtained for D-2 are summarized in Table 3. There was no significant difference between days in surfacing (1-way ANOVA $F=0.011$, 1/130 d.f; $p>0.25$) or dive times (1-way ANOVA $F=2.626$; 2/197 d.f.; $p=0.075$). Overall, D-2 spent only 3.2% of its time at the surface during our (daytime) observations. The daily mean diving times of 1.2 to 1.5 min are within the range reported by Anderson and Birtles (1978) for individuals grubbing rhizomes of *Zostera*. However, the mean time of approximately 2.6 sec taken by D-2 to break the surface, exhale, inhale and submerge was much higher than the mean of 1.4 sec reported by Anderson and Birtles (1978).

During the first three weeks when D-2 was being tracked from land at all high and low tides, the proportion of time the transmitter was at the surface was significantly greater at night than in the daytime (defined on the basis of published times of sunrise and sunset) (F=23.85; 1, 49 d.f.; p=0.000; proportions transformed to arc-sines). However, it was independent of the tidal cycle (F=0.177; 1, 49 d.f.; p=0.676; tidal cycle separated into four categories: high and low (one hour on either side of high and low tides respectively) and flood and ebb (the intervening four hours, as appropriate)). There was also a significant time/tide interaction (F=5.964; 1, 49 d.f.; p=0.018); the proportion of time the transmitter was at the surface being greater at high tide during the day and at low tide at night. Based on these data we decided to land-track in the evenings only to reduce the number of triangulation failures due to poor and intermittent signals. Analysis of the tracking data obtained at night from the land stations between November 1986 and February 1988 confirmed that the duration of the signal (time the antenna was above the surface) was independent of the tidal cycle (Kruskal Wallis statistic=3.86; n=62 (30 ties)); p=0.277).

It takes several hours from the time a signal is received by a satellite before the location is available from Service Argos. Because of this delay and our inability to locate PTT signals from the ground, we were unable to find and observe D-1, D-3, D-4, D-5, or D-6. However, a local resident reported observing D-1 in Upstart Bay on November 11 1986 within 'skin-touching distance of another dugong'. Two others were close by. All were in water about 1.25 m deep. D-1 had been located by Service Argos about 1 km away 1.25 hours earlier. During the period between October 12 and November 22 1986, when this dugong was resident in Upstart Bay, activity levels as measured by the long-term tip counter fluctuated widely (Figure 3). The activity levels on consecutive days were serially correlated (non-parametric runs test for serial randomness of measurements; Zar, 1984 p. 419; $N_1 = 37$, $N_2 = 5$; $u = 9.8$, $s = 0.23$; $p < 0.05$), but apparently independent of the lunar cycle. Given the observed association of D-1 with other animals in Upstart Bay, it is likely that these results reflect intense social interactions, perhaps not unlike the cavorting that is reported in manatees (Hartman, 1979). Manatees fitted with PTT's show increased tip-counter activity when intensely interacting with other manatees (Rathbun, unpublished data).

Like the VHF transmitters on D-2, most of the PTT's spent more time on the surface at night. A log-linear model was used to investigate the effects of PTT (the data for PTT 5517 were analyzed separately for 1986 (D-1) and 1987 (D-6)), and time (day/night) on the number of locations as a proportion of suitable satellite passes. There was a significant three-way interaction (Log Likelihood Chi-square =23.94, 4 d.f., $p < 0.001$). The proportion of passes for which locations were obtained was higher at night than in the day for all PTT's except 5536 (Figure 4). In addition, the mean number of tips for the one-hour activity sensors in PTT's 5534, 5535, and 5536, were all significantly lower at night than in the day time (2-way ANOVA, 1/396 d.f.,p=0.006). These results suggest that dugongs spend more time resting at or near the surface at night than during the day.

Movements and habitat usage

The only animal to undertake large scale movements was D-1, which was classified as pubertal on the basis of his body length of 2.3 m (male dugongs tend to become sexually mature when they are between 2.2 and 2.5 m long; Marsh *et al.*, 1984), and the fact that he had not yet acquired the secondary sexual characteristic of erupted tusks. D-1 was located by Service Argos for the first time three days after being tagged. He had moved to Bowling Green Bay, one bay south of the capture site in Cleveland Bay. He was next located in Upstart Bay, a minimum distance by sea of 143 km south of where he was tagged (Figure 5 and Table 4). D-1 then spent six weeks in Upstart Bay. Two days after an unseasonable cold snap, when inshore sea surface temperatures measured by the PTT fell nearly 2°C (Figure 6), D-1 travelled back to the area where he had been caught (Figure 5 and Table 4), completing the journey in two days at an average speed of at least 3 km per hour. After two days in Cleveland Bay, the dugong journeyed back to its former haunts in Upstart Bay where it remained until the PTT came off eight days later.

The other dugongs (the immature male (D-2) and the four adult males (D-3, D-4, D-5, D-6)) did not undertake any long journeys. The furthest that any of them moved from their respective capture sites was 22 km (D-6) (Figure 8); the other animals remained within 10 km. D-5 made several journeys to tidal pools about 10 km upstream from the mouth of Dead Dog Creek, adjacent to the area where he spent most of his time.

None of the dugongs was detected more than 7 km from the mainland (Table 1); or 4 km from the nearest island. Unfortunately, we do not know whether D-1 journeyed around the coast on his trips between Cleveland and Upstart bays. There was no significant difference ($F=1.47, 2/284$ d.f., $p=0.23$) between the temperatures recorded on these journeys (when locations were not available) and those recorded when D-1 was resident in the inshore waters of Cleveland and Upstart Bays. This suggests that D-1 travelled in inshore waters.

D-1 demonstrated a detailed knowledge of its local environment in Cleveland, Bowling Green and Upstart bays and tended to use the same areas on each journey (Figure 5). His home range was estimated for Upstart Bay only. Like the home ranges of the other dugongs, it was surprisingly small. When the estimated home ranges were based on guaranteed locations only, they showed that each dugong spent 95% of his time in an area of between 4.3 and 11.4 km^2; 50% of his time in an area of between 1.1 and 2.9 km^2 (Table 1; Figures 7 to 9). Including Quality 1 locations increased the home range estimates for the satellite-monitored dugongs to a maximum of 18 km^2 (MAP 0.95) and 5 km^2 (MAP 0.50). Similarly, including the triangulated positions in the home range calculations for D-2 increased the MAP (0.95) to 23 km^2, the MAP (0.50) to 7.0 km^2. Given the inaccuracy of the triangulated positions, these last two values should be regarded only as very approximate. There was considerable overlap between the home ranges of D-1 and D-2 in Cleveland Bay (Figure 9), and between those of D-3 and D-4 on the Murdoch Island Reef flat (Figure 8b). Thirty-eight percent of the MAP (0.50) for D-3 was within the MAP

(0.50) of D-4; the corresponding overlap for their MAP (0.95) home ranges was 43%.

The home ranges of all the dugongs overlapped known seagrass beds (Figures 7 to 9). The seagrasses recorded from these areas include *Halodule uninervis* (all locations), *H. pinifolia* (Cleveland Bay only), *Halophila ovalis* (all locations), *H. ovata* (Cleveland Bay), *H.spinulosa* (all locations), *H. decipiens* (Starcke River region only), *H. tricostata* (Upstart Bay only), *Cymodocea serrulata* (all locations), *Syringodium isoetofilium* (Starcke River region only) and *Zostera capricorni* (Upstart Bay only) (Coles *et al.*, 1987 and unpublished). All these genera are known to be eaten by dugongs (Marsh *et al*, 1982).

When D-1 was resident in Upstart Bay, his distance from shore was inversely related to tidal height. Although the correlation between tidal height and distance from shore was higher at night ($r=-0.505$) than during the day ($r=-0.301$), there was no significant difference between the resultant regression lines, either in slope ($t=0.42$, 130 d.f., $p>0.5$) or intercept ($t=1.45$,130 d.f., $p>0.10$). Similar analyses were not possible for the dugongs tagged in the Starcke River region as reliable information on tidal heights and bathymetry is not available.

Costs of conventional and satellite telemetry of dugongs

The capital costs of both conventional and satellite tracking, the recurrent costs of satellite tracking, and the personnel and vehicle requirements of conventional tracking are summarized in Table 5. The costs of land-tracking are based on simultaneous fixed station triangulation from three stations, a much more accurate technique than the one employed in this study due to personnel and equipment limitations.

Discussion

Evaluation of techniques

A floating, tethered radio transmitter effectively circumvents the problem of radio signals attenuating in salt water and provides an effective method of studying the movements and habitat usage of individual dugongs. Despite the problems we have had in keeping PTT's attached to dugongs for more than two to three months, a similar attachment assembly with a conventional transmitter remained attached to D-2 for 10 months. We are hopeful that a more robust version of the assembly will last for at least nine months, the estimated battery life of a PTT with a duty cycle similar to that of PTT's 5534 to 5536. Mate *et al.*,(1988) state that "manatees are perhaps the most ideally suited marine mammals for satellite tracking because they are relatively inactive and inhabit shallow water allowing a floating transmitter to remain at the surface much of the time." The results of this project demonstrate that this statement should be widened to include dugongs.

These preliminary results suggest that conventional radio transmitters are superior to PTT's if the objective is to relocate dugongs repeatedly in order to obtain behavioral observations. Under these circumstances, it would be necessary to tag dugongs in clear water areas such as Shark Bay in Western Australia or Moreton Bay in Queensland. Our experience suggests that there may be two major hindrances to reliance on this methodology to relocate dugongs in a behavioral study. The transmitters attached to five of the six dugongs studied spent significantly more time at the surface at night, so the radio signal was most reliably received when direct observation was impossible. A further obstacle to direct observation was D-2's learned wariness of power-boats. Both these behaviours have been reported by traditional hunters. They frequently complain that dugongs become very wary of power boats (Marsh, personal observation), and Davis (1985) notes that the Yolngu people of northern Arnhem Land state that dugongs sleep at the sea surface at night.

When the objective is to track movements *per se* the PTT may offer substantial advantages, including increased accuracy and number of locations. Although a PTT assembly for a dugong costs about 14 times as much as one with a conventional transmitter (Table 5), the recurrent costs are much less. Conventional telemetry from land, boats and aircraft requires a receiving sub-system, personnel and transport as detailed in Table 5. The relative cost-effectiveness of the two methods will depend on the location and topography of the study site, the availability of personnel, vehicles, boats, aircraft, and computers, and the number and behaviour of the study animals. However, in the remote areas that characterize most of the dugong's range in northern Australia, a PTT is the only logistically feasible method od tracking them. The incorporation of a short-range VHF transmitter into the PTT housing has the potential to combine some of the advantages of both systems.

Movements and habitat usage

The results of this study have to be interpreted with caution. We have obtained information on the movements of only six dugongs, all male, for periods of from one to 16 months. All were caught in shallow waters close to shore, as this is the only place that it is feasible to catch dugongs by the methods used. Thus it is inappropriate to generalize at this stage. It is also likely that the estimated home ranges are underestimated because the location fixes were biased to periods when the animals were stationary or moving slowly. Also the dugongs were tracked for only a small proportion of the year.

Accepting these limitations, the results indicate that all the radio-tagged dugongs spent most of their time in the vicinity of very localised areas of inshore intertidal and subtidal seagrass beds (Figures 7 to 9). The home ranges of some individuals, including adult males, overlapped (Figures 8 and 9). The pubertal male D-1 showed that dugongs are capable of rapid sustained swimming. One such long range movement coincided with a drop in the sea surface temperature, even though the temperature (>27° C) was still well within the known range of the thermal tolerance of dugongs. In Shark Bay, the southern limit of their range in Western Australia, individuals do not abandon feeding areas until temperatures drop below 19°C (Anderson,1986). It is also possible that the long range movements of D-1 occurred because he was patrolling for oestrous females much like adult male manatees in Florida (Bengston, 1981). D-1's behaviour in Upstart Bay and the motion sensor activity of his PTT (Figure 3) suggest that he was involved in intense social interactions at that time. None of the four adult males in the Starcke River region (where dugong numbers are exceptionally high; Marsh and Saalfeld, in review) undertook long range movements, even though a female dugong killed by Aborigines in this area in January 1984 was in very early pregnancy (Smith, 1987), indicating that mating does occur at the time of year when the dugongs were monitored by the satellite.

The pattern of dugong movements observed in this study is remarkably similar to that revealed for manatees in Florida using similar techniques. Some manatees spend prolonged periods in localised areas; others undertake journeys of the order of 100 km between areas of preferred habitat; seasonal movements occur in response to low water temperatures; and some males cover large ranges as they patrol for oestrus females (Bengston, 1981, Mate *et al.*, , 1988; Rathbun *et al.*, in press). We find this similarity surprising as we assumed that dugongs would be much more mobile than manatees. This assumption, based on their more streamlined shape obviously is incorrect, and requires reassessment.

Implications for management

Despite their limitations, these data support the zonal management policy of the Great Barrier Reef Marine Park Authority which imposes a high level of protection on some inshore seagrass areas that support large numbers of dugongs. The radio-tagged dugongs seemed to spend most of their time in such areas. However, the data indicate that the effectiveness of the protected areas in the Stracke River region would be enhanced if their seaward margins were extended to the 10 fathom (18m) depth contour, if there landward margins were extended to include the intertidal area, and if gill-netting were banned from the tidal reaches of the adjacent rivers and creeks.

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Legend to Figures

Figure 1. Assembly used to attach a radio-transmitter to a dugong. There is a weak link in the nylon wishbone beneath the acetal bushing which is designed to break if the tether becomes tangled. The buckle contains a claw that permits the nylon webbing to be tightened and locked in place.

Figure 2. A dugong being supported at the surface by the inflatable stretcher while being fitted with a PTT. The stretcher is tendered by an inflatable on each side.

Figure 3. Daily fluctuations in the activity of D-1 while he was resident in Upstart Bay between Qctober 12 and November 22 1986. The activity is based on the number of minutes in each 24-hour period that the PTT tipped through >90° at least once. The peaks in activity may represent times when the dugong was involved in intense social behaviour.

Figure 4. The daytime and night-time satellite passes on which location messages were received as a proportion of possible passes plotted separately for each PTT at each location (PTT 5517=17 etc). Possible passes were those for which the satellite(s) was above the horizon for the minimum interval between the first and last messages required to calculate a location (see text for details).

Figure 5. The long distance movements undertaken by D-1 along the North Queensland coast between October 5 and December 7 1986 (see Table 4). ● October 5 - October 12; ■ November 22 - 23; ◆ November 26-29.

Figure 6. Mean daytime and night-time seawater temperatures in

Cleveland and Upstart Bays as measured by PTT 5517 between November 16 and December 6 1986. The dotted lines mark the times when the dugong was travelling between the two bays.

Figure 7. Locations where D-1 was detected in Upstart Bay in relation to the known seagrass beds mapped by Coles *et al* (unpublished). The size of each black circle represents the number of location records per 0.25 km^2 (see scale). The 95% and 50% isopleths of the two portions of D-1's home range in the Bay are also shown. ♦ PTT probably off dugong. ★ PTT found on beach.

Figure 8. The 95% and 50% isopleths of the home ranges of D-3, D-4, D-5, and D-6 in the Starcke River region based on satellite-captured locations in relation to seagrass beds mapped by diving from a boat by Coles *et al* (1985), or from an aircraft by Marsh and Saalfeld (in review). (a) The home range of each dugong in relation to the number of location records of all qualities per 0.25 km^2 (see scale). (b) The spacing of the estimated home ranges of the four dugongs along the coast.

Figure 9. Locations of D-2 in Cleveland Bay detected by conventional telemetry in relation to the known seagrass beds mapped by Coles *et al.* (unpublished) and depth contours (measured in metres). The seagrass beds certainly extend further inshore than this (Marsh personal observation).(a) The 95% and 50% isopleths of the home range of D-2 based on (1) locations obtained when homing from an aircraft or (2) actual sightings when homing from a boat in relation to the satellite tracked positions of D-1. (b) The actual locations on which the home range of D-2 in (a) is based in relation to

the 95% and 50% isopleths of his home range based on locations obtained when triangulating sequentially from the three fixed stations marked by on the map. The three stars close together south-east of Mt Matthew represent three alternative sites used as the third fixed station during the study.

Table 1: Movement and habitat usage of the six male dugongs caught in the inshore waters of the Great Barrier reef lagoon in the summers of 1986/87 and 1987/88 and tracked using conventional and satellite telemetry.

	Dugong Number					
	D-1	D-2	D-3	D-4	D-5	D-6
Body length (m)	2.30	1.83	2.52	2.53	2.73	2.42
Reproductive status	pubertal	immature	mature	mature	mature	mature
Date of initial capture	5 Oct. 86	12 Oct. 86	23 Nov. 87	24 Nov. 87	26 Nov. 87	27 Nov. 87
Location of capture	<Cleveland Bay 19.25°S 146.80°E>		< Starcke River area 14.50°S 144.80°E >			
Transmitter	PTT 5517	VHF	PTT 5534	PTT 5535	PTT 5536	PTT 5517
Tagged period (days)	63	483	47	94	64	32
Number of locations:						
guaranteed[1]	142	23	56	104	35	67
non-guaranteed[2]		45	32	66	52	25
Home range (km^2):						
MAP(0.95)[3] guaranteed locations only	8.0[4]	6.6	4.3	7.8	8.0	11.4
guaranteed & non-guaranteed locations		23.1[5]	5.2	11.8	10.3	18.0
MAP(0.50)[3] guaranteed locations only	1.9[4]	2.2	1.1	1.7	2.5	2.9
guaranteed & non-guaranteed locations		7.0[5]	1.3	1.8	5.0	3.3
Maximum distance from capture site (km):						
guaranteed locations only	183[6]	3	4	7	10	22
guaranteed & non-guaranteed locations		6	5	7	10	22
Maximum distance from coast (km):						
guaranteed locations only	5	3	4	4	3	3
guaranteed & non-guaranteed locations		6	4	5	4	7
Maximum distance from islands (km):						
guaranteed locations only			2	2	2	
guaranteed & non-guaranteed locations			1	4	2	2

[1] PTT location quality 2 or 3 (see text); actual sighting VHF.

[2] PTT location quality 1 (see text); triangulated location VHF error triangle <$2km^2$.

[3] D. J. Anderson (1982).

[4] Home range calculated for Upstart Bay only.

[5] approximate only due to errors associated with locations.

[6] assuming that dugong travelled along the coast.

Table 2: Summary of information received from the various PTT's. Data for the days immediately after each transmitter was deployed or before it detached were excluded from the analyses. The data for PTT 5517 in 1986 was for Upstart Bay only.

Transmitter	No. of locations per day				No. of non-location messages per day				Temperature (°C)		
	Mean	s.e.	Mode	Range	Mean	s.e.	Mode	Range	Mean	s.e.	Range
5517/86	2.8	0.163	3	0-5	2.6	0.218	2	0-6	29.15	0.069	27.30-33.42
5517/87	2.5	0.359	0,4	0-6	2.3	0.256	1,2	0-5	30.93	0.095	28.97-35.00
5534	3.9	0.472	5	1-7	2.5	0.338	2	0-6	28.47	0.122	24.52-32.81
5535	3.6	0.231	3,4	0-7	2.5	0.201	2,3,4	0-5	28.83	0.079	23.24-37.46
5536	2.7	0.290	2	0-6	2.7	0.365	2	0-8	28.46	0.085	22.93-31.64

Table 3: Diving and surfacing times for D-2.

Date	Dive times (min)				Surfacing times (sec)			
	N	X	S.D.	Range	N	X	S.D.	Range
12 Dec	49	1.49	0.67	0.36-3.08				
8 Jan	77	1.37	0.48	0.17-3.18	68	2.66	0.65	0.90-3.70
12 Feb	74	1.21	0.58	0.11-2.30	64	2.57	0.84	0.50-3.75
Overall	200	1.34	0.34	0.11-3.18	132	2.62	0.56	0.50-3.75

Table 4: Details of the journeys of D-1 between Cleveland and Upstart bays in 1986.

Location	Date of first/last location	Time	Maximum transit time (hr)	Apparent speed km/hr coastal	direct
Cleveland Bay	5 Oct	1100			
to					
Bowling Green Bay	8 Oct	1909	79	1.2	
to					
Upstart Bay	11 Oct	0401	81	1.1	0.9
Upstart Bay	22 Nov	0329			
to					
Bowling Green Bay	23 Nov	0313	24	3.6	
to					
Cleveland Bay	24 Nov	0629	27	3.6	2.8
Cleveland Bay	26 Nov	0721			
to					
Bowling Green Bay	28 Nov	0217	43	2.3	
to					
Upstart Bay	29 Nov	1844	40.5	2.1	1.7

Distances: Cleveland Bay to Cape Bowling Green (coastal) 96km

Cape Bowling Green to Upstart Bay (coastal) 87km

Cleveland Bay to Upstart Bay (direct) 143km

Table 5: Equipment and personnel required to track dugongs using conventional and satellite telemetry. Telemetry prices are in $A and assume the use of Telonics equipment and a conversion rate of US 80 cents to the A$.

CONVENTIONAL TELEMETRY	COST
Capital equipment	
(1) **Basic equipment**	
Transmitter 150-152 MHz	315
Housing	94
Peduncle belt	250
Basic receiving subsystem: 2 receivers, 2 yagi antennae 2 headphones, cables.	4500
(2) **Additional equipment for aircraft tracking**	
Aircraft antenna mounting brackets, 2 H antennae, antenna control unit	650
(3) **Additional equipment for land tracking using three stations**[1]	
1 receiver, 1 headphones, 3 twin Yagi precision antennae, cables	3800

Recurrent costs

(1) Boat tracking

Personnel	2 researchers
Transport	Boat e.g. 4.3 aluminum dinghy with 40 HP outboard

Table 5: continued

(2) Aircraft tracking		
Personnel	1 researcher, 1 pilot	
Transport	1 light aircraft e.g. Cessna 182	
(3) Land tracking using three stations		
Personnel	3 researchers	
Transport	Up to 3 vehicles	
SATELLITE TELEMETRY		
<u>Capital costs</u>		
PTT		4375
Housing		94
Peduncle belt		250
<u>Recurrent costs</u>		
Service Argos processing charges per PTT per day		16
Service Argos administrative charges per fortnight		$\geq$ 38
International computer charges per access		~2
Additional equipment	Access to a personal computer	

[1] If the land bordering the study site is flat, it would be necessary to erect towers on which to mount the antennae for the tracking stations to achieve an adequate working range.

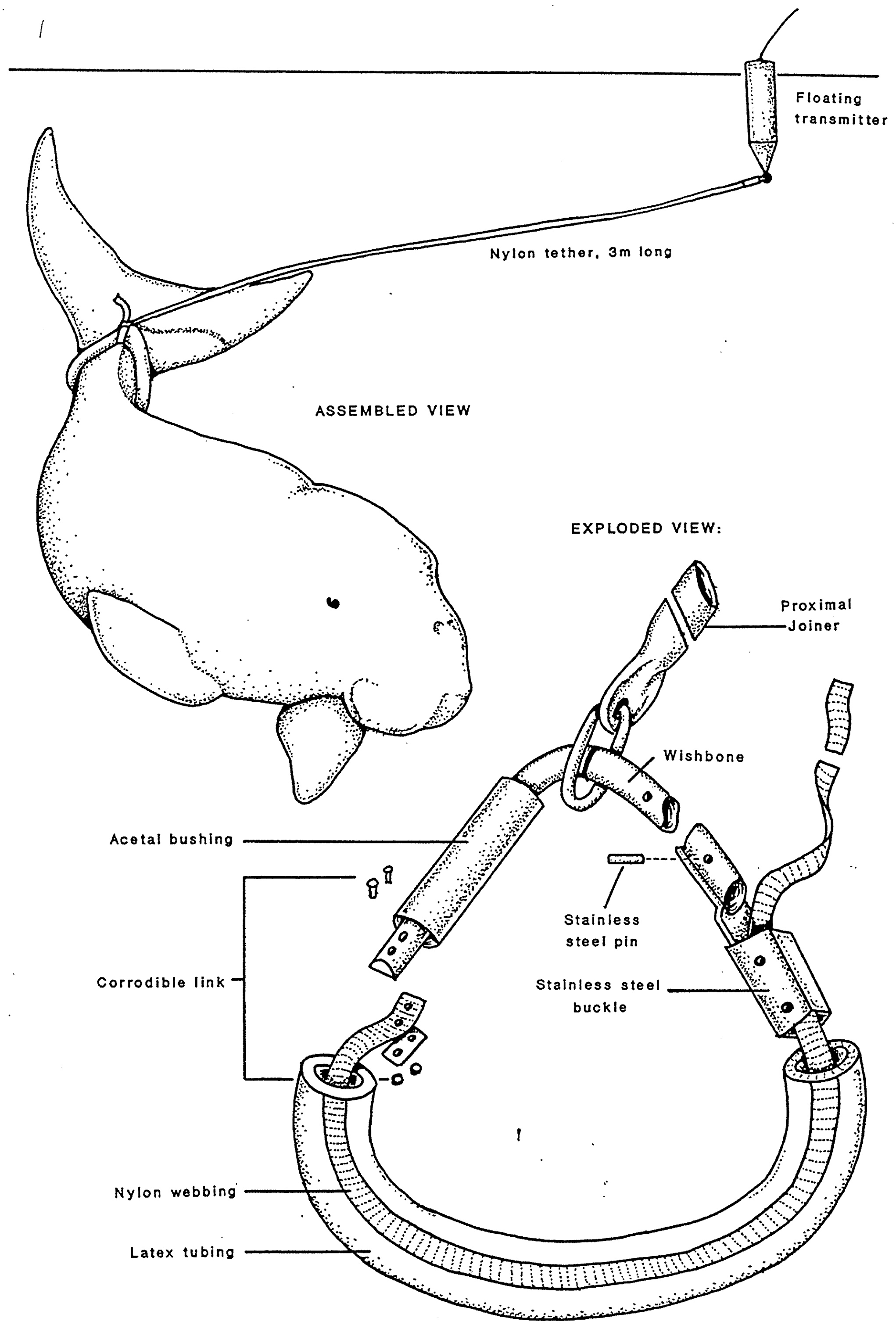


Figure 1. Assembly used to attach a radio-transmitter to a dugong. There is a weak link in the nylon wishbone beneath the acetal bushing which is designed to break if the tether becomes tangled. The buckle contains a claw that permits the nylon webbing to be tightened and locked in place.

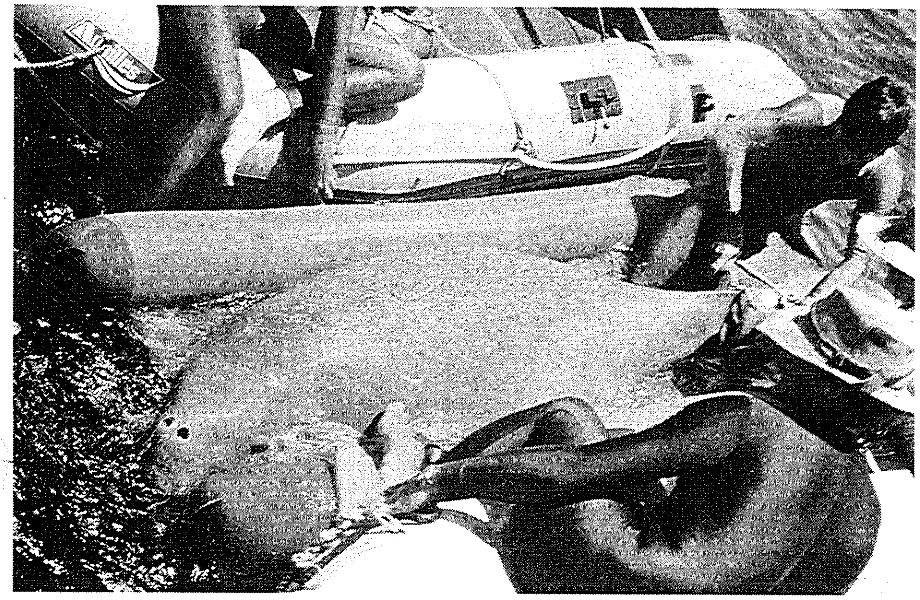


Figure 2. A dugong being supported at the surface by the inflatable stretcher while being fitted with a PTT. The stretcher is tendered by an inflatable on each side.

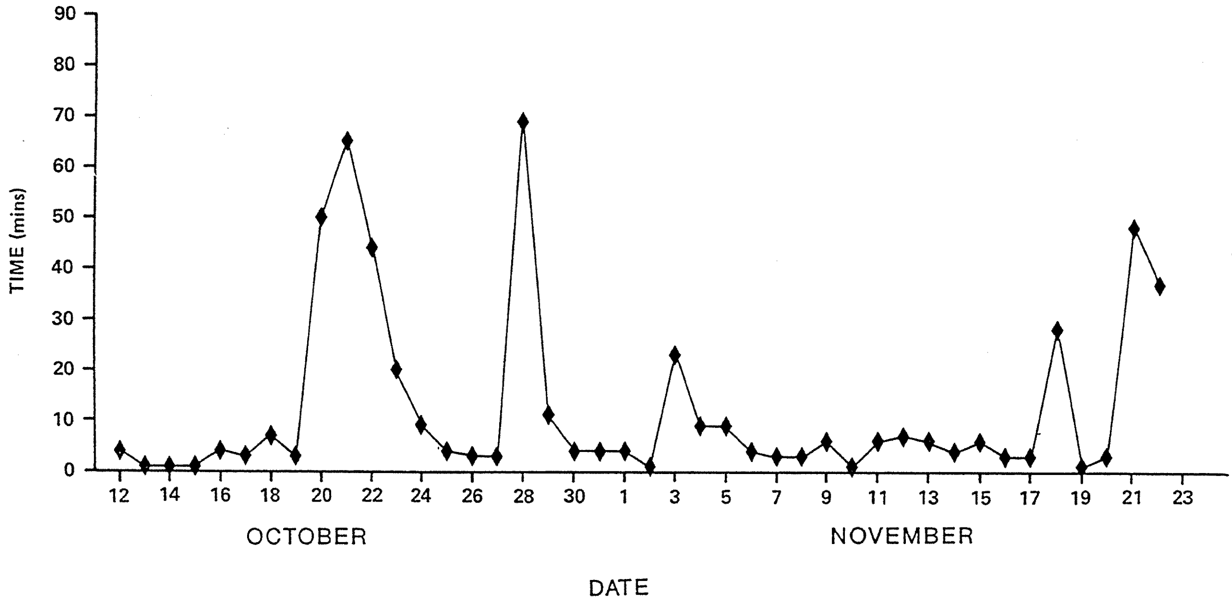


Figure 3. Daily fluctuations in the activity of D-1 while he was resident in Upstart Bay between October 12 and November 22 1986. The activity is based on the number of minutes in each 24-hour period that the PTT tipped through >90° at least once. The peaks in activity may represent times when the dugong was involved in intense social behaviour.

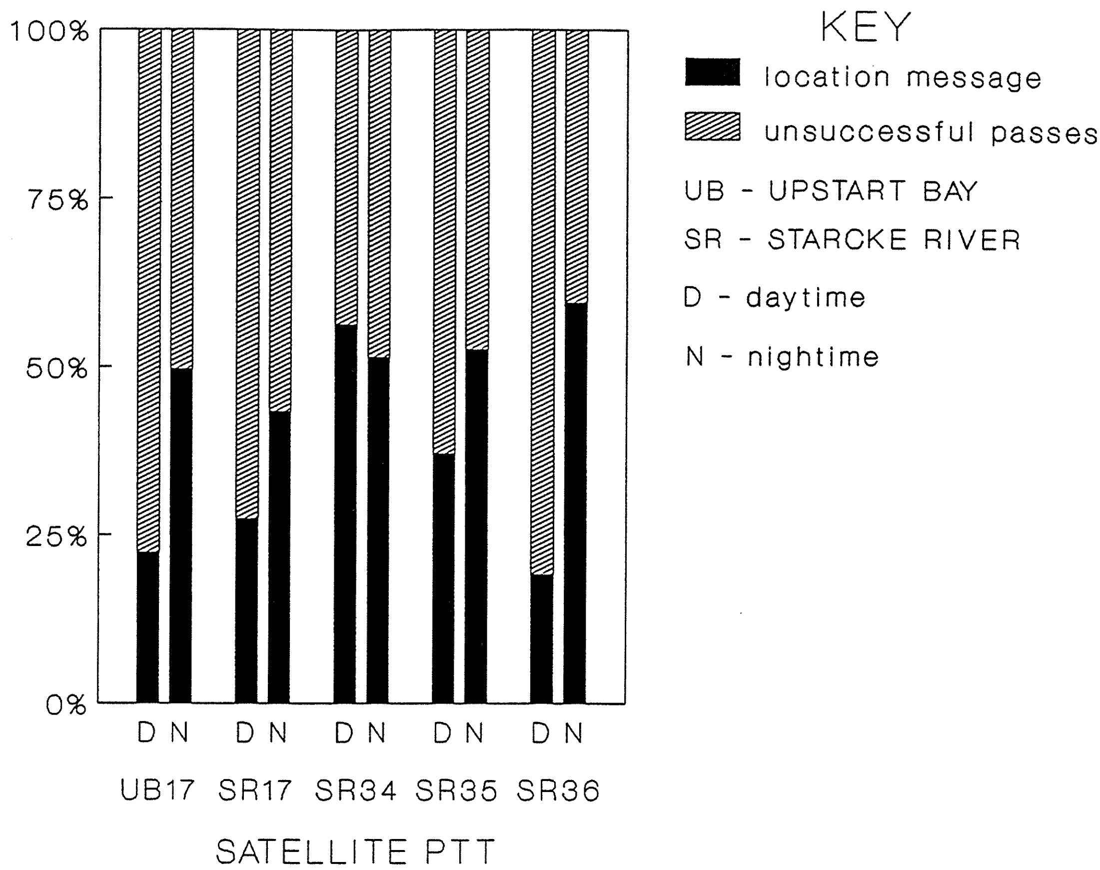


Figure 4. The daytime and night-time satellite passes on which location messages were received as a proportion of possible passes plotted separately for each PTT at each location (PTT 5517=17 etc). Possible passes were those for which the satellite(s) was above the horizon for the minimum interval between the first and last messages required to calculate a location (see text for details).

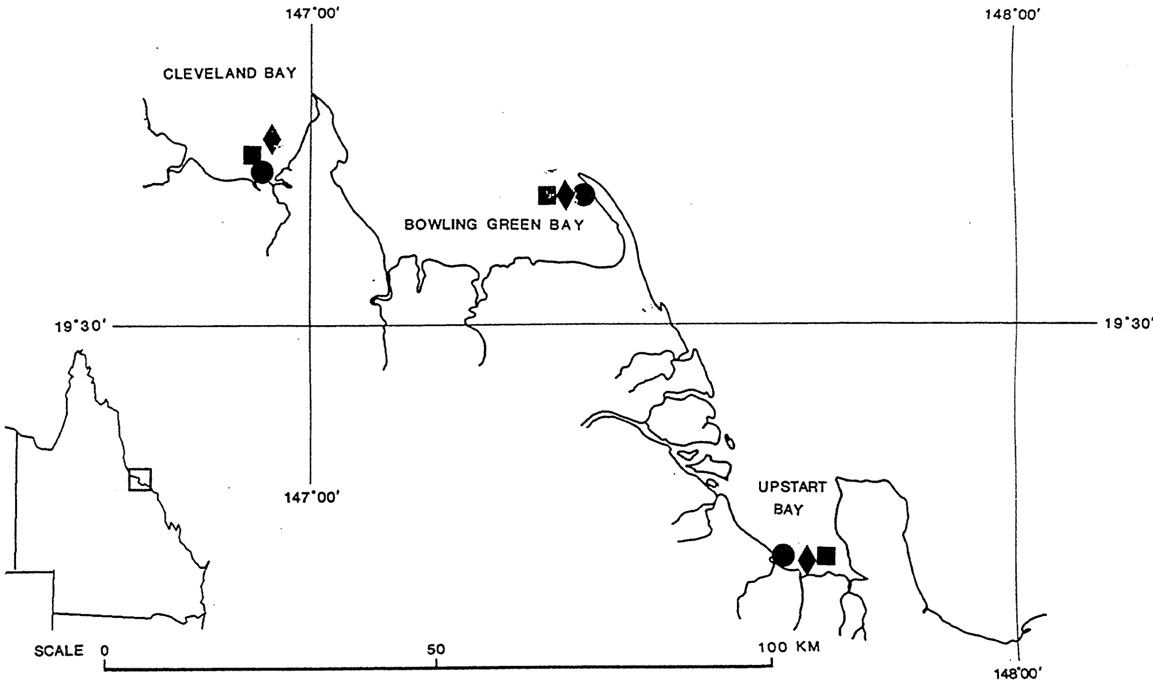


Figure 5. The long distance movements undertaken by D-1 along the north Queensland coast between October 5 and December 7 1986 (see Table 4). ● October 5 - October 12; ■ November 22 - 23; ♦ November 26-29.

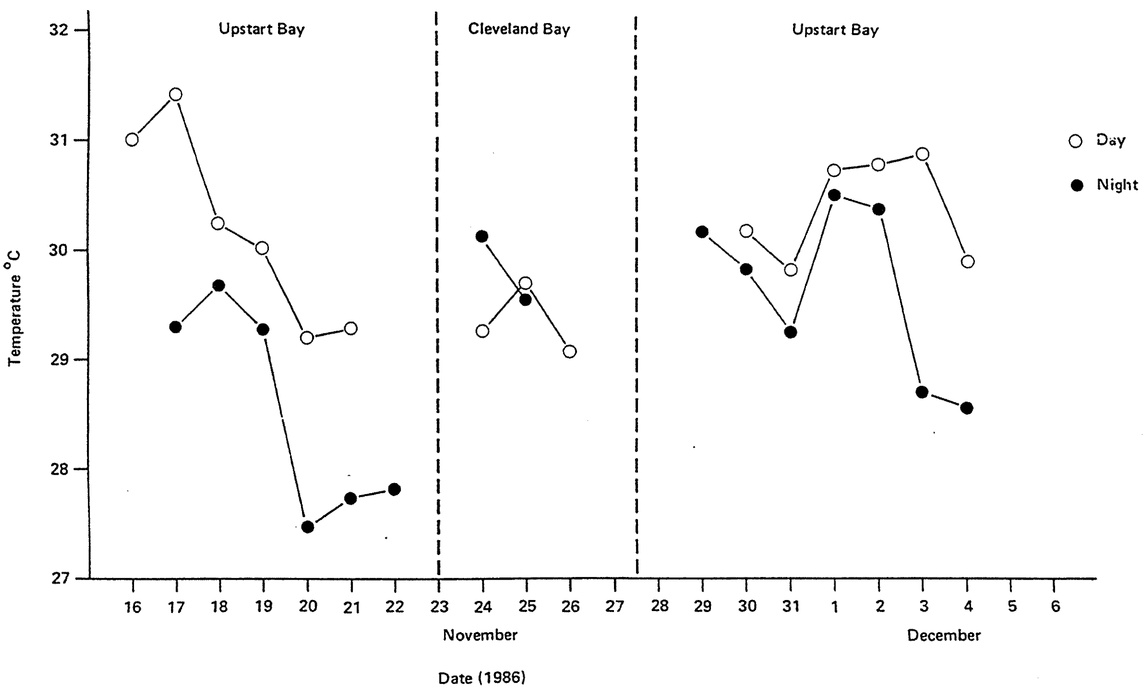


Figure 6. Mean daytime and night-time seawater temperatures in Cleveland and Upstart Bays as measured by PTT 5517 between November 16 and December 6 1986. The dotted lines mark the times when the dugong was travelling between the two bays.

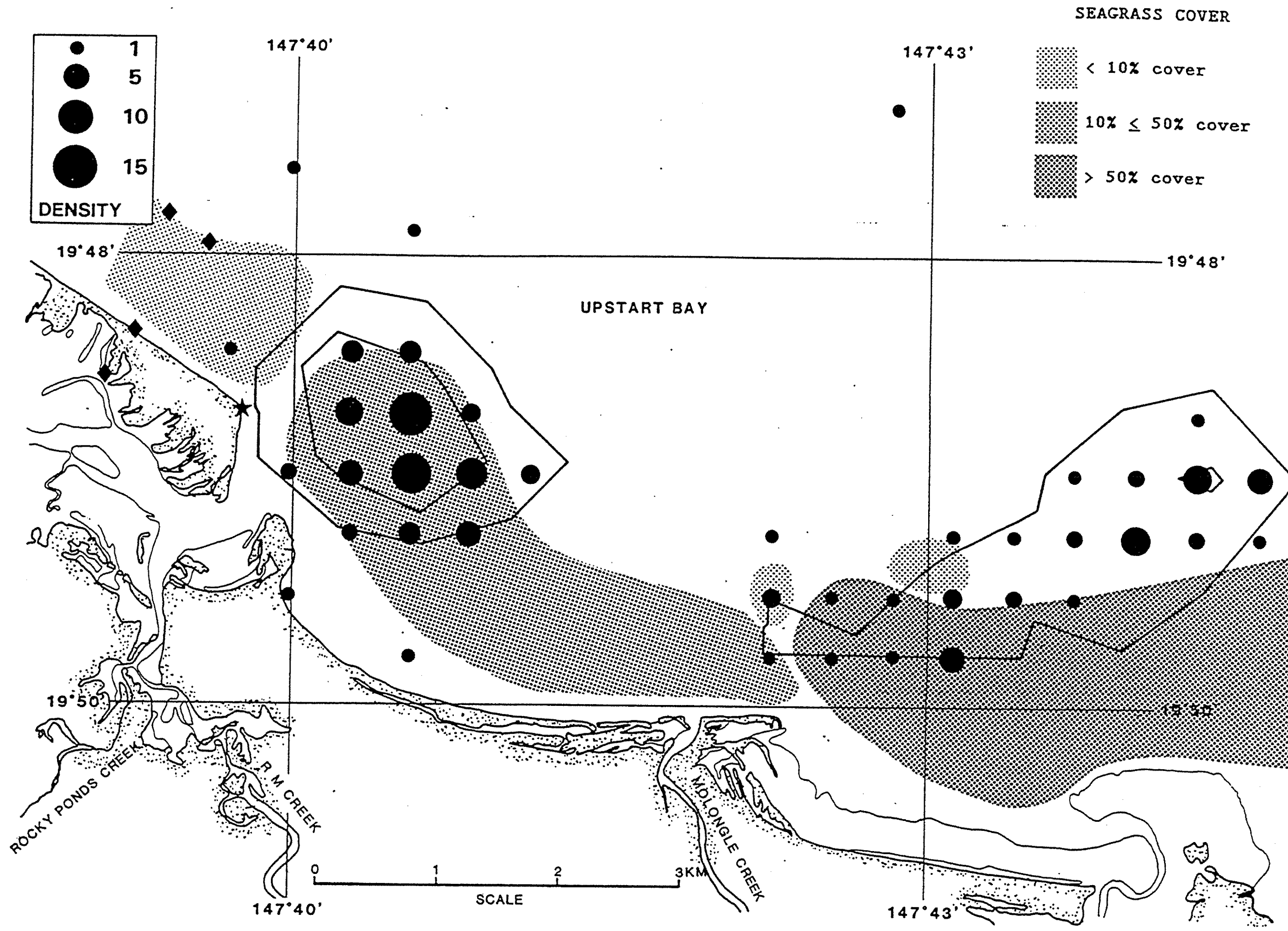


Figure 7. Locations where D-1 was detected in Upstart Bay in relation to the known seagrass beds mapped by Coles *et al* (unpublished). The size of each black circle represents the number of location records per 0.25 km^2 (see scale). The 95% and 50% isopleths of the two portions of D-1's home range in the Bay are also shown. PTT probably off dugong. PTT found on beach.

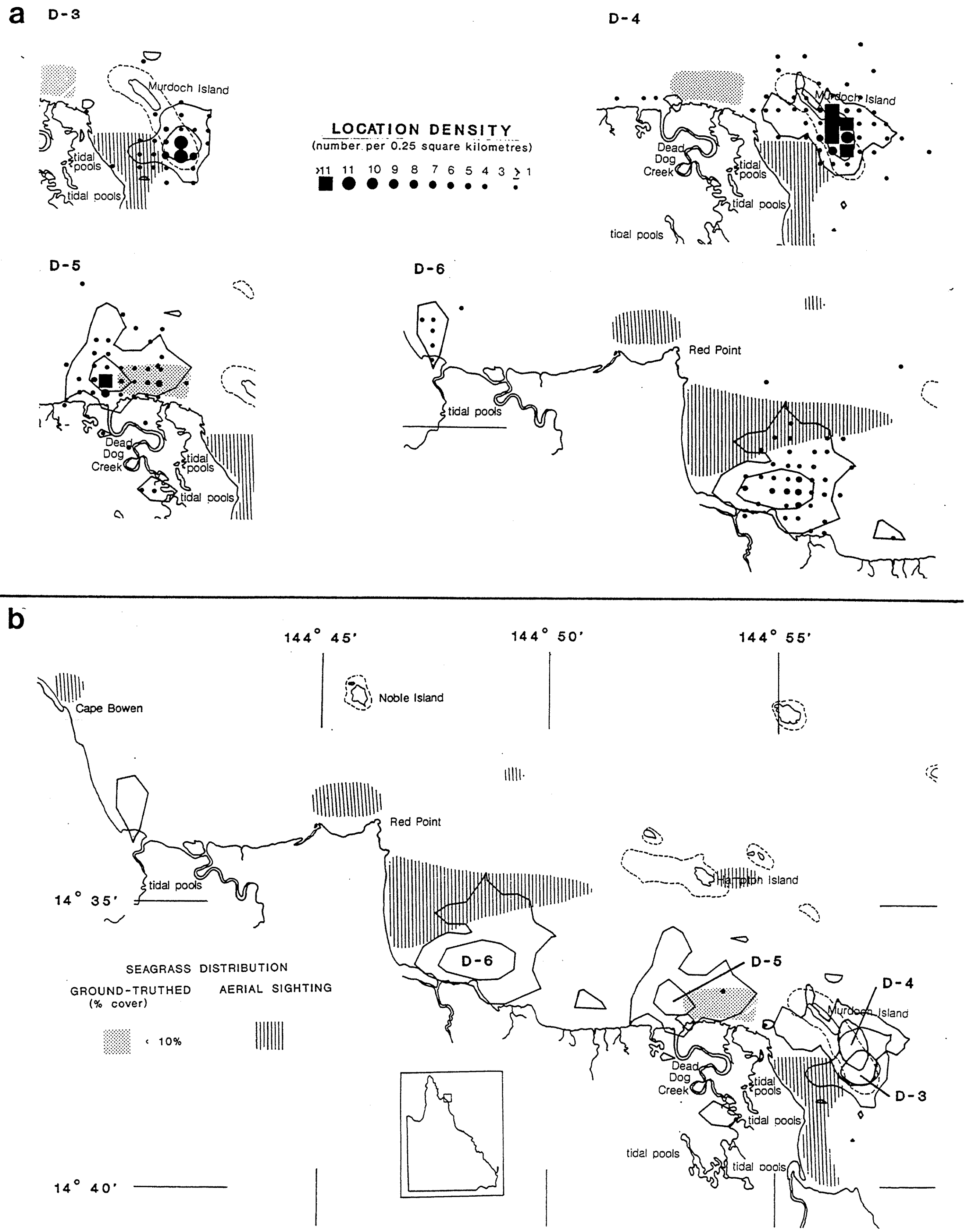
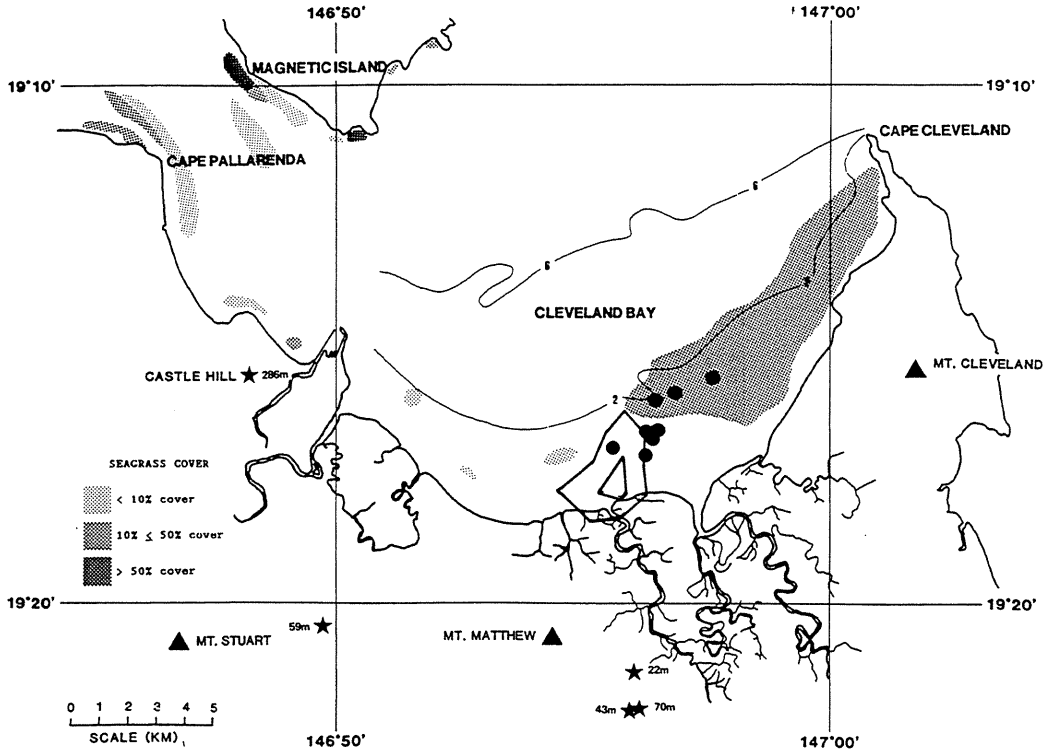


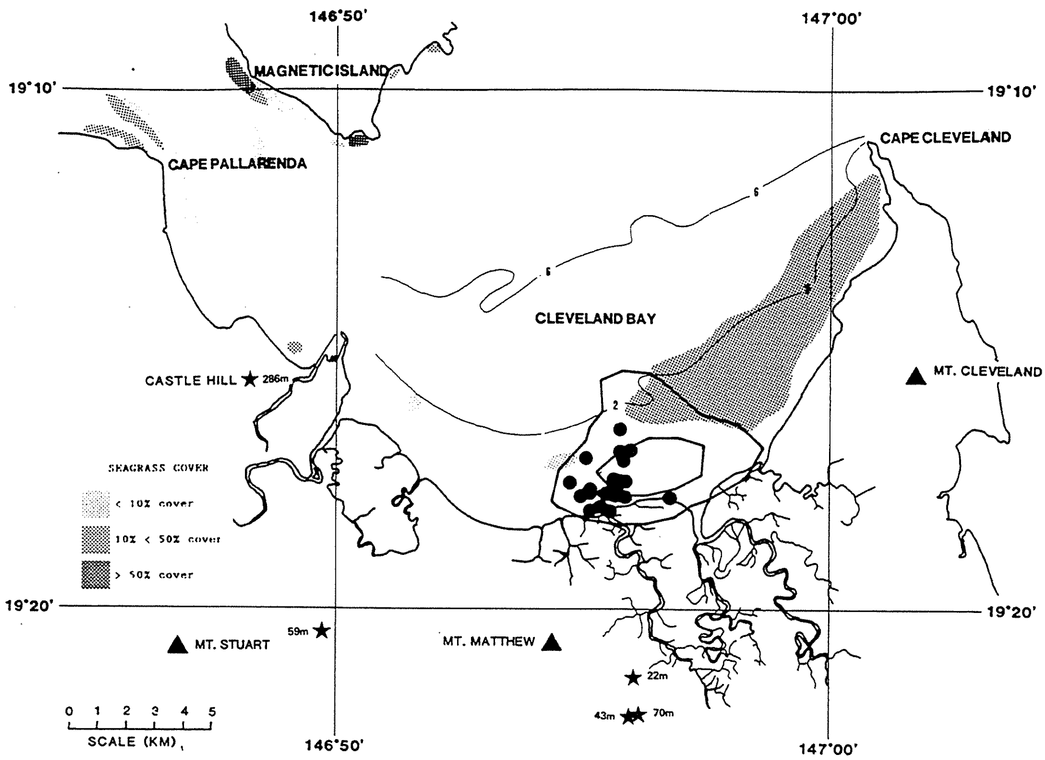
Figure 8. The 95% and 50% isopleths of the home ranges of D-3, D-4, D-5, and D-6 in the Starcke River region based on satellite-captured locations in relation to seagrass beds mapped by diving from a boat by Coles *et al* (1985), or from an aircraft by Marsh and Saalfeld (in review). (a) The home range of each dugong in relation to the number of location records of all qualities per 0.25 km^2 (see scale). (b) The spacing of the estimated home ranges of the four dugongs along the coast.

Figure 9. Locations of D-2 in Cleveland Bay detected by conventional telemetry in relation to the known seagrass beds mapped by Coles *et al.* (unpublished). The seagrass beds certainly extend further inshore than this (Marsh personal observation).(a) The 95% and 50% isopleths of the home range of D-2 based on (1) locations obtained when homing from an aircraft or (2) actual sightings when homing from a boat in relation to the satellite tracked positions of D-1. (b) The actual locations on which the home range of D-2 in (a) is based in relation to the 95% and 50% isopleths of his home range based on locations obtained when triangulating sequentially from the three fixed stations marked by on the map. The three stars close together south-east of Mt Matthew represent three alternative sites used as the third fixed station during the study.

a


146°50'
147°00'
MAGNETIC ISLAND
19°10'
19°10'
CAPE CLEVELAND
CAPE PALLARENDA
CLEVELAND BAY
CASTLE HILL
286m
MT. CLEVELAND
SEAGRASS COVER
< 10% cover
10% ≤ 50% cover
> 50% cover
19°20'
19°20'
MT. STUART
59m
MT. MATTHEW
22m
43m
70m
0 1 2 3 4 5
SCALE (KM)
146°50'
147°00'

b


146°50'
147°00'
MAGNETIC ISLAND
19°10'
19°10'
CAPE CLEVELAND
CAPE PALLARENDA
CLEVELAND BAY
CASTLE HILL
286m
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SEAGRASS COVER
< 10% cover
10% < 50% cover
> 50% cover
19°20'
19°20'
MT. STUART
59m
MT. MATTHEW
22m
43m
70m
0 1 2 3 4 5
SCALE (KM)
146°50'
147°00'

MANAGEMENT OF THE TRADITIONAL HUNTING OF DUGONGS (*Dugong dugon* (Müller, 1776)) IN THE NORTHERN GREAT BARRIER REEF, AUSTRALIA

Running Head: MANAGEMENT OF TRADITIONAL DUGONG HUNTING

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ABSTRACT

Some of the largest concentrations of dugongs (*Dugong dugon*) occur in the coastal waters of eastern Cape York Peninsula, Queensland. Designation of the Great Barrier Reef Marine Park has prompted the development of a program for management of dugong hunting by the Aboriginal communities of the region. Assessment of the population by aerial surveys combined with monitoring of the Aboriginal hunters' harvest suggests that the take is well below the sustainable yield. However, the reproductive rate of dugongs is so low that it will be a decade before the status of the population can be established. Therefore, a conservative management policy for dugongs is recommended while acknowledging the rights of traditional hunters. Greater participation of the Aboriginal communities in the management program is sought to overcome initial misunderstandings and hostility.

Key words: traditional dugong harvest, Australia

INTRODUCTION

The largest known populations of dugongs or sea-cows (*Dugong dugon* (Müller, 1776)) occur in northern Australia (Nishiwaki and Marsh, 1985). The seagrass beds of the east coast of Cape York Peninsula (Figure 1) have been identified as a major region for dugongs, especially the Starcke River area (Nishiwaki and Marsh, 1985).

Although dugongs are listed as vulnerable to extinction in the IUCN Red Data Book (Thornback and Jenkins, 1982), they are still important in the diet and play an important role in the culture of coastal Aborigines in many parts of northern Australia (see Chase, 1981). Dugongs are long-lived animals with a very low reproductive rate (Marsh and others, 1984c); factors that reinforce their vulnerable status.

The region considered in this paper is from Cape Bedford to Hunter Point (Figure 1) on eastern Cape York Peninsula, Queensland, Australia. This region is now included within the Cairns and Far Northern sections of the Great Barrier Reef Marine Park (GBRMP). The Torres Strait region of the Great Barrier Reef to the north (Figure 1) has a different set of dugong management problems (see Marsh, 1986a) and will not be discussed here.

Two Aboriginal communities are located adjacent to the study area (Figure 1). Aborigines from both of these communities have traditionally hunted dugongs. Hopevale, with a population of about 670, is situated approximately 50km north of Cooktown, and 26km by road from the coast. Hopevale residents have beach camps on the coast just north and south of Cape Bedford. The Lockhart River community, with a population of about 350, is situated inside Lloyd Bay, approximately 2km from the beach.

Aboriginal hunting is not the only factor affecting dugong population levels in this region. There is anecdotal evidence that dugongs drown in gill-nets. Although the number killed is unknown, this mortality is of great concern to Aborigines living in this area. However, there are currently only about 30 commercial fishermen operating in the area north of Cooktown (Figure 1), and gill-netting is banned under Queensland law from November through January to protect fish stocks. In addition, under the GBRMP Zoning Plans (GBRMPA, 1983, 1985) gill-netting has been banned from many important dugong habitats along this coast including much of the important Starcke River area. Habitat destruction in this region is minimal. Prawn (shrimp) trawlers are currently prohibited from operating in the coastal seagrass beds inhabited by dugongs (GBRMPA, 1983, 1985).

This paper considers the current level of Aboriginal dugong hunting on the east coast of Cape York Peninsula in relation to recent dugong population estimates. The recent and present management systems for dugong hunting are also discussed.

LEGISLATION

The legal problems associated with Aboriginal marine hunting and the related legislation were reviewed by the Australian Law Reform Commission (1986:163-195). The situation is complicated as the Commonwealth (Federal) and State Governments share the constitutional authority over fisheries in Australian waters and in the management of the Great Barrier Reef Marine Park.

The Great Barrier Reef Marine Park Act (1975) does not refer to traditional hunting and fishing interests or suggest that certain areas should be set aside for traditional use. However, the regulations incorporated in Zoning Plans for the various

Sections of the Park make provision for traditional hunting in all parts of the Park, except Preservation Zones, subject to a permit being granted.

Queensland legislation applies to waters above low water and those inshore waters excluded from the GBRMP. The State Government's Community Services (Aborigines) Act (1984) exempts members of an Aboriginal community residing on Trust Areas (formerly Reserves) from fisheries legislation provided the take is by traditional means for consumption by members of the community; a similar provision is contained in the Queensland Fisheries Act (1976).

The interrelationship of the Commonwealth and State Acts is complicated in the inshore (Queensland) waters of the GBRMP where most dugong hunting occurs. For example, an Aborigine could theoretically be given a permit to hunt dugongs within a specified Zone within the GBRMP, but be prevented from doing so in the Queensland waters within that Zone because he was not a resident of a Trust Area (Australian Law Reform Commission, 1986).

THE ESTABLISHMENT OF THE GREAT BARRIER REEF MARINE PARK: CAUSES FOR CONCERN

As part of the GBRMP zoning process, the GBRMPA invites the public to participate in the preparation of the draft zoning plans, and to comment on the draft plan when it was developed. Submissions received for the zoning of the Cairns Section of the Park (Figure 1) expressed concern over the possible overexploitation of dugongs in the Hopevale region for the following reasons.

(a) There was a paucity of the necessary biological and ecological information on dugongs: there was no indication of whether the population(s) of dugongs in the region was increasing, decreasing or stable (Marsh and Heinsohn, 1982); how many populations were involved; detailed movement patterns; or what might be a safe level of exploitation.

(b) The Starcke River region (Figure 1) was known to be one of the most significant dugong areas in the world and there was concern for their conservation in this area (Marsh and Heinsohn, 1982).

(c) The ability of Hopevale residents to purchase larger speedboats and four-wheel-drive vehicles had increased during the preceding five or so years, permitting easier access to the Starcke River region.

(d) The improved road access facilitated hunting during the dry season.

(e) There were verbal reports that the annual take of dugongs by the community had increased in recent years.

(f) There was a lack of knowledge among community members of the dugong's life history and vulnerable status. In addition, they believed that as large numbers of dugongs had been killed for oil between 1928 and 1932 (the period of the dugong oil industry operated by the Aboriginal Mission), this impact could be repeated without serious effect. Before and after the oil industry period there was an extremely low level of hunting, which would have permitted the dugong population in the area to recover.

GBRMPA ACTIONS PRIOR TO THE IMPLEMENTATION OF THE ZONING PLAN

Zoning requirements: The information contained in the submissions stimulated the Marine Park Authority's concern about the status of the dugong within the Park for two reasons. Firstly, the GBRMP Act (1975) gives the Authority specific responsibility for endangered species and secondly, the large numbers of dugongs in the Park were listed as a reason for the region being given World Heritage Listing.

In allowing traditional fishing and hunting within a designated zone in the Cairns Section (Figure 1) of the GBRMP (GBRMPA, 1983), the Authority is required to give particular regard to:

(a) the need for conservation of endangered species;

(b) the means to be employed in traditional fishing or hunting;

(c) the number of animals to be taken.

In addition, in permitting traditional hunting in the Far Northern Section (GBRMPA, 1985; Figure 1), the Authority has to consider:

(d) the particular purpose;

(e) whether the entry and use of the area will be in accordance with Aboriginal tradition;

(f) evidence that the person is a traditional inhabitant;

(g) the normal place of residence of the person.

In developing a management strategy, the Authority needed to assess its likely impact on (a) dugong numbers; (b) the relationship between the management agencies and the community; and (c) the socio-political situation within the community. They also required information on the Aboriginal perception of dugongs, and the potential for over-harvesting through Aboriginal hunting.

Management decisions: Staff of the GBRMPA met with the Hopevale Aboriginal Council on a number of occasions between December 1982 and November 1983 when the Zoning Plan for the

Cairns Section of the Park with its requirements for permits for traditional hunting became operational. Despite a level of consultation over and above the general statutory requirements, there were a number of aspects relating to communicating with Aborigines/Aboriginal groups which militated against a successful permit system being negotiated. Some of these problems were: the general lack of communication between the Aboriginal Council and the community; the inherent problems of public meetings in Aboriginal communities; a lack of understanding of the community dynamics; and the general 'acceptance' by Aborigines of authorities regulating their lives. All these factors meant that most of the Aboriginal hunters were reluctant to voice their concerns. This resulted in most of the negotiations being conducted between GBRMPA staff and members of the Hopevale Community Council who were not all conversant with or representative of the hunters' viewpoint.

The dugong permit system which evolved from the meetings was implemented in December 1983. As a result, 20 individual permits were issued on a single day prior to a four-week open season in January. The permit conditions were: one dugong per hunter (i.e. a quota of 20 for the community for the season); no female dugongs with attendant calves to be taken; no firearms to be used; catch data sheets to be completed and returned; the permits to be available for inspection within the Park; the permits to be valid north of the Endeavour River (Figure 1) only. The permits were allocated on a 'first come, first served' basis.

Research: Concomitant with the introduction of the dugong permit system, two research projects supported by the GBRMPA were begun. Marsh conducted a series of aerial surveys to estimate the dugong population of the Cape Bedford to Hunter Point region and to form the basis for monitoring future trends in numbers. Smith recorded the numbers of dugongs killed by Aborigines at Hopevale and Lockhart River communities as part of a study of the usage of the marine environment by members of those communities.

REACTION TO THE PERMIT SYSTEM

The introduction of the dugong hunting permit system at Hopevale caused several problems as detailed by Marsh and others (1984d). The major problems area outlined below.

(a) There was widespread apprehension, confusion and misconception in the community regarding the existence, function and regulation of the GBRMP.

(b) The Hopevale people felt victimised as GBRMP regulations on dugong hunting were applied to them but not to other east coast Aboriginal communities such as Lockhart River (where the relevant Zoning Plan had not yet been implemented) or Yarrabah (near Cairns $16^{0}55'$S; $145^{0}46'$E; where Aborigines hunt outside the boundaries of the GBRMP).

(c) There was confusion and discontent among Hopevale residents about the dugong hunting permit system and its operation; they regarded it as an infringement of their traditional hunting rights.

(d) There was dissatisfaction with the number of dugongs allowed per permit and the permit allocation arrangements. Some non-hunters received permits while known hunters missed out.

(e) There was general dissatisfaction with the manner in which the management officers dealt with people.

The dugong permit system at Hopevale produced a negative community attitude towards the management agencies. The relatively sudden and selective (as perceived by the Hopevale community) imposition of the restrictive dugong permit system resulted in an 'us and them', rather than a cooperative situation developing. The dugong permit system also exacerbated existing socio-political tensions within the community, especially as some members considered the 'right' to obtain a dugong permit more important than the actual 'need' for a permit.

Minor alterations were made in the method of distributing the permits for the 1985 and 1986 hunting seasons. This helped reduce some of the ill-feeling, but the general discontent remained. Although these management developments raised the awareness of Hopevale residents to the Government's concern for the management and conservation of dugongs, they also resulted in a disproportionate amount of attention being focussed on dugong hunting, so that the quota became a target.

The zoning plan for the Far Northern Section was not implemented until early 1986. As a result of the problems encountered with the dugong hunting permits at Hopevale, GBRMPA decided during the preparation of the draft zoning plan to delay applying restrictions on dugong hunting at Lockhart River until more biological information and catch data were obtained.

ESTIMATING THE SIZE OF THE DUGONG POPULATION

Aerial survey techniques: The dugong census was carried out with an overall sampling intensity of 9% over a total area of 31,288 km^2. The coastal zone between Cape Bedford (15°15'S; 145°21'E), Cape Melville (14°10'S; 144°30'E) and the outer Barrier Reef was surveyed in November 1984, and again in November 1985. The corresponding area between Campbell Point (13°32'S; 143°35'E) and Hunter Point (11°30'S; 142°50'E) was surveyed in April 1985, and again in November 1985. The intervening Princess Charlotte Bay area was surveyed once in October/November 1985. The survey design, counting procedure and analysis are detailed in Marsh and Saalfeld (in press) and Marsh and Sinclair (1989). Sightings were corrected for perception bias (the proportion of animals visible in the transect which were missed by observers), and standardized for availability bias (the proportion of animals that were invisible due to water turbidity) using survey-specific correction factors. The errors inherent in estimating the correction factors were included in the variance of the population estimate.

Aerial survey results: The results of the aerial surveys are detailed in Marsh and Saalfeld (in press). There were no significant differences between population and density estimates obtained from repeat surveys of the same areas despite variations in the survey conditions. This suggested that the attempts to standardize the biases had been successful. The resultant population estimate was 8110 $\pm$ 1073 (S.E.) dugongs for the whole region in November 1985 at an overall density of 0.26 $\pm$ 0.04 (S.E.) dugongs per km^2, a precision of 13%. Most dugongs were associated with inshore seagrass beds. Comparison of the data from the two surveys of the Starcke River region indicated that dugongs were dispersed quite differently for each survey. There were almost twice as many dugongs in the hunting grounds of the Hopevale Aborigines in November 1985 than in the same month in 1984.

ABORIGINAL DUGONG HUNTING

Methods: Field work was carried out at Hopevale and Lockhart River Aboriginal communities. Four periods of field work were undertaken by Smith: January to March 1984 (Hopevale); May 1984 to

March 1985 (Hopevale); September to December 1985 (Lockhart River); and January to February 1986 (Hopevale). A total of 16 months were spent at Hopevale, and three months at Lockhart River.

Whenever possible, data and specimen material were obtained from dugongs caught, in order to determine their size, age, reproductive status and diet as described in Marsh (1980), Marsh and others (1984a) and Marsh and others (1984b). The reproductive specimens were analyzed using the techniques detailed in Marsh and others (1984a and b). For age determination, one tusk from each animal was prepared and analyzed as per Marsh (1980). Information was obtained on Aboriginal knowledge of dugongs and dugong hunting through both formal and informal interviews with recognised dugong hunters, and by participant observation.

Aboriginal dugong hunting equipment and techniques: The dugong hunting equipment and techniques are similar to those described for Mornington Island in the Gulf of Carpentaria (16°36'S; 139°21'E) in Marsh and others (1980-81). All dugong hunting occurs from 4m to 5m aluminum or fiberglass dinghies, powered by 9.9hp to 60hp (usually 25hp to 40hp) outboard motors. Harpoons with detachable heads are used for taking dugongs. Another method of capture, 'lassoing', although not common, is gaining popularity amongst the younger hunters at Lockhart River. The dugong is chased and tired out, then one person jumps overboard and places a lasso over the dugong's head. The rope is then pulled tight by another person on the boat. Dugongs are butchered immediately after they are taken ashore.

The question of which methods or technologies are to be regarded as 'traditional' is, for most purposes, a subordinate one. The Australian Law Reform Commission (1986) believes that in determining whether an activity is 'traditional', attention should focus on the purpose of the activity rather than the method. The actual methods of capture are usually part of a highly complex system of knowledge, beliefs and attitudes, and hence the adaptation of modern technologies does not necessarily mean the system has lost its impetus, nor that a resource will automatically be exploited at a level greater then occurred before European influence (Chase, 1981).

Significance and uses: Dugongs are currently caught for the meat they provide, and secondarily for the oil which is extracted by boiling the parts of the dugong not used for food, such as the head. Dugong oil is used as a panacea for almost any ache, pain or illness. In addition to its commodity value, dugong hunting also has a cultural significance which we believe it is impossible for a person who is not an Aborigine to appreciate. Some community members have told us that they consider dugong hunting to be an important expression of their Aboriginality.

Areas used for dugong hunting: Hopevale Aborigines hunt dugongs from Lookout Point north to the Jeannie River (Figure 1), in approximately 1m to 3m depth of water (i.e. usually within a couple of kilometers of the coast). Dugong hunting from the beach camps at Cape Bedford in January (wet season), typically involves a coastal voyage of about 90km (50nm) to the Starcke River area.

At Lockhart River most dugongs are caught between First and Second Red Rocky Points (Figure 1). They are also taken inside Cape Direction, in Lloyd Bay and off Cape Direction. With suitable weather, dugongs are also hunted between the Pascoe River and Temple Bay (Figure 1).

Catch data: Between January 1984 and February 1987, a total of 74 dugongs (38 females; 33 males; 3 of undetermined sex) were taken by Hopevale hunters (Table 1). In a favorable three month period (late September to late December, 1985) 15 dugongs (4 females; 11 males) were caught by Lockhart River hunters (Table 1). In addition to this, there was an unconfirmed report of two dugongs (one a pregnant female) being caught just prior to that period, and at least four dugongs being taken in the Pascoe River area by Aborigines visiting from the western side of Cape York Peninsula. Estimates of annual catches at Lockhart River cannot be extrapolated from these data due to the seasonal variability of hunting, and the unpredictable availability of boats. The data collected indicated that dugongs of all ages including reproductively-active females were hunted.

From our observations we are confident that Hopevale hunters were not hunting selectively, except perhaps in very rare circumstances by older, more experienced hunters. Most hunting occurred in extremely turbid water, and since animals could not be followed and observed underwater, hunters opportunistically harpooned any available animal. At Lockhart River, there was the potential for selection during hunting as the clarity of the water allowed the animals to be observed for a few minutes before harpooning. However, from observations, and the catch data, it was apparent that an attempt was made to catch any dugong encountered.

Most trips to the hunting area of the Hopevale Aborigines are by boat and involve a 90km voyage. As a result, the number of hunting trips is limited by fuel costs, tides and weather. The small number of dugongs caught per boat per trip is also limited by the small size of most boats used. Dugong hunting is presently limited by weather and the low number of serviceable boats at

Lockhart River.

MANAGEMENT OF DUGONG HUNTING IN THIS AREA

Sustainable yield: As outlined above, the estimate of the dugong population of the Great Barrier Reef lagoon between Cape Bedford and Hunter Point of 8110 $\pm$ 1073 (S.E.) animals is likely to be low. Results of the aerial surveys (Marsh and Saalfeld, in press) and satellite telemetry of individual dugongs (Marsh and Rathbun, manuscript) indicate that they undergo local movements . Thus the population(s) from which the Aboriginal hunters are harvesting are unlikely to be restricted to the hunting areas per se.

Dugong life history data (Marsh, 1986a) suggest that a conservative estimate of the sustainable harvest of the dugong population of the whole region surveyed is of the order of two percent of females. Assuming a 1:1 sex ratio (as suggested by all the available data), 8000 dugongs would be able to support a harvest of approximately 80 females per year for Hopevale and Lockhart River communities. Using the lower bounds of the confidence limits of the population estimate, the sustainable harvest level would be 70 females per year. A outlined above, these are likely to be underestimates of the sustainable yield.

The catch statistics indicate that the combined annual dugong harvest by Aboriginal hunters from Hopevale and Lockhart River communities is substantially less than the estimated sustainable yield. Therefore, the present Aboriginal take alone is unlikely to be damaging the dugong population of the GBRMP in the eastern Cape York Peninsula region surveyed. However, given that the number of dugongs incidentally drowned in gill-nets is unknown, it is possible (but we consider it unlikely) that the combination of traditional and incidental man-induced mortality is reducing dugong stocks in this region.

The status of the dugong population: Dugongs are long-lived animals with a life-span of up to 70 years, a minimum pre-reproductive period of 9 to 10 years, and a mean calving interval which has been estimated as 3 to 7 years for various populations (Marsh and others, 1984c; Marsh, 1986a). Marsh (1986a) has calculated that even with the most optimistic combination of these parameters, a low schedule of natural mortality and no anthropogenic causes of mortality, the maximum rate of increase is likely to be of the order of 5% per year. Under the present zoning and management regulations, the level of man-induced mortality in the northern sections of the GBRMP should be low. Thus, barring catastrophes, the annual rate of population change is also expected to be relatively low.

In a hypothetical example, Marsh and Saalfeld (in press) calculate that it would take 10 annual aerial surveys to detect a 5% per year decline in the population with 95% confidence. Alternatively, two surveys 10 years apart could establish with 95% confidence that a population decreasing at 5% per year is declining. As a compromise between information and cost, Marsh and Saalfeld (in press) suggest that large-scale surveys should be conducted every 5 years in the northern sections of the GBRMP, so as to coincide with the required revision of the zoning plans. Thus it will probably be at least a decade before the status of the dugong population is determined in this region. Meanwhile a conservative management policy needs to be adopted.

Proposed management system: Based on the population estimates and traditional catch data, a modified system to manage the traditional hunting of dugongs was recommended to GBRMPA (Marsh, 1986b; Smith, 1987), and is currently being tested. This management system involves a hierarchical list of management options. In increasing severity, they are:

(a) community dugong hunting permits;

(b) declaring current dugong hunting areas as 'official', hunting areas;

(c) closed seasons;

(d) quotas.

This broad management system allows each community to be covered by the same scheme, but permits flexibility to cater for the unique situation experienced at each community. It also allows for applying different options as circumstances change.

The dugong hunting permit system currently being tested at Hopevale and Lockhart River is as follows.

(a) Dugong hunting is permitted via a dugong hunting permit issued to the Aboriginal Councils for the whole community. The permit stresses that the whole carcass should be used, and that hunting should not utilise commercial freezer boats.

(b) The areas presently used for dugong hunting by each community have been declared 'hunting areas'. This declaration serves two functions: (1) the recognition of Aboriginal dugong hunting rights for the area, and (2) prevention of expansion of hunting into other areas (should the means become available) until the status of the dugong population is determined.

(c) There is no quota applied to the communities.

(d) The closed season at Hopevale has been retained because of the potential for overharvesting provided by the easy road access to the hunting grounds in the dry season, given the large number of vehicles in this community. The details of its duration and timing are determined through discussions with the Council. There is provision for the Council to apply for a special permit(s) to take dugong(s) for special community occasions (e.g. dance festivals). There is no closed season at Lockhart River because dugong hunting is not as seasonal an activity as at Hopevale and there is not the same potential for overharvesting, especially as there are few boats available.

(e) The management agency is responsible for maintaining catch records for the communities.

(f) Provision has been made for the collection of dugong skulls, or at least the tusks, and any available capture information.

(g) The management plan for dugong hunting will be reassessed at the time of the reviews of the Cairns and Far Northern Zoning Plans.

The response of the communities to the management system currently being tested has not yet been formally articulated. However, the response of the Hopevale community was foreshadowed in verbal presentations at the 57th Congress of the Australian and New Zealand Association for the Advancement of Science in Townsville in August 1987. The delegates from Hopevale represented the strong feeling that the community should play an important role in determining management structures and in administering those structures. They suggested the use of Community By-laws as a way of controlling local hunting practices. In principle, this approach was welcomed by the staff of the GBRMPA at the meeting. We hope that the management of dugong hunting within the GBRMPA will increasingly become the responsibility of the traditional hunters themselves.

CONCLUSIONS: IMPLICATIONS FOR OTHER AREAS

The events outlined above represent one of the only attempts to manage a traditional (i.e. non-commercial) dugong fishery by other than a complete closure. The Division of Wildlife in Papua New Guinea attempted to manage the dugong fishery in Daru in Torres Strait between 1978 and 1982, but this initiative was halted prematurely due to lack of funds (Hudson, 1986). A number of lessons can be learned from the experience in the Great Barrier Reef Marine Park.

The anecdotal and/or qualitative information on which the original planning and management decisions were based was obviously inadequate for effective management. Shoreline surveys (see Heinsohn, 1981) are acceptable for identifying major dugong habitat areas, but are unsuitable for estimating numbers or monitoring trends. If the decision to limit (rather than ban) hunting is to be made, data are required on the number of populations involved, population size and dynamics, and catch statistics. Although these data are technically difficult, expensive and time-consuming to obtain, we believe that they are essential to effective management of a population subject to traditional harvest. Of course, as in this case, it may be impossible to postpone management initiatives until the research is completed. Management regulations must therefore have the capacity to be flexible in order to incorporate new research findings.

It is also vital to attempt to obtain statistics on any non-traditional causes of mortality, e.g. incidental catch, even though this is generally much more difficult to document than the traditional catch. Despite the low density of fishermen and the remoteness of the waters on the eastern side of Cape York Peninsula, local Aborigines regard the absence of attempts to obtain data on the incidental catch of dugongs as a serious neglect of a fundamental issue in dugong management.

Western styles of environmental management should not be imposed on traditional hunters and fishermen; they should be involved in making the initial management decisions. However, the Hopevale experience shows that legislative requirements may not allow sufficient lead-time to develop the cross-cultural rapport required to achieve this satisfactorily. In such situations, the initial attempts at management must be accompanied by culturally appropriate education and extension programmes, especially when the initiatives are complex, such as in the GBRMP zoning. It is inappropriate to go to considerable effort to make management systems culturally appropriate if they are not adequately explained to the user groups. The relevant management agency should also have the capacity to respond to escalating demands from traditional hunters who want to assume a more active role in both developing and administering management policies.

Superficially, one might expect that the problem of managing dugong hunting at Lockhart River would be similar to Hopevale. However, we believe that the socio-economic and logistical differences between the two communities could lead to overharvesting at Hopevale but not at Lockhart River, and hence have recommended a closed season at Hopevale only. There are no global solutions to the management of traditional fishing; rather management must be customised to each community. If this can be done within a common framework as in the GBRMP, it is likely to be more acceptable to the communities concerned and be easier to administer as well.

As outlined above, it will probably be at least a decade before the status of any dugong population is established. In the meantime, we believe that management needs to be conservative while acknowledging the rights of traditional hunters.

ACKNOWLEDGEMENTS

The research on which this paper is based was funded by the Great Barrier Reef Marine Park Authority. We thank the following people: members of Hopevale and Lockhart River communities for their insights and assistance in data collection; staff of the Great Barrier Reef Marine Park Authority, especially Claudia Baldwin, for useful discussions; Mary Fisher of the Australian Law Reform Commission and Noel Pearson of Hopevale for perceptive and constructive criticism of the manuscript.

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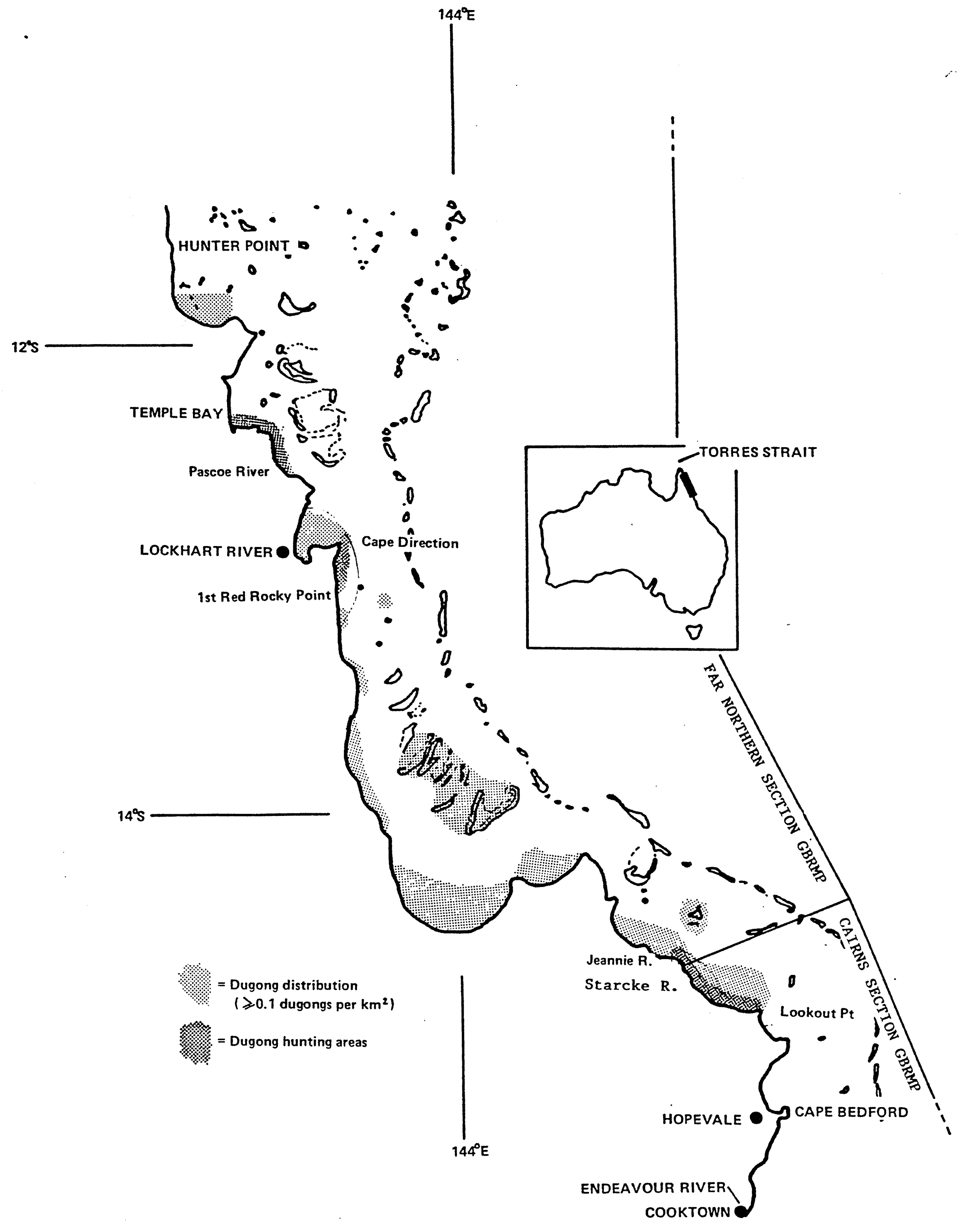
LEGEND TO FIGURE

Figure 1: The distribution of dugongs between Cape Bedford and Hunter Point in November 1985 as revealed by aerial survey in relation to the Hopevale and Lockhart River dugong hunting areas.

TABLE 1: Number of dugongs caught at Hopevale from January 1984 to February 1987; and at Lockhart River from late September to late December 1985.

	NO.OF DUGONGS CAUGHT			
YEAR	FEMALES	MALES	UNDETERMINED	TOTAL
HOPEVALE:				
1984	3	10	2	15
1985	14	5		19
1986	6	6	1	13
1987	15	12		27
TOTAL	38	33	3	74
LOCKHART RIVER:				
Sept-Dec.				
1985	4	11		15


144°E
HUNTER POINT
12°S
TEMPLE BAY
Pascoe River
LOCKHART RIVER
Cape Direction
1st Red Rocky Point
TORRES STRAIT
FAR NORTHERN SECTION GBRMP
14°S
Jeannie R.
Starcke R.
Lookout Pt
CAIRNS SECTION GBRMP
= Dugong distribution (≥0.1 dugongs per km²)
= Dugong hunting areas
HOPEVALE
CAPE BEDFORD
144°E
ENDEAVOUR RIVER
COOKTOWN

INCIDENTAL SIGHTINGS OF DUGONGS

IN THE GREAT BARRIER REEF MARINE PARK

1973-1988

collated by

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INTRODUCTION

As part of the program to establish a sound ecological basis for managing dugongs in the Great Barrier Reef Marine Park, dedicated, systematic, aerial surveys were carried out throughout the inshore waters of the Park and in some offshore waters between November 1984 and March 1988 (Marsh and Saalfeld, 1988, manuscripts a and b). All such areas were surveyed at least once during this period; some were surveyed twice.

These surveys were usually performed by a team of six comprising a pilot/navigator, a survey leader, and four trained observers in a Partenavia 68B high winged aircraft at an altitude of 450′ (137m) and a speed of 100 knots (185 km hr^{-1})(Marsh and Sinclair, manuscript). In order to standardize the bias as much as possible, surveys were carried out only in fine, calm conditions (sea state Beaufort 3 or less). Consequently, most surveys were carried out between late September and early December in order to maximize the chance of suitable weather.

Thus each area was surveyed within a very restricted time-frame to give a 'snapshot' picture of dugong distribution and abundance. In order to extend the information about the temporal distribution of dugongs within the Park, incidental sightings made between 1973 and 1988 have been summarized below. Most of this information has come from observers in aircraft flying under less rigid conditions than those required for the dedicated systematic surveys. The remainder has come from observers on the shore, in boats, and occasionally swimming or diving.

METHODS

The sightings resulted from several sources which have been categorized as follows:

1. Heinsohn, J.C.U. survey

Sightings of dugongs made during dedicated aerial surveys conducted by George Heinsohn and his co-workers in the Great Barrier Reef region between 1973 and 1979 inclusive (see Heinsohn 1976a, 1976b, 1976c, 1977) (Heinsohn and Marsh 1979, 1980) and (Marsh and Heinsohn 1979). These surveys were typically conducted using three observers in a high wing aircraft flying at a height of 900' (274 m) and 90 knots (167 km hr^{-1}). A single transect of undefined width was usually flown about 500 m from, and parallel to, the shore. Sometimes additional transects were flown over extensive areas of seagrass.

2. Coastal Surveillance

Dugong sightings reported by observers on Coastal Surveillance (Coastwatch) aircraft within the Great Barrier Reef Marine Park. Most observations were reported by observers on the littoral flights which patrol the eastern shoreline of Cape York from Cairns north. The flights were conducted in Shrike Aerocommander high wing aircraft which typically carried two professional observers, one of which also acted as a recorder. The aircraft flew at variable heights usually between 500'(150 m) and 1500'(455 m) and at an airspeed of about 140 knots (260 km hr^{-1}). The observers were instructed to report significant sightings of wildlife such of dugongs. However, such sightings were a low priority for the Coastwatch Teams, and the experience of members of the James Cook Dugong Research Group who went on some flights was that the observers were often too busy to sight dugongs, and even when animals were seen, they were often not reported. Under these circumstances negative sightings have no significance. Recorded sightings were telexed to the Coastal Surveillance Centre in Canberra in the standard post-flight reports which were subsequently despatched to users such as the Great Barrier Reef Marine Park Authority.

3. Sightings by members of the public

These sightings have been classified with reference to the platform from which the sighting was made e.g. power boat, small power boat (<5 m), helicopter, light commercial plane, yacht, in water (ie. diving), research vessel. Such sightings forwarded were by members of the public through the Marine Mammal Sighting Program conducted at James Cook University. Observers were encouraged to report sightings by completing a standard sighting sheet (see Appendix 1). Dugong sightings from partially incomplete sighting sheets were classified as unknown.

RESULTS AND DISCUSSION

The sightings are summarized in Figures 1 through 8 and in Appendix 2: Tables 1 through 7, correct to the nearest 2.5 nm.

These incidental sightings of dugongs have added to our knowledge of dugong distribution in a large proportion of the Great Barrier Reef. Combined with those from the more rigorously controlled aerial surveys, they extend the time-frame of our knowledge of dugong distribution.

These incidental sightings generally confirmed the dugong areas identified during the dedicated, systematic, aerial surveys of the Far Northern, Cairns, Central and Mackay/Capricorn Sections of the

Great Barrier Reef Marine Park (Marsh and Saalfeld 1988 and manuscripts a, b). Dugongs were also sighted in the following areas where they were not seen in the dedicated surveys: Orford Ness (11°18'S; 142°49'E) in the Far Northern Section; Cairns Reef (15°42'S; 135°34'E), and between Port Douglas and the mouth of the Daintree River (16°29'S; 145°28'E) in the Cairns Section; Palm Island in the Central Section (18°40'S; 146°33'E), and between Gladstone and Curtis Island (23°51'S; 151°16'E) in the Mackay/Capricorn Section.

Groups sizes (see Tables 1 -7) were often larger than sighted on the dedicated aerial surveys (Marsh and Saalfeld 1988, and manuscripts a and b) with groups of the order of 100 dugongs being sighted by observers on Coastwatch aircraft.

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LEGEND TO FIGURES

Figure 1. Incidental dugong sightings between the northern tip of Cape York Peninsula and Shelburne Bay in relation to the areas protected by Marine National Park A or higher zoning.

Figure 2. Incidental dugong sightings between Cape Grenville and Bathurst Head in relation to the areas protected by Marine National Park A or higher zoning.

Figure 3. Incidental dugong sightings between Cape Melville and Weary Bay in relation to the areas protected by Marine National Park A or higher zoning.

Figure 4. Incidental dugong sightings between Cape Tribulation and Dunk Island in relation to the areas protected by Marine National Park A or higher zoning.

Figure 5. Incidental dugong sightings between Dunk Island and Cape Cleveland in relation to the areas protected by Marine National Park A or higher zoning.

Figure 6. Incidental dugong sightings between Cape Cleveland and Abbot Point in relation to the areas protected by Marine National Park A or higher zoning.

Figure 7. Incidental dugong sightings between Bowen and Flaggy Rock in relation to the areas protected by Marine National Park A or higher zoning.

Figure 8. Incidental dugong sightings between Townshend Island and Curtis Island in relation to the areas protected by Marine National Park A or higher zoning. Sightings from North West Island and Lady Elliott Island have not been included in this figure.

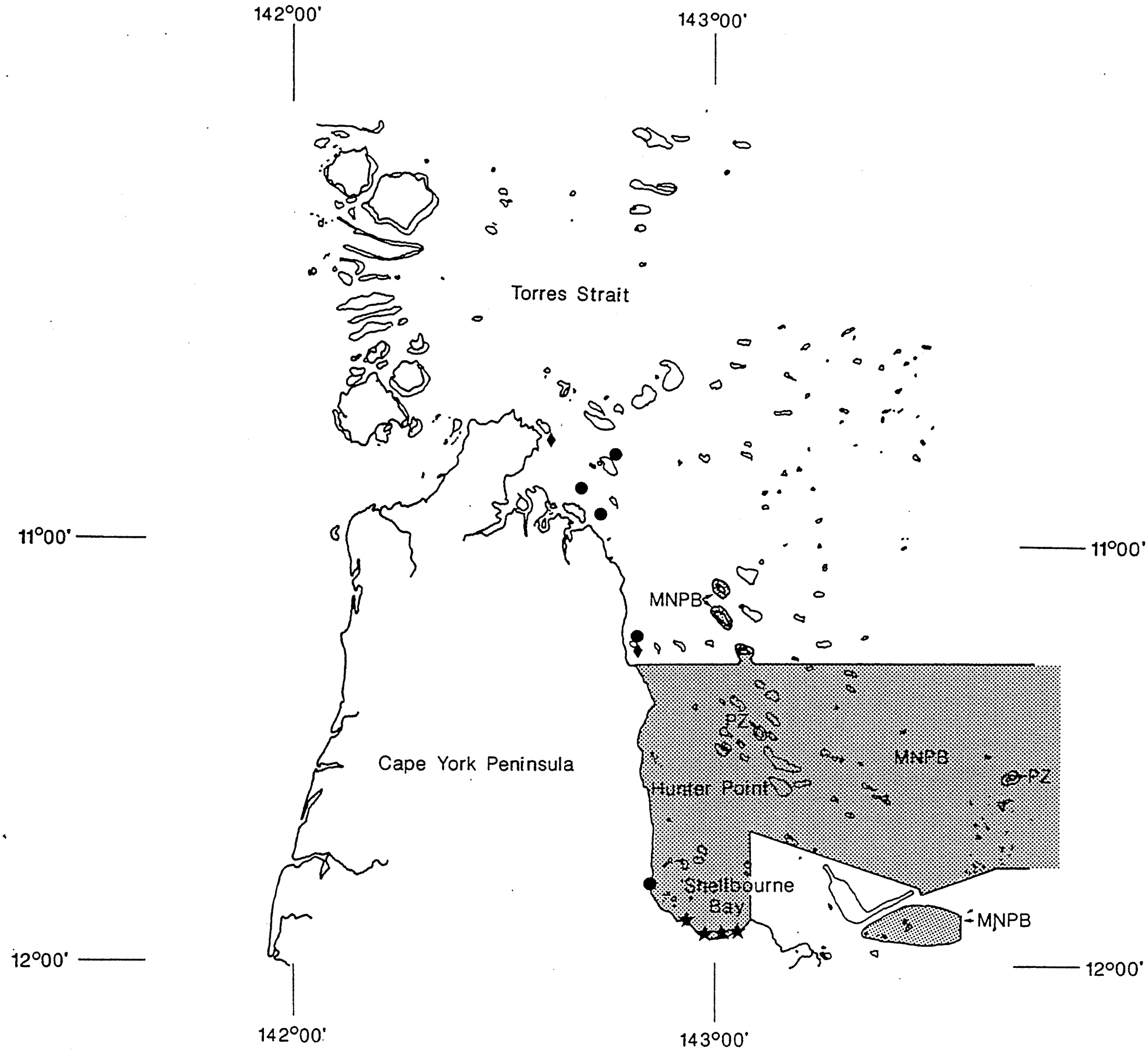

Figure 1. Incidental dugong sightings between the northern tip of Cape York Peninsula and Cape Grenville in relation to the areas protected by Marine National Park A or higher zoning.

● One to five dugongs sighted on one date only

◆ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

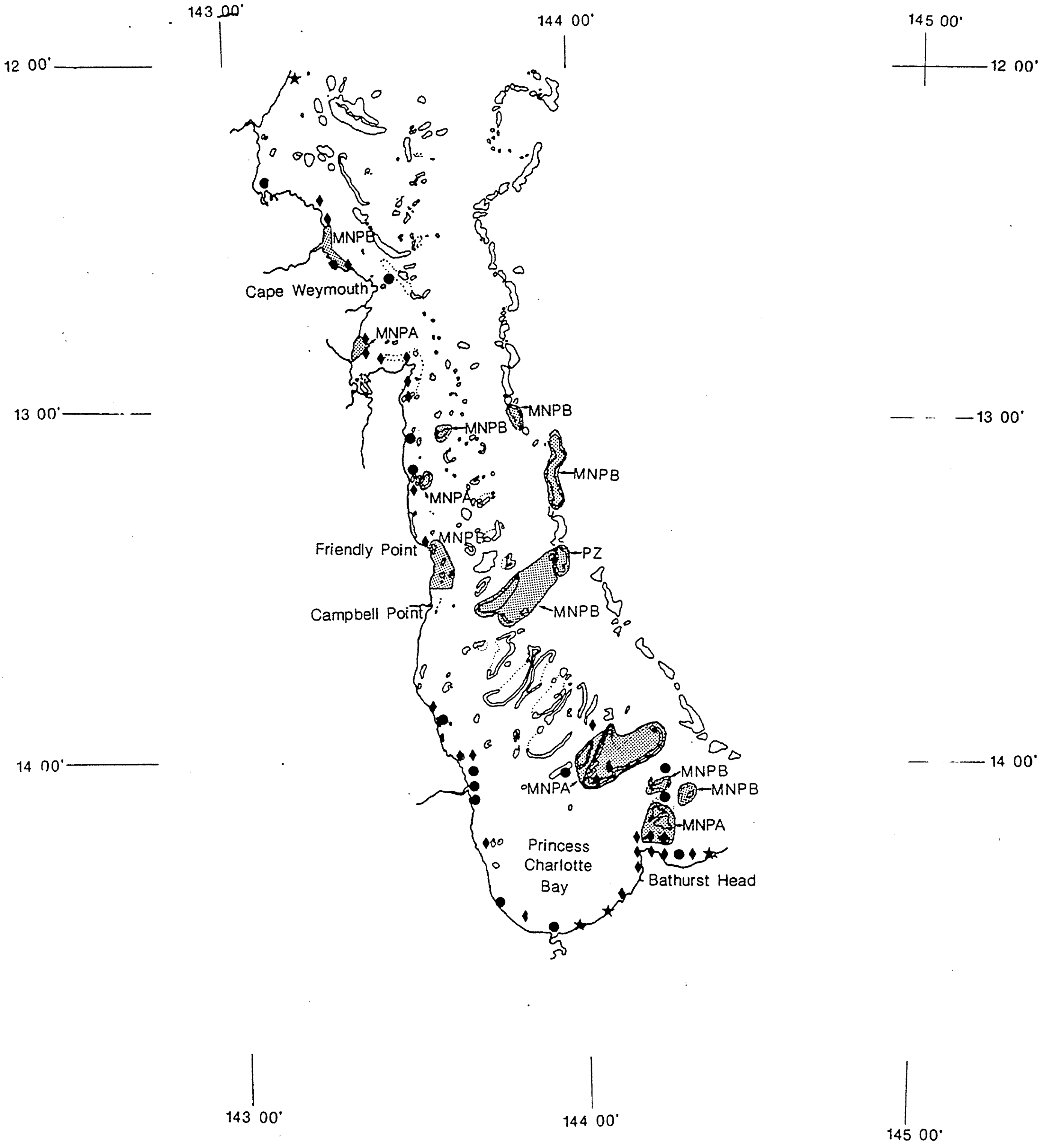

Figure 2. Incidental dugong sightings between Cape Grenville and Cape Melville in relation to the areas protected by Marine National Park A or higher zoning.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

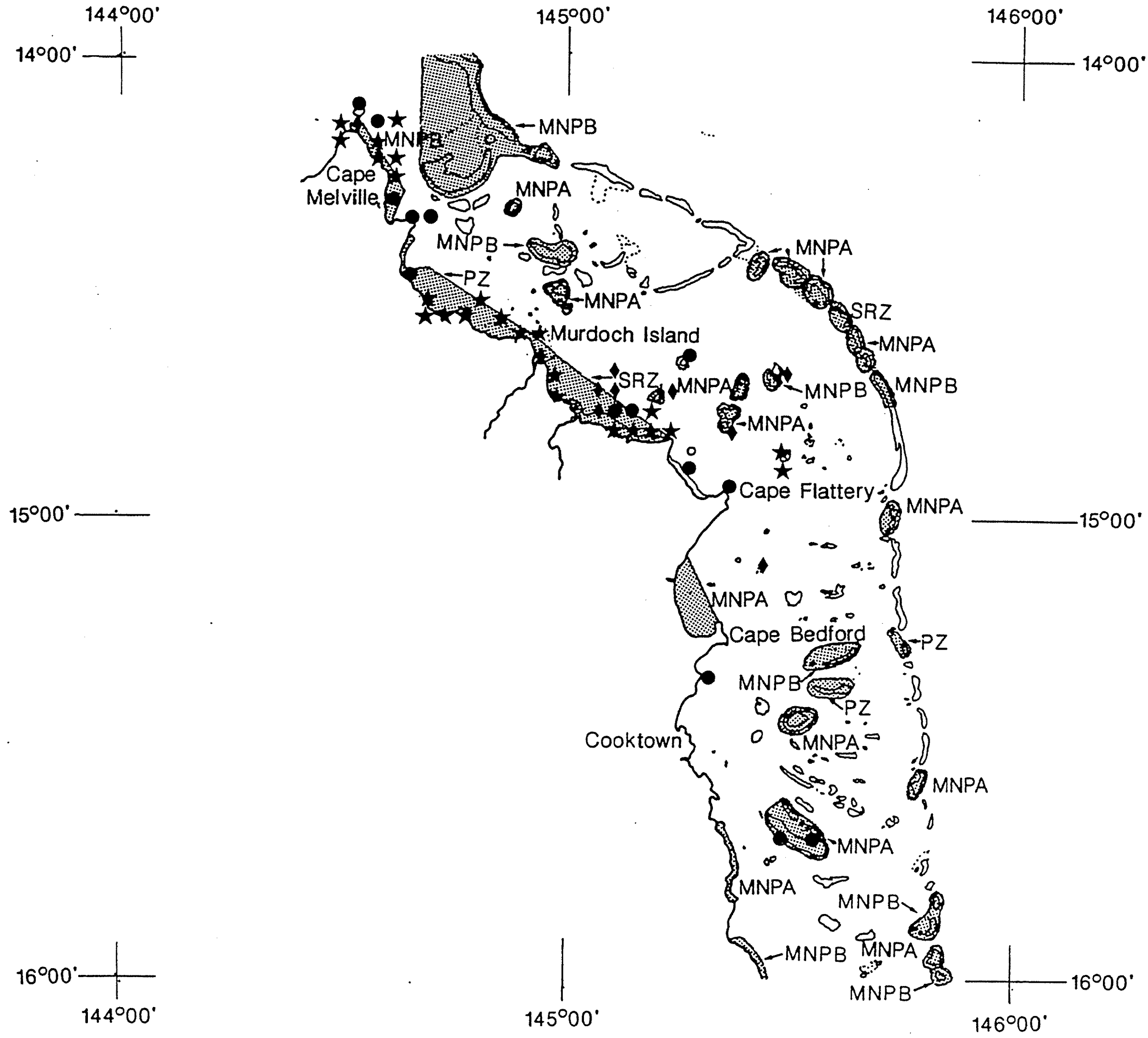

Figure 3. Incidental dugong sightings between Cape Melville and Cape Tribulation in relation to the areas protected by Marine National Park A or higher zoning.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

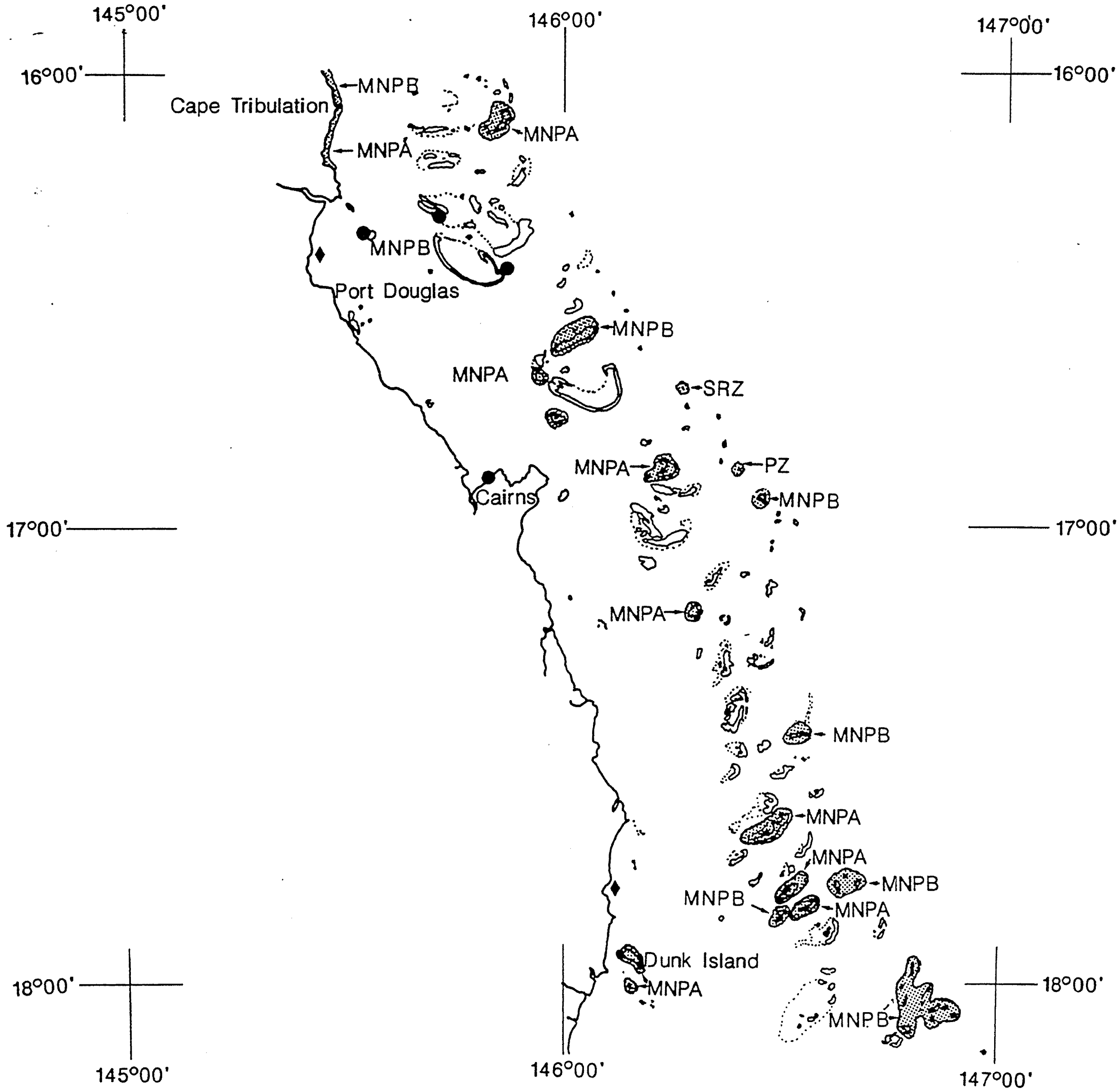

Figure 4. Incidental dugong sightings between Cape Tribulation and Dunk Island in relation to the areas protected by Marine National Park A or higher zoning.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

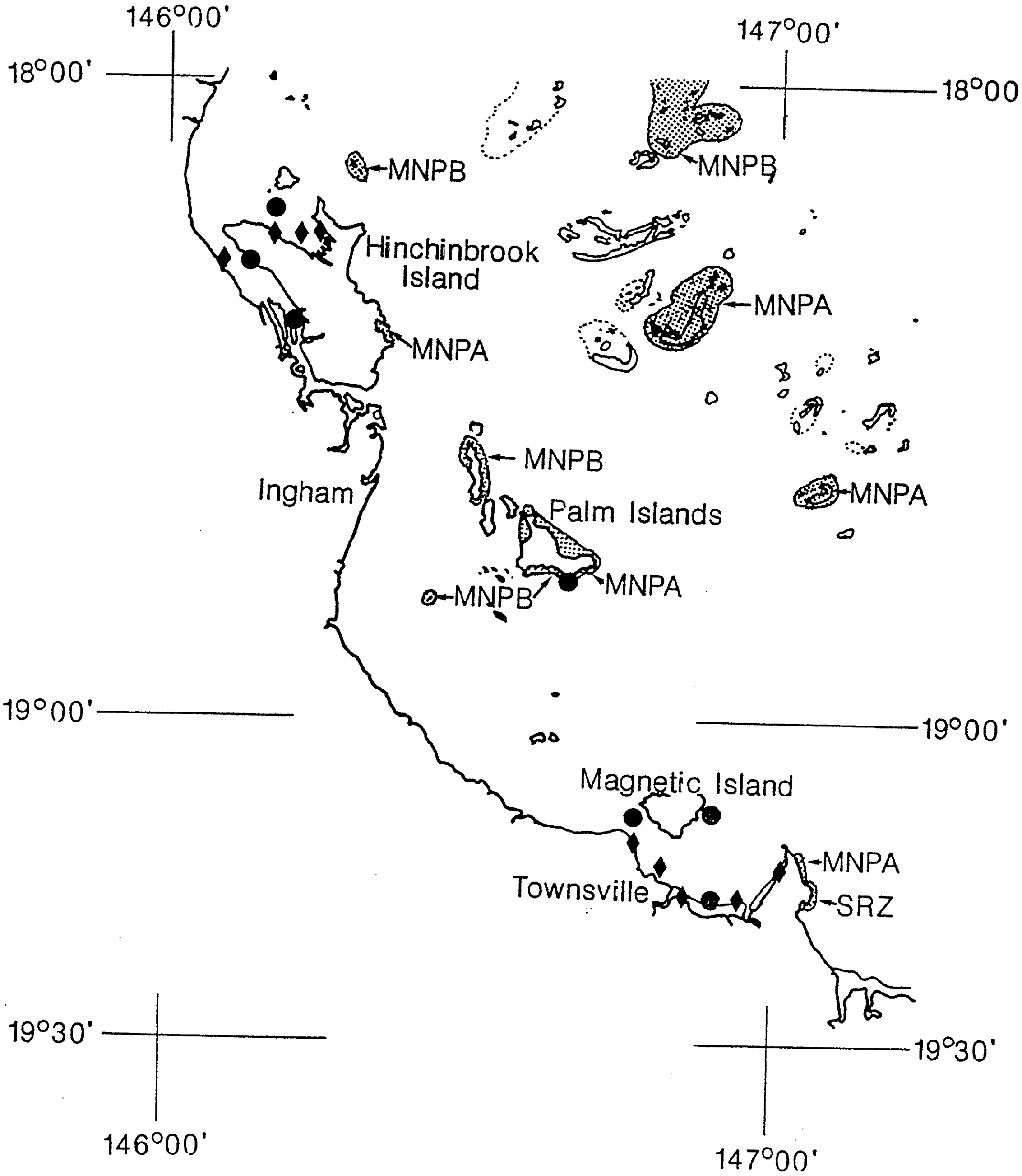

Figure 5. Incidental dugong sightings between Dunk Island and Cape Cleveland in relation to the areas protected by Marine National Park A or higher zoning.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

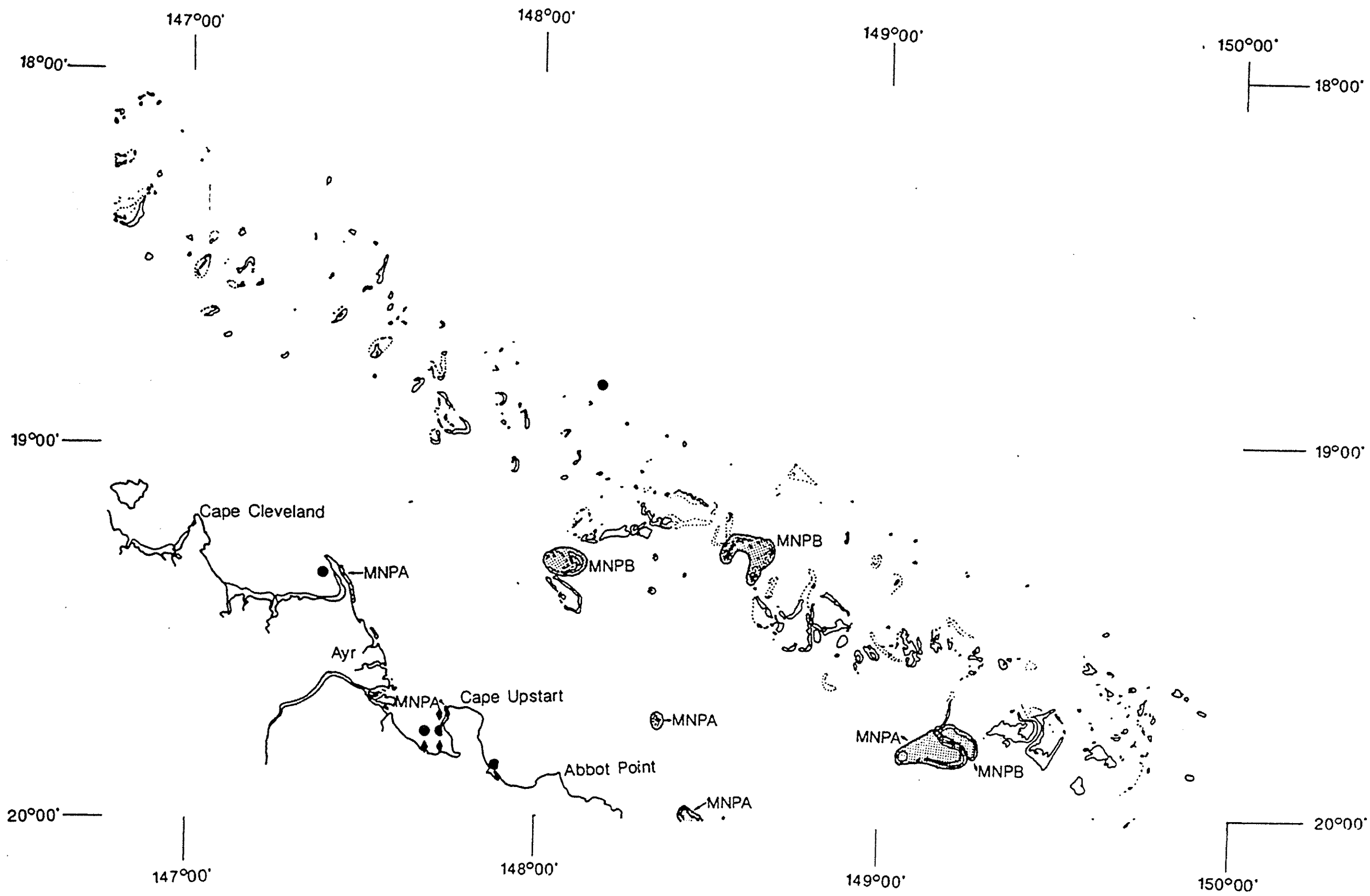

Figure 6. Incidental dugong sightings between Cape Cleveland and Bowen in relation to the areas protected by Marine National Park A or higher zoning.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

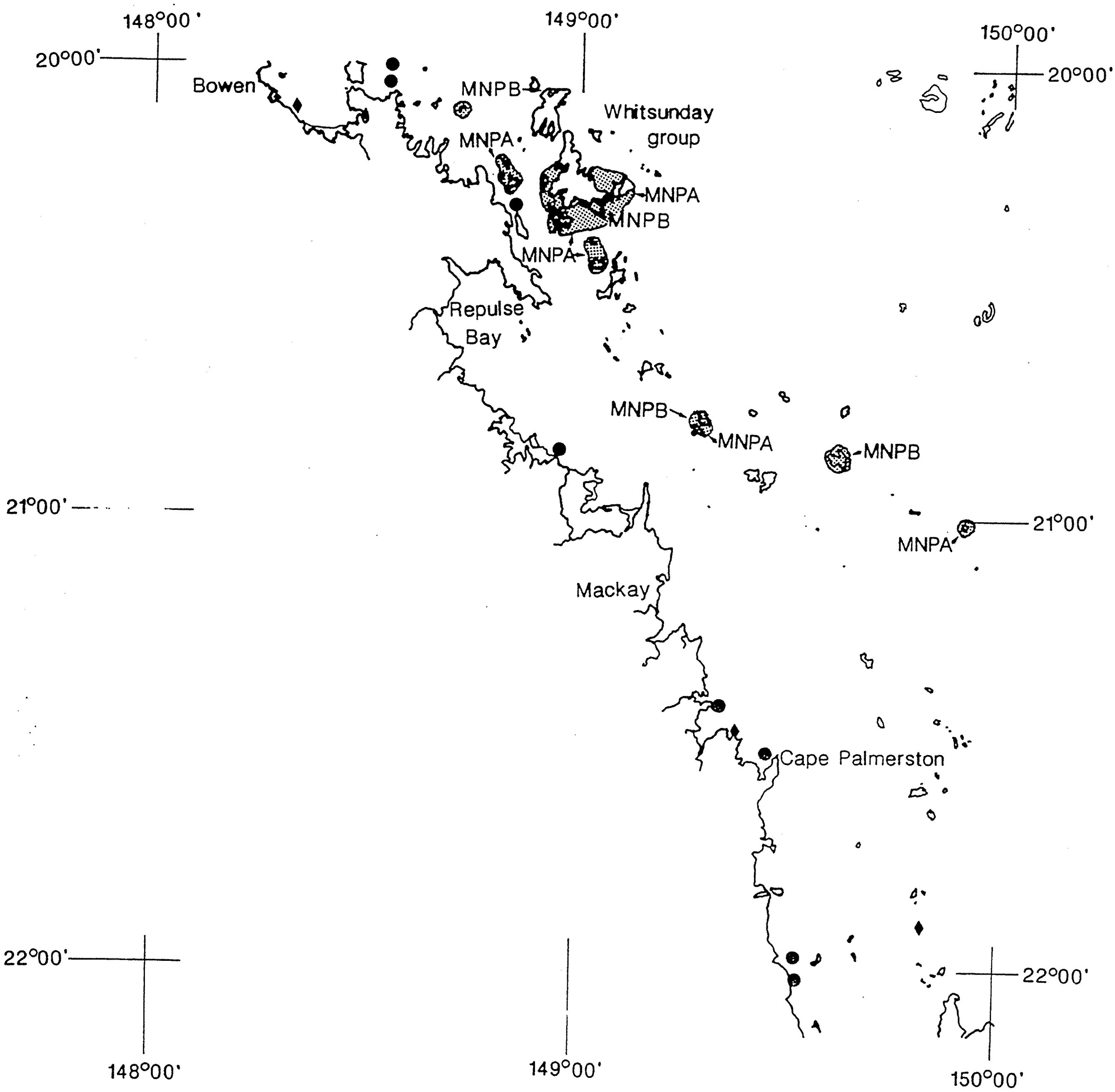

Figure 7. Incidental dugong sightings between Bowen and Townshend Island in relation to the areas protected by Marine National Park A or higher zoning.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

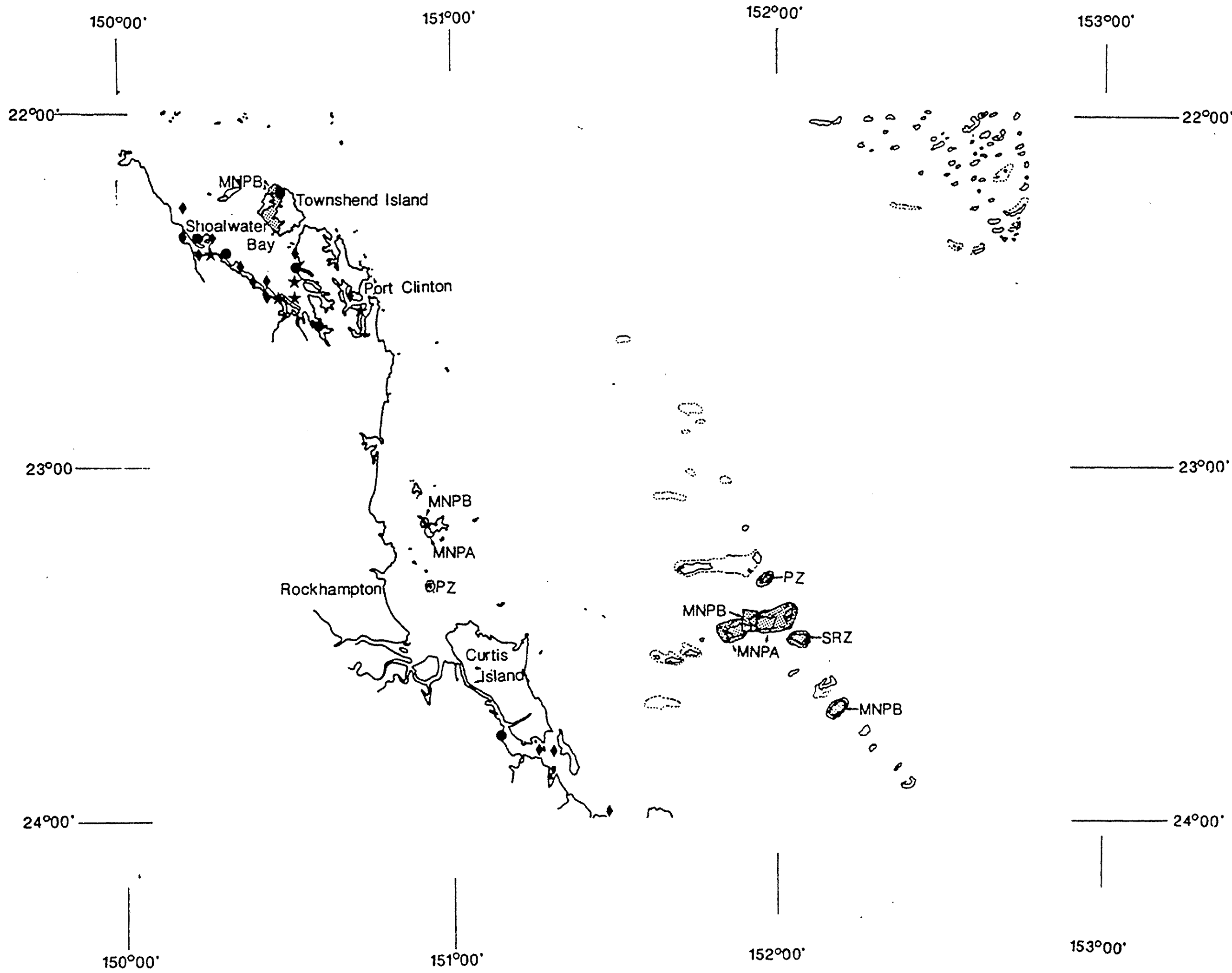

Figure 8. Incidental dugong sightings between Townshend Island and Curtis Island in relation to the areas protected by Marine National Park A or higher zoning.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

APPENDIX 1.

MARINE MAMMAL SIGHTING INFORMATION SHEET

WHALES, PORPISES AND DOLPHINS, DUGONGS *(*Essential Information)*

*OBSERVER (Name and Address) ....

....

*DATE OF SIGHTING .... *TIME OF SIGHTING ....

*SHORE, BOAT OR PLANE .... TYPE OF BOAT OR PLANE ....

*LOCATION OF SIGHTING (DESCRIBE AS FULLY AS POSSIBLE IN RELATION TO LANDMARKS OR REEFS) ....

....

....

WEATHER (CLEAR/CLOUDY/OVERCAST/RAINING) ....

....

SEAS (SMOOTH-SLIGHT/MODERATE/ROUGH) ....

....

WIND (SPEED AND DIRECTION) ....

WATER (CLEAR/SLIGHTLY-MUDDY/MUDDY) ....

*SPECIES .... *NUMBER OF ANIMAL(S) ....

*ANY CALVES PRESENT YES ☐ NO ☐ *NUMBER OF CALVES ....

*LENGTH(S) OF ANIMAL(S) ....

DESCRIBE ANY MARKINGS OR WOUNDS ....

....

....

CHARACTERISTICS OBSERVED WHICH RESULTED IN SPECIES IDENTIFICATION (COLOUR, SPOUT, DORSAL FIN, FLIPPERS, SNOUT, TAIL (FLUKES), OTHER ....

....

....

BEHAVIOUR (STATIONARY, ROLLING ON SIDE, TYPE OF MOVEMENT AND SURFACING, FLUKES (TAIL) OUT OF WATER, SWIMMING STEADILY, JUMPING, SURFING WAVES, OTHER ....

....

....

....

*DIRECTION OF SWIMMING WHEN FIRST SEEN ....

SWIMMING SPEED ....

DESCRIBE ANY SOUNDS PRODUCED ....

WERE ANY OTHER LARGE MARINE ANIMALS PRESENT (OTHER MARINE MAMMAL SPECIES, SEA BIRDS, SPLASHING FISH, SHARKS, OTHER) ....

....

SKETCHES

ARE PHOTOS AVAILABLE? YES ☐ NO ☐

ADDITIONAL COMMENTS ....

....

....

....

RETURN TO —

Whale Sightings,
C/- Biological Sciences,
James Cook University of North Queensland,
TOWNSVILLE, QUEENSLAND, 4811
PHONE 077 814860

CONTACTS: Dr H. Marsh Dr G. Heinsohn, Dr P. Arnold, and Mr A. Birtles

APPENDIX 2

Summary tables of sightings.

Table 1.
Incidental dugong sightings between Hunter Point (11°31',142°50') and Campbell Point (13°33', 143°35') in the Far Northern Section.

No.Dugongs	/calves	Latitude	Longitude	Date of sighting D/M/Y	Observer
2		11°27'	142°44'	18/11/78	Heinsohn, J.C.U. survey
1		11°27'	142°49'	15/11/76	Heinsohn, J.C.U. survey
4		11°32'	143°09'	19/03/86	Coastal Surveillance
10		11°43'	142°56'	21/12/86	Coastal Surveillance
5		11°49'	142°51'	27/01/87	Coastal Surveillance
1		11°51'	142°54'	15/11/76	Heinsohn, J.C.U. survey
20	2	11°51'	142°54'	15/10/84	helicopter
25		11°52'	142°55'	05/01/88	Coastal Surveillance
30		11°53'	142°56'	01/09/85	Coastal Surveillance
10		11°54'	142°53'	17/11/85	Coastal Surveillance
12		11°54'	142°54'	02/01/88	Coastal Surveillance
10		11°54'	142°54'	23/01/08	Coastal Surveillance
30		11°54'	142°57'	09/10/85	Coastal Surveillance
20		11°54'	142°57'	06/02/86	Coastal Surveillance
5		11°54'	143°00'	21/07/85	Coastal Surveillance
1		11°54'	143°00'	15/11/76	Heinsohn, J.C.U. survey
72		11°54'	143°00'	18/11/78	Heinsohn, J.C.U. survey
50		11°54'	143°04'	09/12/84	Coastal Surveillance
1		11°54'	143°06'	15/11/76	Heinsohn, J.C.U. survey
10		11°54'	143°07'	04/11/86	Coastal Surveillance
40		11°56'	142°03'	02/09/85	Coastal Surveillance
5		11°56'	143°00'	12/07/85	Coastal Surveillance
50		11°56'	143°01'	21/12/87	Coastal Surveillance
10		11°56'	143°20'	05/09/85	Coastal Surveillance
6		11°56'	143°14'	18/11/78	Heinsohn, J.C.U. survey
3		11°57'	142°58'	21/09/85	Coastal Surveillance
60		11°57'	143°00'	26/08/85	Coastal Surveillance
70		11°57'	143°00'	20/12/87	Coastal Surveillance
4		11°57'	143°11'	30/06/85	Coastal Surveillance
1		11°57'	143°11'	06/12/87	Coastal Surveillance
3		11°57'	143°11'	17/09/85	Coastal Surveillance
40		12°01'	142°11'	30/12/85	Coastal Surveillance
3	1	12°14'	143°08'	01/08/85	power boat
40		12°19'	143°53'		Unknown
1		12°20'	143°06'	15/11/76	Heinsohn, J.C.U. survey
6		12°27'	143°15'	15/11/87	Heinsohn, J.C.U. survey
6		12°27'	143°23'	15/11/76	Heinsohn, J.C.U. survey
1		12°33'	143°47'	05/03/86	small power boat (<5 m)
26		12°34'	143°22'	18/11/78	Heinsohn, J.C.U. survey
2		12°36'	143°27'	05/03/86	small power boat (<5 m)
2	1	12°46'	143°24'	05/03/86	small power boat (<5 m)
1		12°50'	143°23'	15/11/76	Heinsohn, J.C.U. survey
20		12°51'	143°23'	18/11/78	Heinsohn, J.C.U. survey
4		12°55'	143°32'	30/09/86	Coastal Surveillance
15		12°56'	143°32'	10/02/87	Coastal Surveillance
20		12°56'	143°32'	30/09/86	Coastal Surveillance

1	13°04'	143°31'	15/11/76	Heinsohn, J.C.U. survey
1	13°09'	143°31'	15/11/76	Heinsohn, J.C.U. survey
2	13°09'	143°31'	15/11/76	Heinsohn, J.C.U. survey
1	13°11'	143°31'	15/11/76	Heinsohn, J.C.U. survey
8	13°15'	143°31'	15/11/76	Heinsohn, J.C.U. survey
2	13°22'	143°33'	15/11/76	Heinsohn, J.C.U. survey
20	13°22'	143°34'	19/01/87	Coastal Surveillance
2	13°22'	143°34'	18/11/78	Heinsohn, J.C.U. survey

Table 2.
Incidental dugong sightings between Campbell Point (13°33',143°35') and Princess Charlotte Bay (14°05',144°25') in the Far Northern Section.

No.Dugongs	/calves	Latitude	Longitude	Date of sighting D/M/Y	Observer
5		13°33'	143°42'	18/11/78	Heinsohn, J.C.U. survey
12		13°51'	143°34'	21/02/84	Coastal Surveillance
2		13°51'	143°35'	26/03/84	Coastal Surveillance
1		13°52'	143°37'	15/11/76	Heinsohn, J.C.U. survey
20		13°54'	144°01'	02/08/85	Coastal Surveillance
8		13°58'	143°37'	03/06/85	Coastal Surveillance
8		13°58'	143°41'	03/06/85	light commercial plane
10		14°00'	144°04'	02/12/87	Coastal Surveillance
4		14°01'	143°58'	16/11/85	Coastal Surveillance
1		14°01'	144°07'	06/01/86	small power boat (<5 m)
1		14°02'	143°41'	15/11/76	Heinsohn, J.C.U. survey
2	1	14°02'	144°15'	15/04/85	light commercial plane
1		14°04'	143°41'	19/06/78	Heinsohn, J.C.U. survey
1		14°04'	144°03'	06/01/86	Coastal Surveillance
10		14°04'	144°04'	11/12/85	Coastal Surveillance
16		14°04'	144°13'	24/04/85	light commercial plane
15	2	14°04'	144°14'	27/01/88	Coastal Surveillance
2		14°04'	144°15'	20/09/86	Coastal Surveillance
8		14°05'	144°13'	02/12/87	Coastal Surveillance
1		14°06'	143°42'	19/06/78	Heinsohn, J.C.U. survey
2		14°06'	144°17'	12/05/85	Coastal Surveillance
3		14°09'	144°14'	20/11/85	Coastal Surveillance
20		14°09'	144°14'	30/01/84	Coastal Surveillance
12		14°09'	144°16'	15/01/83	small power boat (<5 m)
4	1	14°11'	144°14'	12/06/84	light commercial plane
6		14°12'	144°13'	15/04/76	Heinsohn, J.C.U. survey
1		14°14'	144°11'	15/04/76	Heinsohn, J.C.U. survey
1		14°14'	144°11'	15/11/76	Heinsohn, J.C.U. survey
5		14°14'	144°14'	11/04/74	Heinsohn, J.C.U. survey
2		14°15'	144°11'	15/11/76	Heinsohn, J.C.U. survey
1		14°15'	144°13'	15/04/76	Heinsohn, J.C.U. survey
6		14°15'	144°16'	25/02/85	Coastal Surveillance
10		14°15'	144°16'	07/06/85	Coastal Surveillance
20		14°15'	144°20'	15/04/85	Coastal Surveillance
20		14°16'	144°11'	31/01/87	Coastal Surveillance
12		14°16'	144°11'	19/06/78	Heinsohn, J.C.U. survey
3		14°16'	144°14'	19/06/78	Heinsohn, J.C.U. survey
21		14°16'	144°16'	15/11/76	Heinsohn, J.C.U. survey
1		14°17'	144°10'	15/04/76	Heinsohn, J.C.U. survey
2		14°17'	144°18'	15/04/76	Heinsohn, J.C.U. survey
25		14°19'	144°11'	19/01/85	Coastal Surveillance
4		14°19'	144°12'	18/11/78	Heinsohn, J.C.U. survey
2		14°23'	144°09'	01/07/85	Coastal Surveillance
1		14°23'	144°09'	19/06/78	Heinsohn, J.C.U. survey
2		14°24'	143°46'	19/06/78	Heinsohn, J.C.U. survey
60		14°25'	144°03'	17/12/85	Coastal Surveillance
40		14°25'	144°07'	08/01/86	Coastal Surveillance
30		14°25'	144°24'	08/01/86	Coastal Surveillance
2		14°26'	144°06'	19/06/78	Heinsohn, J.C.U. survey
12		14°28'	143°53'	10/04/86	Coastal Surveillance

2	14°28'	143°56'	15/11/76	Unknown
2	14°28'	143°56'	15/06/84	light commercial plane
30	14°28'	144°00'	17/11/85	Coastal Surveillance
40	14°28'	144°00'	11/01/87	Coastal Surveillance
50	14°28'	144°00'	13/12/86	Coastal Surveillance
50	14°28'	144°00'	12/01/87	Coastal Surveillance
50	14°28'	144°00'	20/01/87	Coastal Surveillance
20	14°28'	144°00'	18/02/85	Coastal Surveillance
50	14°28'	144°01'	20/01/87	Coastal Surveillance
20	14°28'	144°03'	28/12/86	Coastal Surveillance
1	14°29'	143°56'	19/06/78	Heinsohn, J.C.U. survey
2	14°29'	144°02'	02/12/86	Coastal Surveillance

Table 3.
Incidental dugong sightings between Cape Melville (14°05′,144°25′) and Cape Bedford (15°15′, 144°21′) in the Far Northern and Cairns Sections.

No.Dugongs /calves		Latitude	Longitude	Date of sighting D/M/Y	Observer
10		14°06′	144°31′	25/01/83	Coastal Surveillance
10		14°06′	144°31′	21/02/83	Coastal Surveillance
30		14°07′	144°31′	**/**/**	power boat
20		14°08′	144°32′	03/02/86	Coastal Surveillance
2		14°09′	144°28′	19/06/78	Heinsohn, J.C.U. survey
1		14°09′	144°34′	15/11/76	Heinsohn, J.C.U. survey
30		14°10′	144°29′	31/03/87	light commercial plane
20		14°10′	144°30′	21/04/85	Coastal Surveillance
30		14°10′	144°30′	31/03/87	Coastal Surveillance
30		14°10′	144°30′	31/03/87	Coastal Surveillance
20		14°10′	144°31′	30/01/87	Coastal Surveillance
15		14°10′	144°32′	11/04/74	Heinsohn, J.C.U. survey
60		14°10′	144°33′	13/06/87	Coastal Surveillance
30		14°10′	144°33′	05/10/87	Coastal Surveillance
2		14°10′	144°34′	15/07/87	Coastal Surveillance
1		14°11′	144°31′	19/06/78	Heinsohn, J.C.U. survey
20		14°11′	144°32′	13/03/84	Coastal Surveillance
20		14°11′	144°33′	14/03/84	Coastal Surveillance
2	1	14°13′	143°43′	09/08/86	Coastal Surveillance
2	1	14°13′	143°43′	09/08/86	Coastal Surveillance
8		14°14′	143°43′	19/06/78	Heinsohn, J.C.U. survey
60		14°13′	144°35′	28/01/87	Coastal Surveillance
1		14°12′	144°29′	15/11/76	Heinsohn, J.C.U. survey
20		14°12′	144°35′	27/01/87	Coastal Surveillance
90		14°30′	144°42′	18/12/86	Coastal Surveillance
90		14°14′	144°35′	08/03/87	Coastal Surveillance
20		14°14′	144°36′	14/04/84	Coastal Surveillance
20		14°14′	144°38′	02/04/85	Coastal Surveillance
25		14°14′	144°38′	28/02/84	Coastal Surveillance
20		14°14′	144°45′	31/03/87	light commercial plane
20		14°15′	144°36′	01/03/84	Coastal Surveillance
20		14°16′	144°36′	18/01/88	Coastal Surveillance
9		14°16′	144°36′	15/11/76	Heinsohn, J.C.U. survey
5		14°17′	144°35′	11/04/74	Heinsohn, J.C.U. survey
40		14°17′	144°36′	21/05/83	Coastal Surveillance
11		14°19′	144°37′	04/12/75	Heinsohn, J.C.U. survey
5		14°21′	144°40′	11/04/74	Heinsohn, J.C.U. survey
2		14°22′	144°38′	19/06/78	Heinsohn, J.C.U. survey
15		14°27′	144°39′	15/04/76	Heinsohn, J.C.U. survey
40		14°31′	144°40′	15/12/85	Coastal Surveillance
7		14°31′	144°41′	19/06/78	Heinsohn, J.C.U. survey
21		14°31′	145°48′	15/11/76	Heinsohn, J.C.U. survey
30		14°32′	144°43′	02/12/85	Coastal Surveillance
50		14°32′	144°45′	24/11/87	Coastal Surveillance
1		14°32′	144°46′	11/11/85	Coastal Surveillance
70	20	14°32′	144°46′	10/03/86	Coastal Surveillance
1		14°32′	144°48′	04/12/75	Heinsohn, J.C.U. survey
100		14°33′	144°42′	18/10/87	Coastal Surveillance
1		14°33′	144°44′	11/11/85	Coastal Surveillance
25		14°33′	144°46′	17/11/85	Coastal Surveillance
20		14°33′	144°46′	01/12/85	Coastal Surveillance

60		14°34′	144°40′	11/04/74	Heinsohn, J.C.U. survey
2		14°34′	144°45′	19/10/82	Coastal Surveillance
60		14°34′	144°47′	08/01/85	Coastal Surveillance
47		14°34′	144°54′	24/12/86	Coastal Surveillance
30		14°35′	144°53′	13/07/85	Coastal Surveillance
20		14°36′	144°35′	20/01/87	Coastal Surveillance
25		14°36′	144°35′	28/10/85	Coastal Surveillance
9		14°36′	144°39′	18/09/86	Coastal Surveillance
575		14°36′	144°41′	19/06/78	Heinsohn, J.C.U. survey
40		14°36′	144°44′	18/09/86	Coastal Surveillance
20		14°36′	144°52′	13/11/85	Coastal Surveillance
35		14°36′	144°52′	24/07/83	Coastal Surveillance
25		14°36′	144°54′	17/11/85	Coastal Surveillance
100		14°36′	144°54′	20/11/85	Coastal Surveillance
25		14°36′	144°54′	01/08/86	Coastal Surveillance
200		14°36′	144°54′	23/11/84	Coastal Surveillance
20		14°36′	144°57′	29/07/83	Coastal Surveillance
30		14°37′	144°55′	27/10/84	Coastal Surveillance
92		14°37′	144°51′	09/12/83	light commercial plane
30		14°37′	144°53′	29/11/85	Coastal Surveillance
1		14°37′	144°54′	15/11/76	Heinsohn, J.C.U. survey
20		14°37′	144°55′	13/11/85	Coastal Surveillance
1		14°37′	144°56′	20/01/85	light commercial plane
50		14°37′	144°56′	11/08/86	Coastal Surveillance
25		14°37′	144°57′	17/11/85	light commercial plane
2		14°38′	145°17′	21/06/85	light commercial plane
40		14°39′	144°56′	**/**/**	yacht
1		14°40′	145°06′	11/05/74	Heinsohn, J.C.U. survey
15		14°41′	144°58′	11/04/74	Heinsohn, J.C.U. survey
7		14°41′	144°59′	19/06/78	Heinsohn, J.C.U. survey
337		14°41′	144°59′	18/11/78	Heinsohn, J.C.U. survey
2		14°42′	145°07′	16/01/87	Coastal Surveillance
1		14°42′	145°31′	26/09/85	light commercial plane
100		14°43′	144°58′	19/12/85	Coastal Surveillance
100		14°43′	144°58′	15/12/85	Coastal Surveillance
3	1	14°43′	145°07′	16/10/85	Unknown
1		14°43′	145°14′	22/09/84	Coastal Surveillance
20		14°44′	144°59′	25/02/85	Coastal Surveillance
28	10	14°44′	145°05′	20/01/85	light commercial plane
3	1	14°44′	145°07′	16/10/85	small power boat (<5 m)
4	1	14°44′	145°13′	16/10/85	small power boat (<5 m)
10		14°45′	145°00′	07/06/85	light commercial plane
1		14°45′	145°09′	12/12/84	Coastal Surveillance
4	1	14°45′	145°12′	16/10/85	Unknown
2		14°46′	145°04′	05/01/85	light commercial plane
6	1	14°46′	145°06′	29/10/86	small power boat (<5 m)
6	2	14°46′	145°06′	21/06/85	light commercial plane
120		14°46′	145°11′	21/06/85	Unknown
20		14°46′	145°14′	30/06/85	Coastal Surveillance
20		14°47′	145°01′	14/07/85	light commercial plane
9		14°47′	145°01′	16/11/85	light commercial plane
6		14°47′	145°01′	20/06/85	Coastal Surveillance
50		14°47′	145°02′	10/05/85	light commercial plane
2		14°47′	145°02′	11/01/86	light commercial plane
3		14°47′	145°10′	23/06/85	light commercial plane
20		14°47′	145°14′	01/08/86	Coastal Surveillance
35		14°47′	145°14′	05/09/85	Coastal Surveillance
3	1	14°47′	145°22′	16/10/85	Unknown
21		14°48′	145°10′	11/04/74	Heinsohn, J.C.U. survey
14		14°48′	145°14′	09/06/85	Coastal Surveillance

80		14°49′	145°00′	30/10/85	Coastal Surveillance
150		14°49′	145°07′	15/11/76	Heinsohn, J.C.U. survey
21		14°49′	145°08′	11/04/74	Heinsohn, J.C.U. survey
100		14°49′	145°08′	15/11/76	Heinsohn, J.C.U. survey
47		14°49′	145°11′	08/11/85	light commercial plane
50		14°49′	145°12′	16/06/86	Coastal Surveillance
70		14°49′	145°12′	19/06/78	Heinsohn, J.C.U. survey
14		14°49′	145°13′	09/06/85	light commercial plane
35		14°49′	145°13′	05/09/85	Coastal Surveillance
50		14°49′	145°13′	24/02/86	light commercial plane
8	2	14°49′	145°14′	13/11/85	Unknown
6	1	14°49′	145°14′	05/12/86	light commercial plane
8	2	14°49′	145°14′	13/11/85	small power boat (<5m)
1		14°49′	145°14′	15/11/76	Heinsohn, J.C.U. survey
2	1	14°49′	145°21′	16/10/85	small power boat (<5m)
100		14°50′	145°14′	19/07/85	Coastal Surveillance
30		14°50′	145°14′	01/09/85	Coastal Surveillance
80		14°50′	145°14′	30/10/85	Coastal Surveillance
9		14°50′	145°17′	20/01/85	light commercial plane
5	1	14°50′	145°17′	26/01/85	light commercial plane
20		14°50′	145°17′	30/06/85	Coastal Surveillance
100		14°50′	145°17′	21/06/85	Coastal Surveillance
30		14°51′	145°28′	04/03/85	sighting from shore
1		14°53′	145°16′	18/11/78	Heinsohn, J.C.U. survey
30		14°54′	145°29′	31/03/87	light commercial plane
20		14°56′	142°59′	20/01/87	Coastal Surveillance
1		14°57′	145°22′	03/11/86	small power boat (<5m)
9		14°58′	144°41′	16/11/85	Coastal Surveillance
12		15°07′	145°26′	21/08/85	Coastal Surveillance
12		15°07′	145°26′	20/08/85	Coastal Surveillance
1		15°08′	145°26′	07/08/85	Coastal Surveillance

Table 4.

Incidental dugong sightings between Cape Bedford (15°15′,144°21′) and Dunk Island (17°57′,146°10′) in the Cairns Section.

No.Dugongs	/calves	Latitude	Longitude	Date of sighting D/M/Y	Observer
1		15°21′	145°19′	15/11/76	Heinsohn, J.C.U. survey
1		15°41′	145°29′	01/01/85	Coastal Surveillance
1		15°42′	145°33′	01/01/86	Coastal Surveillance
1		16°20′	145°44′	17/04/85	light commercial plane
1		16°22′	145°32′	22/11/84	Coastal Surveillance
1		16°24′	145°36′	11/04/74	Heinsohn, J.C.U. survey
1		16°25′	145°46′	08/02/86	Coastal Surveillance
2		16°54′	145°49′	20/03/88	Coastal Surveillance
3		17°47′	146°06′	23/10/85	small power boat (<5 m)
1	1	17°47′	146°06′	15/01/87	sighting from shore

Table 5.
Incidental dugong sightings between Dunk Island (17°57',146°10') and Cape Cleveland (19°11',147°01') in the Central Section.

No.Dugongs /calves		Latitude	Longitude	Date of sighting D/M/Y	Observer
2		18°09'	146°09'	**/**/**	Unknown
31		18°13'	146°10'	11/04/74	Heinsohn, J.C.U. survey
30	15	18°13'	146°14'	12/11/87	Unknown
1		18°16'	146°03'	28/02/87	small power boat (<5m)
1		18°16'	146°03'	31/03/86	sighting from shore
2		18°16'	146°04'	18/12/86	power boat
1		18°16'	146°06'	17/06/75	Heinsohn, J.C.U. survey
1		18°24'	146°11'	04/12/75	Heinsohn, J.C.U. survey
2		18°32'	146°48'	**/**/**	Unknown
1		18°47'	146°39'	09/06/86	sighting from shore
1		18°51'	148°10'	18/04/85	light commercial plane
1		19°09'	146°16'	15/06/85	Coastal Surveillance
1		19°09'	146°54'	08/05/79	Heinsohn, J.C.U. survey
1		19°10'	146°46'	08/05/79	Heinsohn, J.C.U. survey
1		19°10'	146°47'	31/05/86	yacht
2	1	19°13'	146°46'	07/11/86	in water (ie. diving)

Table 6.

Incidental dugong sightings between Cape Cleveland (19°11',147°01') and Repulse Bay (20°30',148°50') in the Central Section.

No.Dugongs	/calves	Latitude	Longitude	Date of sighting D/M/Y	Observer
20		19°13'	147°00'	08/05/79	Heinsohn, J.C.U. survey
8		19°14'	146°19'	**/**/**	Unknown
1		19°15'	146°50'	08/11/86	sighting from shore
1		19°15'	146°54'	08/05/79	Heinsohn, J.C.U. survey
2	1	19°16'	146°47'	09/11/86	sighting from shore
6		19°16'	146°52'	08/05/79	Heinsohn, J.C.U. survey
9		19°16'	146°55'	08/05/79	Heinsohn, J.C.U. survey
27		19°16'	146°56'	08/05/79	Heinsohn, J.C.U. survey
3		19°22'	147°24'	09/07/78	Heinsohn, J.C.U. survey
2		19°38'	147°40'	23/03/75	Heinsohn, J.C.U. survey
1		19°41'	147°43'	22/03/75	Heinsohn, J.C.U. survey
2	1	19°43'	147°44'	23/07/87	small power boat (<5 m)
1		19°44'	147°44'	22/03/75	Heinsohn, J.C.U. survey
1		19°47'	147°41'	22/03/75	Heinsohn, J.C.U. survey
1		19°48'	147°40'	18/04/75	Heinsohn, J.C.U. survey
1		19°48'	147°42'	18/04/75	Heinsohn, J.C.U. survey
11		19°48'	147°44'	22/03/75	Heinsohn, J.C.U. survey
1		19°49'	147°41'	18/04/75	Heinsohn, J.C.U. survey
1		19°49'	147°42'	22/03/75	Heinsohn, J.C.U. survey
1		19°49'	147°43'	22/03/75	Heinsohn, J.C.U. survey
1		19°49'	147°44'	22/03/75	Heinsohn, J.C.U. survey
3		19°51'	149°44'	15/05/87	research vessel
1		19°54'	147°53'	09/07/78	Heinsohn, J.C.U. survey
2	1	20°03'	148°17'	20/07/85	Unknown
8		20°06'	148°19'	09/07/78	Heinsohn, J.C.U. survey
1		20°19'	148°41'	28/09/87	yacht

Table 7.
Incidental dugong sightings between Repulse Bay (20°30',148°50') and Bustard Head (24°02',151°46) in the Southern Section of the Great Barrier Reef Marine Park.

No.Dugongs	/calves	Latitude	Longitude	Date of sighting D/M/Y	Observer
2	1	20°27'	148°48'	21/08/84	sighting from shore
6		20°36'	148°39'	18/11/84	sighting from shore
2		20°36'	148°39'	24/11/84	sighting from shore
3		20°51'	148°58'	09/07/78	Heinsohn, J.C.U. survey
4		21°25'	149°21'	09/07/78	Heinsohn, J.C.U. survey
3		21°25'	149°22'	09/07/78	Heinsohn, J.C.U. survey
1		21°27'	149°31'	09/07/78	Heinsohn, J.C.U. survey
15	2	21°53'	149°50'	21/05/87	helicopter
2		21°59'	149°31'	09/07/78	Heinsohn, J.C.U. survey
1		22°02'	149°32'	09/07/78	Heinsohn, J.C.U. survey
3		22°13'	150°29'	07/11/79	Heinsohn, J.C.U. survey
1		22°15'	150°10'	01/10/75	Heinsohn, J.C.U. survey
1		22°20'	150°17'	01/10/75	Heinsohn, J.C.U. survey
3		22°20'	150°43'	17/11/84	Unknown
1		22°21'	150°12'	19/06/75	Heinsohn, J.C.U. survey
11		22°21'	150°15'	19/06/75	Heinsohn, J.C.U. survey
2		22°22'	150°11'	07/11/79	Heinsohn, J.C.U. survey
1		22°22'	150°14'	19/06/75	Heinsohn, J.C.U. survey
63		22°22'	150°16'	07/11/79	Heinsohn, J.C.U. survey
11		22°23'	150°14'	01/10/75	Heinsohn, J.C.U. survey
1		22°24'	150°13'	19/06/75	Heinsohn, J.C.U. survey
42		22°24'	150°17'	19/06/75	Heinsohn, J.C.U. survey
1		22°24'	150°18'	19/06/75	Heinsohn, J.C.U. survey
1		22°24'	150°18'	01/10/75	Heinsohn, J.C.U. survey
1		22°24'	150°31'	01/10/75	Heinsohn, J.C.U. survey
8		22°24'	150°32'	07/11/79	Heinsohn, J.C.U. survey
17		22°26'	150°21'	08/08/79	Heinsohn, J.C.U. survey
6		22°26'	150°21'	07/11/79	Heinsohn, J.C.U. survey
1		22°26'	150°32'	01/10/75	Heinsohn, J.C.U. survey
1		22°28'	150°23'	19/06/75	Heinsohn, J.C.U. survey
58		22°28'	150°31'	08/08/79	Heinsohn, J.C.U. survey
1		22°28'	150°33'	01/10/75	Heinsohn, J.C.U. survey
7		22°29'	150°36'	07/11/79	Heinsohn, J.C.U. survey
1		22°30'	150°25'	01/10/75	Heinsohn, J.C.U. survey
60		22°30'	150°30'	01/10/75	Heinsohn, J.C.U. survey
60		22°31'	150°29'	01/10/75	Heinsohn, J.C.U. survey
1		22°32'	150°26'	19/06/75	Heinsohn, J.C.U. survey
11		22°32'	150°29'	19/06/75	Heinsohn, J.C.U. survey
15		22°32'	150°31'	07/11/79	Heinsohn, J.C.U. survey
15		22°32'	150°40'	07/11/79	Heinsohn, J.C.U. survey
80		22°33'	150°44'	08/08/79	Heinsohn, J.C.U. survey
1		22°34'	150°44'	19/06/75	Heinsohn, J.C.U. survey
19		22°34'	150°44'	07/11/79	Heinsohn, J.C.U. survey
3		22°36'	150°36'	01/10/75	Heinsohn, J.C.U. survey
8		22°36'	150°43'	14/11/84	small power boat (<5 m)
14		22°37'	150°43'	08/08/79	Heinsohn, J.C.U. survey
3		23°46'	151°09'	08/01/79	Heinsohn, J.C.U. survey
20		23°47'	151°16'	08/11/79	Heinsohn, J.C.U. survey
17		23°59'	151°29'	08/08/79	Heinsohn, J.C.U. survey

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Part 4

Raw data tables and programmes used in the estimation of prevailing weather conditions and the calculation of population and density estimates

SECTION 1

Raw data tables for dugongs in the survey area from the tip of Cape York south to Cape Bedford

Section 1: Raw data tables for dugongs in the survey area from the tip of Cape York south to Cape Bedford.

Table 1: Details of weather conditions encountered during the surveys.

Table 2: Beaufort Sea State and glare (for the north/east and south/west side of the aircraft) for each transect.

Table 3: Raw data for the surveys: dugong sightings.

Table 4: Logistics of flight time for each survey.

Table 5: Raw data used to calculate correction factors for each survey or sub-section of survey.

TABLE 1: Details of weather conditions encountered during the surveys.

Date	Session	Wind Speed (knots)	Wind Direction	Cloud Cover (oktas)	Cloud Height (ft)	Beaufort Sea State Inshore mode(range)	Beaufort Sea State Offshore mode(range)	Glare North mode(range)	Glare South mode(range)	Tide Time
Blocks 1 - 4, November 1984										
13/11/84	1	7	E	1	3000	1.0	1.0(0.5-1.0)	1.0		Low 0425[a]
	2	10	ESE	0	-	3.0(2.0-3.0)	3.0(1.5-3.0)	1.0(0.0-2.0)		High 1201[a]
14/11/84	1	<5	NW	2	2000	1.0(0.0-1.0)	0.5-1.0	1.0(0.0-1.0)		Low 0521[a]
	2	7	ESE	0	-	2.5(1.5-3.0)		1.0(0.0-2.0)		High 1450[a]
15/11/84	1	13	ESE	1	2500	2.0(1.0-3.0)		1.0(1.0-2.0)		Low 0710[a]
	2	13	SE	0	-	2.5(0.0-3.0)		1.0(0.0-2.0)		High 1544[a]
Blocks 6 - 13, April 1985										
21/04/85	1	10	E	3,7	1500,3000	1.5(1.0-2.5)	2.0(1.0-2.5)	1.5(0.0-3.0)	0.0(0.0-1.0)	High 0943[b]
	2	10-15	E	5,5	1500,30000	2.0(1.0-2.0)	2.0(1.0-2.0)	1.0(0.0-2.0)	0.0(0.0-1.0)	Low 1558[b]
22/04/85	1	5	E	2,4	1500,2000	2.0(1.0-2.5)	2.0(1.0-2.5)	2.0(0.0-3.0)	0.0	High 0956[b]
	2	10	ENE	4	1000	2.0(1.5-2.5)	2.0(1.0-2.0)	1.0(0.0-2.0)	0.5(0.0-1.0)	Low 1617[b]
23/04/85	1	10	ESE	5,4	700,20000	1.5(1.0-2.0)	1.5(1.0-2.5)	2.0(1.0-3.0)	0.5(0.0-1.0)	High 1004[b]
24/04/85	1	10	SE	6	1000	2.0(1.5-2.0)	3.0(2.0-3.5)	2.0(0.0-3.5)	1.0(0.0-1.0)	High 0849[b]
	2	12	ESE	5	1400	2.5(2.0-3.0)	2.5(1.0-3.0)	2.0(1.0-3.0)	1.0(0.0-1.0)	Low 1649[b]
25/04/85	1	5	E	3	1000	1.5(1.0-2.5)	2.0(1.5-3.0)	2.0(1.0-3.0)	0.0(0.0-1.0)	High 0806[b]
	2	10	E	2	1000	3.0(2.0-3.0)	2.0(1.0-3.0)	2.0(2.0-3.0)	0.5(0.0-1.0)	Low 1551[b]
26/04/85	1	10	E	7	8000	2.0(2.0-2.5)	1.0(1.0-3.0)	2.0(1.0-3.0)	0.5(0.0-1.0)	High 0426[b]
	2	10	ESE	4	1500	1.5(1.0-2.0)	1.0(1.0-2.0)	2.0(1.0-3.0)	2.0(0.0-2.0)	Low 1519[b]
Blocks 1 - 7, November 1985										
31/10/85	1	10	SSE	3	1500	3.0(0.0-4.0)		1.0(0.0-2.0)	1.0(0.0-2.5)	High 0931[a]
	2	20	SSE	3	5000	3.0(1.0-4.0)		1.0	1.0(0.0-1.0)	Low 1605[a]
01/11/85	1	10	E	3-8	1500	3.0(1.0-3.0)	3.0(2.0-3.0)	2.0(0.0-2.0)	1.0(1.0-2.0)	High 1035[a]
02/11/85	1	10	E	5	1000	2.5(2.0-3.0)	3.0(2.0-3.0)	2.0(0.0-2.0)	1.0(0.0-2.0)	High 1120[a]
03/11/85	1	10	E	1-6	1500	2.5(1.0-3.0)	2.5(1.0-3.0)	2.0(0.0-2.5)	2.0(0.0-2.0)	Low 0416[a]
	2	10	E	3,5	1000,5000	2.5(2.0-3.0)	2.5(2.0-3.0)	2.0(0.0-2.0)	1.0(0.0-2.0)	High 1522[a]
05/11/85	1	10	E	2,2	1500,12000	2.0(1.0-2.5)	2.0(1.0-2.5)	0.0(0.0-2.5)	2.0(0.0-2.0)	Low 0846[a]
	2	15	E	1	1000	2.5(0.0-3.0)		1.0(0.0-2.0)	1.0(0.0-2.0)	High 1629[a]
06/11/85	1	10	E	5	1500	2.0(1.0-2.5)		1.0(0.0-2.0)	1.0(0.0-2.0)	Low 0957[a]
	2	15	E	1	1500	2.0(1.0-3.0)		2.0(0.0-2.5)	1.0(0.0-2.0)	High 1659[a]

TABLE 1: continued.

Date	Session	Wind Speed (knots)	Wind Direction	Cloud Cover (oktas)	Cloud Height (ft)	Beaufort Sea State Inshore mode(range)	Beaufort Sea State Offshore mode(range)	Glare North mode(range)	Glare South mode(range)	Tide Time
Blocks 1 - 7, November 1985										
07/11/85	1	10	E	2-6	2000	1.0(0.0-2.5)		1.0(0.0-2.0)	0.0(0.0-2.0)	Low 1046[a]
	2	15	E	4,3	1500,9000	2.0(2.0-2.5)	2.0(1.0-2.5)	1.0(1.0-2.5)	1.0(0.0-2.0)	High 1729[a]
08/11/85	1	10	E	2-6	1000	2.5(1.0-2.5)	2.5(1.0-4.0)	1.0(0.0-2.0)	1.0(0.0-2.5)	Low 1133[a]
Blocks 8 - 13, November 1985										
17/11/85	1	5	NE	2	1500	0.5(0.0-1.0)	0.0(0.0-1.0)	1.0(0.0-2.5)	0.0(0.0-1.0)	Low 0700[b]
	2	10	E	1	1500	2.0	1.0(1.0-2.5)	2.0(0.0-2.0)	1.0(0.0-2.0)	High 1517[b]
18/11/85	1	0	-	2	2000	0.0(0.0-1.0)	0.0	1.0(-.0-1.0)	0.0(0.0-1.0)	Low 0900[b]
	2	0	-	1	1500	1.0(0.0-1.0)	0.0(0.0-1.0)	1.0(0.0-1.0)	0.0(0.0-1.0)	High 1625[b]
19/11/87	1	0	-	3	1000	1.0(0.0-1.5)	1.0(0.0-1.0)	1.0(0.0-2.0)	1.0(0.0-1.0)	Low 1025[b]
	2	10	ENE	-	-	2.0(1.0-2.5)	2.0(1.0-3.0)	2.0(0.0-2.0)	0.0(0.0-2.0)	High 1717[b]
20/11/85	1	5	E	1,4	1500,12000	1.0	1.0(0.0-1.0)	1.0(0.0-2.5)	1.0(0.0-2.0)	Low 1026[b]
	2	8	N	1,4	1500,12000	1.0(0.0-1.0)	1.0(0.0-1.0)	1.0(0.0-2.5)	0.5(0.0-1.0)	High 1800[b]
21/11/85	1	0	-	1	1500	0.5(0.0-1.0)	0.5(0.0-0.5)	1.0(0.0-2.0)	0.5(0.0-1.0)	Low 1219[b]

[a] Neap tides. Times are for Cape Flattery and equal Cairns -10 mins.

[b] Tide times are for Cape Grenville and equal Cairns +40 mins.

TABLE 2: Beaufort Sea State and glare (for the north/east and south/west sides of the aircraft) for each transect.

Scale : 0 = no glare
1 = 0 < 25% field of view glare affected
2 = 25 < 50% field of view glare affected
3 = > 50% field of view glare affected

Transect No.	Beaufort Sea State Inshore mode(range)	Beaufort Sea State Offshore mode(range)	Glare North mode(range)	Glare South Mode(range)
Blocks 1 - 4, November 1984				
1	1.0	1.0	detailed glare data not recorded for this survey	
2	1.0	1.0(0.5-1.0)		
3	1.0	1.0		
4	-	1.0		
5	2.5(2.0-3.0)	2.5(2.0-2.5)		
6	-	1.5-3.0		
7	3.0	2.5-3.0		
8	3.0	3.0(2.0-3.0)		
9	-	3.0		
10	1.0	0.5(0.5-1.0)		
11	0.5	0.5(0.5-1.0)		
12	0.0-1.0	1.0		
13	0.5	1.0		
14	-	0.5		
15	2.0			
16	2.5(2.0-2.5)			
17	2.0(2.0-2.5)			
18	2.0(0.0-2.5)			
19	2.0(2.0-2.5)			
20	2.0			
21	2.5			
22	2.0(2.0-2.5)			
23	2.5			
24	2.5-3.0			
25	1.5(1.0-2.0)			
26	1.0-2.0			
27	1.0-2.0			
28	2.5(2.0-3.0)			
29	2.5			
30	2.5(2.0-3.0)			
31	3.0			
32	3.0			
33	2.5			
34	2.5			
35	2.5-3.0			
36	3.0			
37	2.0(2.0-2.5)			
38	1.5-2.0			
39	2.0			
40	2.0(2.0-2.5)			

Table 2: continued.

Transect No.	Beaufort Sea State Inshore mode(range)	Beaufort Sea State Offshore mode(range)	Glare North mode(range)	Glare South Mode(range)
Blocks 6 - 13, April 1985				
1	2.0(2.0-2.5)	2.0(1.0-2.5)	2.0(1.0-2.0)	0.0
2	1.0(1.0-1.5)	1.0(1.0-2.0)	2.0(0.0-3.0)	0.0(0.0-1.0)
3	1.5(1.5-2.0)	1.5(1.0-2.0)	1.5(0.0-2.0)	0.0
4	1.5	1.0(1.0-2.0)	1.0(0.0-2.0)	0.0
5	1.5(1.5-2.0)	2.0(1.5-2.5)	1.0	0.0
6	1.5(1.0-2.0)	2.0(1.0-2.5)	1.5(1.0-2.0)	0.0
7	2.0	2.0(1.0-2.0)	1.0	0.0
8	1.0	1.5(1.0-2.0)	2.0(0.0-2.0)	0.0
9	2.0	2.0(1.5-2.0)	1.0	0.0
10	-	2.0	0.5(0.0-1.0)	0.0
11	1.5	1.5(1.5-2.0)	1.0	1.0
12	2.0	2.0	1.0	0.0
13	2.0(2.0-2.5)	2.0(2.0-2.5)	2.0	0.0
14	2.0(2.0-2.5)	2.0(2.0-2.5)	1.5(0.0-1.5)	0.0
15	2.5	2.5(2.0-2.5)	2.0(1.0-2.0)	0.0
16	2.0	2.0(2.0-2.5)	2.0	0.0
17	1.0(1.0-2.0)	2.0(1.5-2.5)	2.0	0.0
18	1.5(1.5-2.0)	1.5(1.0-2.0)	2.0(1.0-2.0)	0.0
19	2.0(1.0-2.0)	2.0(1.5-2.5)	2.0(1.0-2.0)	0.0
20	-	2.0(1.5-2.5)	3.0(2.0-3.0)	0.0
21	2.0	2.0(1.5-2.5)	2.5(2.0-3.0)	0.0
22	-	2.0(1.0-2.0)	2.0(1.0-3.0)	0.0
23	-	1.5(1.0-1.5)	2.5(2.0-3.0)	0.0
24	2.0	1.5(1.0-2.5)	2.0	0.0
25	2.5	2.0(2.0-2.5)	1.5(1.0-2.0)	1.0
26	2.5	2.0(1.0-2.5)	2.0	1.0
27	-	2.5(1.5-2.5)	2.0	1.0
28	2.5	2.5(1.0-3.0)	2.0	0.5(0.0-1.0)
29	2.0(2.0-2.5)	2.0(2.0-2.5)	3.0(1.0-3.0)	0.5(0.0-1.0)
30	3.0	2.5(1.0-2.5)	2.0	0.5(0.0-1.0)
31	3.0(2.5-3.0)	2.0(1.0-3.0)	2.0	0.0
32	2.5(2.0-3.0)	2.0(2.0-2.5)	2.0(2.0-3.0)	1.0(0.0-1.0)
33	2.0	1.0(1.0-2.0)	3.0(2.0-3.0)	0.0
34	2.5	2.0(1.0-2.5)	2.0	0.0
35	2.0	1.5(1.0-2.0)	2.0	1.0(0.0-1.0)
36	2.0	2.0(1.0-3.0)	2.0(1.0-2.0)	1.0
37	2.0(2.0-2.5)	1.5(1.5-2.5)	1.5(1.0-2.0)	1.0
38	-	2.5(2.0-3.0)	3.0(0.0-3.5)	1.0
39	2.0	3.0(2.0-3.0)	3.0(1.0-3.0)	0.0
40	1.0	1.0(1.0-2.0)	2.0	0.0
41	2.0	1.5(1.0-2.0)	2.0(2.0-3.0)	2.0(1.0-2.0)
42	2.0(1.5-2.5)	2.0(2.0-3.0)	2.0(2.0-3.0)	0.0
43	2.0	3.0(2.0-3.0)	2.0(1.0-2.0)	0.0(0.0-1.0)
44	2.0	2.5(2.5-3.5)	2.0(0.0-2.5)	1.0
45	2.0(1.5-2.5)	3.0(2.0-3.5)	2.0	0.5(0.0-1.0)
46	1.5	1.0(1.0-2.0)	2.0	1.0
47	1.0(1.0-1.5)	2.0(1.0-2.0)	2.0(1.0-2.0)	0.0(0.0-1.0)
48	1.5	2.0(1.0-2.0)	1.0(1.0-2.0)	1.0(0.0-1.0)
49	2.0	2.0(1.0-2.0)	2.0	0.0
50	1.0(1.0-1.5)		2.0	0.0
51	1.5(1.0-2.0)		2.0	0.0
52	2.0(1.0-2.0)		2.0(0.0-2.0)	0.0
53	1.0(1.0-2.5)		1.5(1.0-3.0)	0.0
54	2.5(2.0-2.5)		1.5(0.0-2.5)	0.0
55	2.0(1.5-2.5)		3.0	0.0
56	2.5(2.0-2.5)		3.0	0.0
57	1.5(1.0-2.0)		3.0	0.0

Table 2: continued.

Transect No.	Beaufort Sea State Inshore mode(range)	Offshore mode(range)	Glare North mode(range)	South Mode(range)
Blocks 1 - 4, November 1985				
1	2.5(1.0-3.0)	3.0	1.0-2.0	1.0
2	3.0	3.0	1.0	1.0-2.0
3	3.0	3.0(2.0-3.0)	1.0-2.0	1.0
4	3.0	3.0(2.0-3.0)	1.0	1.0-2.0
5	3.0	3.0(2.0-3.0)	1.0-2.0	2.0
6	3.0	3.0(2.0-3.0)	1.0-2.0	1.0-2.0
7	3.0(2.0-3.0)	2.0(2.0-3.0)	1.0-2.0	1.0
8	3.0	3.0	1.0-2.0	2.0
9	3.0	3.0(2.0-3.0)	2.0(0.0-2.0)	1.0(1.0-2.0)
10	3.0	2.5(2.0-3.0)	0.0-2.0	0.0-2.0
11	3.0	3.0(2.0-3.0)	2.0(1.0-2.0)	2.0(1.0-2.0)
12	2.0(2.0-3.0)	3.0(2.0-3.0)	1.0(0.0-1.0)	1.0(0.0-1.0)
13	2.5-3.0	3.0(2.0-3.0)	2.0(0.0-2.0)	1.0(0.0-2.0)
14	2.5	2.5(2.0-3.0)	2.0(1.0-2.0)	2.0(1.0-2.0)
15	3.0(2.5-3.0)	2.5(2.0-3.0)	1.0	2.0(1.0-2.0)
16	3.0(2.0-3.0)	3.0(2.0-3.0)	0.0(0.0-1.0)	2.0(0.0-2.0)
17	2.5(2.0-2.5)	2.5(2.0-3.0)	2.0(1.0-2.0)	2.0(1.0-2.0)
18	2.5(2.0-2.5)	3.0(2.0-3.0)	2.0(0.0-2.0)	1.0-2.0
19	2.5(2.0-3.0)	2.5(2.0-3.0)	1.0(0.0-2.0)	2.0(0.0-2.0)
20	2.5(2.0-2.5)	2.5(1.0-3.0)	2.0(0.0-2.0)	2.0(0.0-2.5)
21	3.0(2.5-3.0)	2.5(2.0-3.0)	0.0(0.0-1.5)	2.0(0.0-2.0)
22	3.0(1.0-3.0)	2.0(1.0-2.5)	1.0(0.0-2.0)	2.0(1.0-2.0)
23	2.5(2.0-3.0)	2.5(2.0-3.0)	1.0(0.0-2.0)	1.0(0.0-2.0)
24	2.0-2.5	2.0-2.5	0.0-2.0	2.0(1.0-2.0)
25	2.0(2.0-2.5)	2.0(1.0-2.5)	0.0(0.0-2.0)	0.0(0.0-2.0)
26	2.0(1.0-2.5)	2.5(1.0-2.5)	0.0-2.0	0.0(0.0-2.0)
27	2.5(2.0-2.5)	2.0(1.0-2.0)	1.0(0.0-2.0)	1.0(0.0-2.0)
28	2.5(2.5-3.0)		1.0	1.0
29	3.0(2.5-3.0)		2.0	2.0
30	3.0(2.5-3.0)		1.0	1.0-2.0
31	3.0(2.5-3.0)		2.0	2.0
32	3.0(2.5-3.0)		1.0	1.0-2.0
33	2.5(2.0-3.0)		1.0(1.0-2.0)	1.0(0.0-2.0)
34	2.5(2.5-3.0)		1.0	1.0-2.0

Table 2: continued.

Transect No.	Beaufort Sea State Inshore mode(range)	Offshore mode(range)	Glare North mode(range)	South Mode(range)
Blocks 5, November 1985				
1	3.0(2.5-4.0)		1.0	1.0
2	3.0(1.0-4.0)		1.0	0.0
3	3.0(1.0-4.0)		1.0	1.0
4	3.5(2.0-4.0)		1.0	1.0
5	3.0(0.0-3.0)		1.0(0.0-2.0)	1.0(0.0-2.0)
6	3.0(0.5-3.0)		0.0-1.0	1.0(0.0-2.0)
7	3.0(1.0-4.0)		2.0(1.0-2.0)	2.5(1.0-2.5)
8	1.0(1.0-4.0)		0.0-1.0	1.0
9	2.5(0.0-3.0)		0.0-2.0	0.0-2.0
10	2.5(1.0-3.0)		1.0-2.0(0.0-2.5)	2.0(0.0-2.5)
11	2.5(2.0-3.0)		1.0(0.0-2.0)	1.0(1.0-2.0)
12	2.0(0.0-3.0)		1.0(0.0-2.0)	1.0(0.0-2.0)
13	2.5(1.0-4.0)		2.0(0.0-2.0)	2.0(0.0-2.5)
14	2.0(1.0-2.5)		1.0(0.0-2.0)	1.0(0.0-2.0)
15	1.0(1.0-2.5)		1.0(0.0-2.0)	1.0(0.0-2.0)
16	1.0(0.0-2.5)		1.0(0.0-2.0)	0.0(0.0-2.0)
17	2.0(1.0-2.5)		1.0(0.0-2.0)	0.0(0.0-2.0)
18	2.0(1.0-2.5)		0.0-1.0(0.0-2.0)	0.0-2.0
19	2.0(1.0-2.5)		1.0-2.0(0.0-2.0)	1.0-2.0
20	1.0(1.0-2.5)		1.0(0.0-1.0)	0.0-2.0
21	2.0(1.0-2.5)		1.0-2.0	0.0-2.0
22	2.5(1.0-2.5)		2.0(0.0-2.0)	1.0
23	2.0(1.0-2.5)		1.0(0.0-2.0)	1.0(0.0-2.0)

Table 2: continued.

Transect No.	Beaufort Sea State Inshore mode(range)	Beaufort Sea State Offshore mode(range)	Glare North mode(range)	Glare South Mode(range)
Blocks 2 - 16, November 1985				
1	2.0	2.0(1.0-2.5)	0.0(0.0-2.0)	0.0-2.0
2	2.0	2.5(1.0-2.5)	1.0(0.0-1.0)	1.0(0.0-2.0)
3	2.0	1.0(1.0-2.0)	0.0(0.0-2.0)	0.0(0.0-2.0)
4	1.5(1.0-2.0)	2.0(1.0-2.5)	0.0-1.0	0.0(0.0-2.0)
5	2.0	2.0(1.0-2.5)	1.0(0.0-2.0)	1.0(0.0-2.0)
6	2.0-2.5	1.0(1.0-2.5)	1.0(0.0-1.0)	0.0-2.0
7	2.5(2.0-2.5)	2.0(1.0-3.0)	1.0(1.0-2.0)	1.0(0.0-2.0)
8	2.0(1.0-2.5)	2.0(1.0-3.0)	1.0(0.0-2.0)	1.0(0.0-2.0)
9	1.0(1.0-2.5)	2.5(1.0-3.0)	1.0(0.0-2.0)	1.0(0.0-2.0)
10	-	2.5(1.0-3.0)	1.0(0.0-2.0)	2.0(0.0-2.0)
11	2.0	2.5(1.0-4.0)	0.0-2.0	0.0-2.0(0.0-2.5)
12	1.0	2.0(1.0-3.0)	0.0-1.0	0.0-2.0
13	0.5(0.0-1.0)	0.0	0.0	0.0(0.0-1.0)
14	0.0(0.0-1.0)	0.0	0.0	0.0
15	0.0	0.0(0.0-1.0)	0.0	0.0-1.0
16	-	0.0(0.0-1.0)	0.0	0.0-1.0
17	1.0	0.0(0.0-1.0)	0.0(0.0-1.0)	0.0-1.0
18	1.0-1.5	0.5(0.0-1.0)	1.0	1.0-2.0
19	1.0	1.0(0.0-1.0)	0.0-1.0	0.0-1.0
20	2.0-2.5	1.5(1.0-2.0)	1.0(0.0-1.0)	0.0-1.0(0.0-2.0)
21	2.5	2.0(0.0-2.5)	0.0-1.0	1.0-2.0
22	-	2.0(1.0-2.5)	0.0(0.0-2.0)	0.0(0.0-1.0)
23	2.0(2.0-2.5)	1.0(0.0-2.0)	0.0-1.0	2.0
24	2.0	2.0(1.0-3.0)	0.0(1.0-2.0)	0.0(0.0-2.0)
25	1.5(1.0-2.0)	2.0(0.0-3.0)	0.0-1.0	2.0
26	-	1.0(0.0-1.0)	1.0(0.0-1.0)	1.0(1.0-2.0)
27	1.0	1.0(0.5-1.0)	1.0(0.0-1.0)	0.0(0.0-1.0)
28	-	1.0(0.5-1.0)	0.0	1.0
29	1.0(1.0-2.0)	1.0(0.0-1.0)	0.0-1.0	1.0(0.0-1.0)
30	0.0	1.0(0.0-0.5)	0.0(0.0-1.0)	1.0
31	0.5-1.0	0.5	1.0(0.0-1.0)	1.0(0.0-2.0)
32	1.0	1.0(0.0-1.0)	1.0(0.0-1.0)	1.0(0.0-1.0)
33	1.0	1.0(0.0-1.0)	1.0(0.0-1.0)	2.0(0.0-2.5)
34	-	1.0(0.0-1.0)	0.0(0.0-1.0)	1.0-2.0(0.0-2.0)
35	1.0	1.0(0.0-1.0)	1.0(0.0-2.0)	2.0(0.0-2.0)
36	-	1.0(0.0-1.0)	0.0(0.0-1.0)	1.0-2.0
37	1.0	1.0	0.0-1.0	1.0(0.0-2.0)
38	1.0	0.0(0.0-1.0)	0.0	0.0-1.0
39	-	1.0(0.0-1.0)	1.0(0.0-1.0)	1.0(0.0-2.0)
40	1.0(0.0-1.0)	0.0(0.0-1.0)	0.0	0.0-1.0
41	1.0(0.0-1.0)	1.0(0.0-1.0)	0.0	0.0-1.0
42	1.0	0.0(0.0-1.0)	0.0-1.0	0.0-1.0
43	0.5(0.0-1.0)	0.0	0.0(0.0-1.0)	1.0(0.0-1.0)
44	0.0	0.0	0.0	0.0-1.0
45	0.0	0.0	0.0	1.0
46	-	1.0(1.0-2.5)	1.0	2.0(0.0-2.0)
47	2.0	1.0(1.0-2.0)	1.0(0.0-1.0)	2.0(0.0-2.0)
48	-	0.0(0.0-1.0)	0.0-1.0	2.0(0.0-2.0)
49	0.5(0.0-1.0)	1.0(0.0-1.0)	1.0(0.0-1.0)	1.0(0.0-2.50
50	0.5(0.0-1.0)		0.0	1.0
51	0.0		0.0	1.0
52	0.0		0.0	1.0
53	0.0(0.0-1.0)		0.0	1.0
54	0.0		0.0	1.0-2.0
55	1.0		0.0	1.0
56	1.0		0.0(0.0-1.0)	1.0
57	1.0		1.0	1.0

TABLE 3: Raw data for the surveys: dugong sightings.

(a) Blocks 1 - 4, November 1984

Transect No.	No. of observers Port	Starboard	No. of groups of turtles Port Rear	Starboard Rear
001	1	1	0	1
002	1	1	1	1
003	1	1	0	1
004	1	1	0	0
005	1	1	0	0
006	1	1	0	0
007	1	1	0	1
008	1	1	0	2
009	1	1	4	1
010	1	1	3	5
011	1	1	6	0
012	1	1	1	2
013	1	1	1	1
014	1	1	0	0
015	1	1	0	0
016	1	1	0	0
017	1	1	0	0
018	1	1	0	0
019	1	1	0	0
020	1	1	0	0
021	1	1	0	0
022	1	1	0	0
023	1	1	0	1
024	1	1	0	1
025	1	1	0	1
026	1	1	6	4
027	1	1	0	1
028	1	1	0	2
029	1	1	0	0
030	1	1	1	1
031	1	1	1	2
032	1	1	2	3
033	1	1	0	1
034	1	1	1	0
035	1	1	1	0
036	1	1	0	0
037	1	1	0	0
038	1	1	0	0
039	1	1	0	1
040	1	1	0	1
			28	34

TABLE 3: continued.

(b) Blocks 6 - 13, April 1985

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Rear	Starboard Mid	Rear	Tandem
001	1	2	2	0	0	0
002	1	2	1	0	1	0
003	1	2	0	0	0	0
004	1	2	1	0	0	0
005	1	2	1	6	0	5
006	1	2	1	1	0	0
007	1	2	0	0	0	0
008	1	2	1	1	0	0
009	1	2	0	0	0	1
010	1	2	0	0	0	0
011	1	2	0	0	0	0
012	1	2	2	0	0	0
013	1	2	0	0	0	0
014	1	2	2	0	0	0
015	1	2	1	0	0	0
016	1	2	0	0	0	0
017	1	2	0	1	0	0
018	1	2	0	0	0	0
019	1	2	0	0	0	0
020	1	2	0	0	0	0
021	1	2	0	0	0	0
022	1	2	0	0	0	0
023	1	2	0	0	0	0
024	1	2	0	0	0	0
025	1	2	1	0	0	0
026	1	2	0	0	0	0
027	1	2	1	0	0	1
028	1	2	2	0	2	0
029	1	2	0	0	1	0
030	1	2	1	0	0	0
031	1	2	0	0	0	0
032	1	2	0	0	0	0
033	1	2	0	0	0	0
034	1	2	0	0	0	0
035	1	2	0	0	0	0
036	1	2	0	0	0	0
037	1	2	0	0	0	0
038	1	2	0	0	0	0
039	1	2	0	0	0	0
040	1	2	0	0	0	0
041	1	2	0	0	0	1
042	1	2	0	0	0	1
043	1	2	0	0	0	0
044	1	2	0	0	0	0
045	1	2	0	0	0	0
046	1	2	0	0	0	0
047	1	2	0	0	0	0
048	1	2	0	0	0	0
049	1	2	0	0	0	0
050	1	2	0	0	0	0
051	1	2	0	1	0	0
052	1	2	0	0	0	0

TABLE 3: continued.

(b) Blocks 6 - 13, April 1985

Transect No.	No. of observers		No. of groups of dugongs			
	Port	Starboard	Port	Starboard		
			Rear	Mid	Rear	Tandem
053	1	2	2	0	1	1
054	1	2	2	0	1	0
055	1	2	0	0	0	1
056	1	2	0	0	0	0
057	1	2	0	0	1	1
			21	10	7	12

TABLE 3: continued.

(c) Blocks 1 - 4, November 1985

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
001	2	2	0	0	0	0	0	0
002	2	2	0	0	0	0	0	0
003	2	2	0	0	0	0	0	0
004	2	2	0	0	0	0	0	0
005	2	2	0	0	0	0	0	0
006	2	2	0	0	0	0	0	0
007	2	2	0	0	0	0	0	0
008	2	2	0	0	0	0	0	0
009	2	2	0	0	0	0	0	0
010	2	2	0	0	0	0	0	0
011	2	2	1	0	5	0	0	2
012	2	2	3	1	9	0	9	6
013	2	2	2	0	2	0	0	0
014	2	2	4	1	4	2	0	1
015	2	2	0	0	0	1	0	2
016	2	2	0	0	0	0	0	0
017	2	2	0	0	0	0	0	2
018	2	2	0	0	2	0	0	0
019	2	2	0	0	0	0	1	0
020	2	2	2	0	1	1	0	0
021	2	2	0	0	0	0	0	0
022	2	2	0	0	1	0	1	2
023	2	2	0	0	0	0	0	0
024	2	2	0	0	0	0	0	0
025	2	2	0	0	1	0	0	0
026	2	2	0	0	0	0	0	0
027	2	2	0	0	0	0	0	0
028	2	2	2	3	4	2	0	0
029	2	2	1	0	2	1	1	2
030	2	2	1	0	1	1	0	0
031	2	2	2	2	0	0	0	1
032	2	2	0	0	0	0	0	0
033	2	2	0	0	1	0	0	0
034	2	2	0	0	0	0	1	0
			18	7	33	8	13	17

TABLE 3: continued.

(d) Block 5, November 1985

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
001	2	1	0	1	0		1	
002	2	1	1	0	2		1	
003	2	1	0	0	0		0	
004	2	1	0	1	2		1	
005	2	1	2	1	0		2	
006	2	1	1	2	1		3	
007	2	1	1	3	2		2	
008	2	1	1	1	0		0	
009	2	2	0	1	0	0	0	0
010	2	2	0	0	0	0	0	1
011	2	2	1	0	2	0	1	1
012	2	2	1	0	3	1	0	1
013	2	2	1	1	1	0	1	3
014	2	2	1	0	1	2	1	0
015	2	2	0	0	3	0	0	1
016	2	2	0	0	0	1	0	0
017	2	2	0	0	1	0	0	0
018	2	2	0	0	2	1	0	1
019	2	2	0	0	0	1	0	0
020	2	2	1	0	0	1	0	0
021	2	2	0	0	0	0	1	0
022	2	2	0	0	0	0	1	0
023	2	2	0	0	0	0	0	0
			11	11	20	7	15	8

TABLE 3: continued.

(e) Blocks 6 - 13, April 1985

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs	Port Rear		Starboard Mid	Rear	Tandem
001	2	2	1	0	2	0	0	1
002	2	2	0	0	0	0	0	0
003	2	2	0	0	0	0	0	0
004	2	2	0	0	1	0	0	0
005	2	2	3	0	2	0	0	4
006	2	2	0	0	0	0	0	0
007	2	2	0	0	0	0	0	0
008	2	2	0	0	0	0	0	0
009	2	2	1	0	0	0	0	0
010	2	2	1	0	0	0	0	0
011	2	2	1	0	0	1	0	0
012	2	2	0	0	0	0	0	0
013	2	2	0	1	0	0	0	0
014	2	2	0	1	0	0	0	1
015	2	2	0	0	0	0	0	1
016	2	2	0	0	0	0	0	0
017	2	2	0	0	1	0	0	0
018	2	2	1	0	1	0	0	0
019	2	2	0	0	0	0	0	1
020	2	2	0	0	0	1	1	0
021	2	2	0	0	0	0	0	0
022	2	2	0	0	0	0	0	0
023	2	2	0	0	0	0	0	0
024	2	2	0	0	0	0	0	1
025	2	2	0	0	0	0	0	0
026	2	2	1	0	0	0	0	0
027	2	2	0	0	1	0	0	0
028	2	2	0	0	0	0	0	0
029	2	2	1	0	1	0	0	0
030	2	2	0	0	4	0	0	1
031	2	2	0	0	0	0	0	0
032	2	2	0	0	0	0	0	0
033	2	2	0	0	0	0	0	0
034	2	2	0	0	0	0	0	0
035	2	2	0	0	0	0	0	0
036	2	2	0	0	1	0	0	0
037	2	2	0	0	0	0	0	0
038	2	2	0	0	0	0	0	1
039	2	2	0	0	1	0	0	0
040	2	2	0	0	2	0	0	2
041	2	2	0	0	0	1	0	0
042	2	2	0	0	0	0	0	0
043	2	2	0	0	0	0	0	0
044	2	2	0	0	0	0	0	0
045	2	2	0	0	0	0	0	0
046	2	2	0	0	0	0	0	0
047	2	2	1	0	0	0	0	0
048	2	2	0	0	0	0	1	0
049	1	2		0		0	0	0
050	1	2		1		0	1	0
051	1	2		0		0	0	0
052	1	2		0		0	0	0

TABLE 3: continued.

(e) Blocks 6 - 13, April 1985

Transect No.	No. of observers Port	Starboard		No. of groups of dugongs Port Rear		Starboard Mid	Rear	Tandem
053	1	2		3		0	2	2
054	1	2		5		0	2	2
055	1	2		0		0	0	0
056	1	2		0		0	0	1
057	1	2		0		0	1	2
			12	12	17	3	3	20

TABLE 4: Logistics of flight time for each survey

Survey	Transit Time (hrs)	Survey Time (hrs)	Dead Time (hrs)
Blocks 1 to 4, November 1984[a]	2.5	10.0	6.1
Blocks 6 to 13, April 1985	7.6	19.7	11.1
Blocks 1 to 7 and blocks 8 and 9 transects 10 to 12, November 1985	5.1	23.5	6.1
Blocks 8 and 9, transects 13 to 32 and blocks 10 to 13, November 1985	6.8	16.6	11.6

[a] Extra expenses: $286 for fuel relocation

TABLE 5: Raw data used to calculate correction factors for each survey or sub-section of survey.

(a) Correction for perception bias

Survey date	Blocks	Transects	No. of groups of dugongs Port mid-seat	 rear-seat	 tandem	 Starboard mid-seat	 rear-seat	 tandem
November 1984	1 to 4	1 to 40	correction factor based on starboard rear-seat observer, November 1985 survey, blocks 8 - 13, transects 13 - 57.					
April 1985	6 to 13	1 to 57		21		10	7	12
November 1985	1 to 4 5[a] 6 and 7 8 and 9	1 to 34 1 to 23 1 to 9 10 to 12	36	18	58	16	18	30
November 1985	8 and 9 10 to 13[b]	13 to 32 33 to 57	5	3	12	2	3	15

[a] starboard perception correction factor for transects 1 to 8, block 5 is based on starboard rear-seat observer correction factor for all transects excluding 1 to 8, block 5.

[b] port perception correction factor for transects 50 to 57, block 11 and transect 49, blocks 12 and 13 is based on port rear-seat observer correction factor for all transects excluding these.

(b) Correction for availability bias

Survey date	Blocks	Transects	No. of dugongs in groups ≤ 8 Surface	 Underwater	 Total
November 1984	1 to 4	1 to 40	71	101	172
April 1985	6 to 13	1 to 57	26	54	80
November 1985	1 to 4 5 6 and 7 8 and 9	1 to 34 1 to 23 1 to 9 10 to 12	78	192	270
November 1985	8 and 9 10 to 13	13 to 32 33 to 57	18	57	75

SECTION 2

Raw data tables for dugongs in the survey area from Cape Bedford south to Bustard Head

Section 2: Raw data table for dugongs in the survey area from Cape Bedford south to Bustard Head.

Table 1: Details of weather conditions encountered during the surveys.

Table 2: Beaufort Sea State and glare (for the north/east and south/west side of the aircraft) for each transect.

Table 3: Raw data for the surveys: dugong sightings.

Table 4: Raw data used to calculate correction factors for the surveys.

Table 5: Logistics of flight time for each survey.

TABLE 1: Details of weather conditions encountered during the surveys.

Date	Session	Wind Speed (knots)	Wind Direction	Cloud Cover (oktas)	Cloud Height (ft)	Beaufort Sea State mode(range)	Glare* North/East mode(range)	Glare* South/West mode(range)	Tide Time
(a) Northern Central Section, September 1986									
22/09/86	1	0	-	2	1000	1.0(0.0-3.0)	1.0(0.0-2.0)	0.0(0.0-2.0)	High 1131[a]
	2	6	SE	0	-	1.0(1.0-2.0)	2.0(1.0-2.0)	0.0(0.0-1.0)	Low 1622[a]
23/09/86	1	<5	V	0	-	1.0(0.0-2.5)	1.0(0.0-2.0)	0.0(0.0-1.0)	Low 0358[a]
	2	10	E	1	3000	1.0(0.0-2.0)	1.0(0.0-2.0)	0.0	High 1525[c]
24/09/86	1	2	N	1	2500	1.0(1.0-2.0)	1.0(0.0-3.0)	0.0(0.0-3.0)	Low 0811[b]
	2	7	NE	2,2	3000,4000	1.0(1.0-2.0)	2.0(1.0-3.0)	0.0	High 1733[b]
(b) Central Section, September - October 1987									
29/09/87	1	10	ESE	2	2000	2.0(0.0-3.0)	1.0(0.0-2.0)	0.0	Low 0657[b]
	2	8	E	0	-	1.0(1.0-3.0)	2.0(1.0-2.0)	0.0	High 1548[b]
	3	0	-	0	-	3.0(1.0-3.0)	1.0-2.0(0.0-2.5)	0.0(0.0-1.0)	
30/09/87	1	0	-	1	1500	0.5(0.0-1.0)	1.0(0.0-2.0)	0.0(0.0-1.0)	High 0413[h]
	2	0	-	3	3000	1.0(0.0-2.0)	2.0(1.0-2.5)	0.0(0.0-1.0)	Low 1008[h]
	3	5	W	0	-	2.0(0.0-3.0)	1.0(0.0-2.0)	0.0(0.0-1.0)	High 1708[h]
1/10/87	1	0	-	1,1	2500,20000	0.0(0.0-1.0)	0.0(0.0-1.0)	0.0	Low 0430[b]
	2	0	-	1	2500	1.0(0.0-3.0)	2.0(1.0-3.0)	0.0(0.0-1.0)	High 1030[b]
5/10/87	1	0	-	3	1500	1.0(1.0-3.0)	1.0(0.0-2.0)	0.0(0.0-2.0)	High 0723[b]
6/10/87	1	0	-	0	-	0.0(0.0-1.0)	1.0(0.0-2.0)	0.0	High 0804[b]
	2	0	-	0	-	1.0(0.0-1.0)	2.0(0.0-3.0)	0.0	Low 1413[b]
	3	8	SE	0	-	2.0(0.0-3.0)	2.0(1.0-2.5)	0.0(0.0-1.0)	
7/10/87	1	0	-	2	1000	0.0(0.0-1.5)	0.0(0.0-1.0)	0.0	High 0844[b]
	2	8	E	2	1500	0.5(0.0-3.0)	3.0(1.0-3.0)	0.0(0.0-1.0)	Low 1453[b]
21/10/87[k]	1	0	-	0	-	0.0(0.0-2.0)	1.0(0.0-2.0)	1.0(0.0-1.0)	High 0753[b]
(c) Mackay/Capricorn Section, November 1986									
18/11/86	1	10	N	4	2500	2.0(0.0-3.0)	1.0(0.0-2.0)	1.0(0.0-2.0)	High 1139[d]
21/11/86	1	5	S	0	-	1.0-3.0	1.5(0.0-2.0)	1.5(0.0-2.0)	Low 0648[d]
	2	10	E	0	-	2.0(0.0-3.0)	1.0(1.0-2.0)	1.0(0.0-2.0)	High 1317[d]
22/11/86	1	5	S	0	-	1.0(0.0-1.0)	1.0(0.0-2.0)	1.0(0.0-2.0)	Low 0552[e]
	2	0	-	0	-	2.0(1.0-3.0)	2.0(1.0-2.5)	2.0(1.0-2.0)	High 1252[e]
23/11/86	1	5	SE	3	2000	0.0-1.0	0.0(0.0-2.0)	1.0(0.0-2.0)	Low 0658[f]
	2	5	E	0	-	2.0(0.0-3.0)	2.0(1.0-2.0)	2.0(1.0-2.0)	High 1338[g]
24/11/86	1	0	-	1	2000	0.0(0.0-1.0)	0.0(0.0-1.0)	0.0(0.0-1.0)	Low 1006[d]
	2	10	NE	0	-	1.0(0.0-3.0)	2.0(1.0-2.0)	2.0(1.0-2.0)	High 1623[h]
5/11/86	1	5-10	E	3	3500		1.0(0.0-2.0)	0.0-2.0	Low 1209[i]
26/11/86	1	15	ESE	4	2500	3.0(3.0-4.0)	2.0	1.0-2.0	High 0650[h]
27/11/86	1	5	SE	0	-	0.0-1.0	0.0(0.0-1.0)	1.0(0.0-2.0)	High 0747[h]
(d) Cairns Section, October 1987									
12/10/87	1	0	-	0	-	1.0(0.0-2.5)	1.0(0.0-2.0)	1.0(0.0-2.0)	High 0854[j]
	2	10-15	E	0	-	0.0(0.0-1.0)	0.0(0.0-2.0)	0.0(0.0-1.0)	Low 1513[j]
13/10/87	1	0	-	0	-	0.0(0.0-2.0)	0.0(0.0-1.0)	0.0(0.0-1.0)	High 0940[j]
	2	5	N	3	3500	0.0(0.0-2.0)	0.0(0.0-1.0)	0.0	Low 1558[j]
	3	10-15	E	2	3500	1.0(0.0-1.0)	0.0(0.0-1.0)	0.0	
14/10/87	1	5	N	2	2500	1.0(0.0-2.0)	1.0(0.0-3.0)	0.0(0.0-2.0)	High 1032[j]
	2	10	ENE	1	2000	1.0(1.0-2.5)	2.0(0.0-2.5)	1.0(0.0-2.0)	Low 1648[j]
15/10/87	1	8-10	E	3	1500	1.0(1.0-3.0)	1.0(0.0-2.0)	1.0(0.0-2.0)	Low 0637[j]
	2	12	E	4	1500	3.0(1.0-3.0)	2.0(0.0-3.0)	2.0(0.0-2.0)	High 1134[j]

TABLE 1: continued.

Date	Session	Wind Speed (knots)	Wind Direction	Cloud Cover (oktas)	Cloud Height (ft)	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)	Tide	Time
(d) Cairns Section, October 1987										
16/10/87	1	10	SE	1	6000	1.5(0.0-2.0)	1.0(0.0-2.0)	1.0(0.0-2.0)	Low	0806[j]

[*] Scale: 0 = no glare, 1 = 0 ≤ 25% field of view glare affected, 2 = 25 ≤ 50%, 3 = > 50%

[a] Lucinda

[b] Townsville

[c] Missionary Bay (Lucinda +40 mins on high and low waters)

[d] Shoalwater Bay (Mackay Outer Harbour -12 mins on high and low waters)

[e] Gladstone Harbour

[f] The Narrows (Gladstone Harbour +45 mins on high water; +55 mins on low water)

[g] Great Kepple Island (Gladstone Harbour +5 mins on high water; +3 mins on low water)

[h] Mackay Outer Harbour

[i] Flock Pigeon Island (Mackay Outer Harbour +25 mins on high and low waters)

[j] Cairns.

[k] transects flown on 21/10/87 are replicates of transects flown on 5/10/87 and subsequently abandoned due to poor weather conditions.

TABLE 2: Beaufort Sea State and glare (for the north/east and south/west sides of the aircraft) for each transect.

Scale : 0 = no glare
1 = 0 ≤ 25% field of view glare affected
2 = 25 ≤ 50% field of view glare affected
3 = > 50% field of view glare affected

(a) Central Section

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
(a) Northern Central Section, September 1986			
001	1.0-2.0	2.0	0.0
002	1.0	2.0	0.0
003	2.0(1.0-2.0)	2.0	0.0
004	1.0	2.0-2.5	0.0
005	2.0(1.0-2.0)	2.0	0.0
006	1.0(1.0-1.5)	1.0-2.0	0.0
007	1.0	0.0-1.0	0.0
008	1.0	1.0	0.0
009	1.0(1.0-2.0)	0.0	2.0-3.0
010	1.0	2.0	0.0
011	1.0	0.0-1.0	0.0-1.0
012	1.0	1.0	0.0
013	1.5(1.0-2.0)	2.0(1.0-3.0)	0.0(0.0-1.0)
014	1.5(1.0-2.0)	1.0	0.0
015	1.5(1.0-2.0)	1.0(0.0-1.0)	0.0
016	1.5(1.0-2.0)	2.0(1.0-2.0)	0.0(0.0-1.0)
017	1.0(0.5-2.0)	2.0	1.0
018	1.0(0.0-2.0)	1.0	0.0
019	1.0(0.0-1.0)	1.0-2.0	0.0
020	1.0(0.0-2.0)	1.0	0.0
021	1.0	1.0-2.0	0.0
022	1.0	0.0-1.0	0.0
023	1.0(1.0-2.0)	1.0-2.0	0.0
024	1.0(1.0-2.0)	2.0	0.0
025	1.0(1.0-2.0)	1.0	0.0
026	1.0(1.0-2.0)	1.0	0.0
027	2.0	2.0(1.0-2.0)	0.0(0.0-1.0)
028	2.0	1.0	0.0
029	1.0-2.0	2.0	1.0
030	1.0	1.0-2.0	0.0
031	1.0	1.0-2.0	0.0-1.0
032	1.0	2.0	0.0
033	1.0	2.0	0.0
034	1.0(1.0-2.5)	2.0	0.0
035	2.0(1.0-2.0)	1.0-2.0	0.0
036	2.0	2.0	0.0
037	2.0	2.0	0.0
038	2.0(1.0-2.5)	2.0	0.0
039	2.5(0.0-3.0)	1.0	0.0
040	2.0(0.0-2.0)	1.0(1.0-2.0)	0.0
041	1.0(0.0-2.0)	0.0-1.0	0.0
042	1.0(0.0-1.0)	1.0(0.0-2.0)	0.0
043	1.0(0.0-1.0)	2.0	0.0(0.0-1.0)
044	1.0	1.0-2.0	0.0
045	0.0	1.0	1.0
046	0.0-1.0	1.0	0.0-0.5

TABLE 2: continued.

(a) Central Section

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
(a) Northern Central Section, September 1986			
047	0.0(0.0-1.0)	1.0	1.0
048	1.0(0.0-1.0)	2.0(1.0-2.0)	1.0
049	1.0	1.0-2.0	1.0(1.0-2.0)
050	1.0	1.0	1.0(0.0-1.0)
051[a]	1.0(0.0-1.0)	0.0-1.0	0.0
052[a]	1.0(0.0-2.0)	1.0-2.0	0.0
053[a]	1.0	1.0	0.0
054[a]	1.0	1.0	0.0
055[a]	1.0	1.0-2.0	0.0
056[a]	1.0	1.0	0.0
057[a]	1.0	2.0	0.0
058[a]	1.0	1.0	0.0
059	1.0(1.0-2.0)	0.0-2.0	0.0-1.0
060	1.0	2.0	0.0
061	1.0(0.0-1.0)	1.0	0.0
062	1.0	1.0-2.0	0.0
063	2.0(0.0-2.0)	1.0(1.0-2.0)	0.0

[a] These transects flown north/south, hence glare is for east/west sides of the aircraft.

TABLE 2: continued

(a) Central Section

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
(b) Northern Central Section, October 1987			
101	0.5	1.0	1.0
102	1.0	1.0	0.0
103	1.0	1.0	1.0
104	0.0(0.0-1.0)	1.0	1.0
105	1.0(0.0-2.0)	0.0-1.0	0.0-1.0
106	1.0-2.0(1.0-2.5)	1.0	1.0
107	0.0(0.0-0.5)	0.0	1.0
108	no data recorded	0.0-1.0	0.0
109	1.5(1.0-1.5)	1.0-2.0	1.0
110	1.5	2.0	1.0
111	1.0(1.0-2.5)	1.0	0.0
112	1.0	1.0	0.0
113	1.0(1.0-2.0)	1.0	0.0
114	1.0	2.0	1.0
115	1.0(1.0-2.0)	1.0	0.0
116	2.0(0.5-3.0)	2.5(1.0-2.5)	0.0(0.0-1.0)
117	2.0-2.5(0.0-2.5)	2.0(1.0-2.0)	0.0
118	1.0(0.0-1.0)	2.0-2.5(0.0-2.5)	0.0
119	0.0(0.0-0.5)	1.0	0.0
120	0.0(0.0-0.5)	0.0-1.0	0.0
121	0.0(0.0-0.5)	0.0	0.0
122	0.5	1.0	0.0
123	0.0-0.5	0.0	0.0
124	1.0(0.5-1.0)	1.0-2.0	0.0
125	1.0	2.5	0.0
126	0.5-1.5	2.0	0.0
127	0.5(0.5-1.0)	2.0	0.0
128	0.0-1.0	2.0-3.0	0.0
129	1.0	2.0	0.0
130	1.0(0.0-1.0)	0.0-1.0	0.0
131	2.0(2.0-3.0)	3.0	1.0
132	3.0(0.0-3.0)	3.0	1.0
133	2.0	3.0	0.0-1.0
134	2.5	3.0	1.0
135	1.0(0.5-1.0)	2.0-2.5	0.0
136	0.5(0.5-1.0)	2.0	0.0
137	0.0-1.0	2.0-2.5	0.0
138	1.0	0.0	0.0
139	0.5-1.0	0.0	0.0
140	0.5(0.0-1.0)	0.0	0.0
141	1.0(0.0-1.0)	0.0	0.0
142	1.0(0.0-1.0)	0.0	0.0
143	0.0-1.0	0.0	0.0
144	0.0(0.0-1.0)	0.0	0.0
145	0.5(0.0-1.0)	0.0(0.0-1.0)	0.0
146	0.0(0.0-0.5)	0.0	0.0
147	0.0(0.0-0.5)	0.0	0.0
148	0.0-0.5	0.0	0.0
149	0.0(0.0-1.0)	1.0	0.0
150	0.5(0.0-0.5)	0.0	0.0
151[a]	0.0	1.0	0.0

TABLE 2: continued.

(a) Central Section

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
(b) Northern Central Section, October 1987			
152[a]	0.0(0.0-1.0)	1.0(1.0-2.0)	0.0
153[a]	1.0	1.0	0.0
154[a]	0.5	1.0-2.0	0.0
155[a]	0.0-1.0	1.0	0.0
156[a]	no data recorded	1.0-2.0	0.0
157[a]	0.0	1.0	0.0
158[a]	0.0	2.0	0.0
159	no data recorded	0.0	0.0
160	1.5(1.0-2.0)	1.0	1.0
161	0.0-1.0	0.0	0.0
162	0.0	0.0	0.0
163	0.5(0.0-1.0)	1.0-2.0	0.0

[a] These transects flown north/south, hence glare is for east/west sides of the aircraft.

TABLE 2: continued.

(a) Central Section

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
(c) Southern Central Section, September - October 1987			
001	0.5(0.5-1.0)	1.0	0.0
002	1.0(0.0-1.0)	2.0	0.0
003	0.0-0.5	0.0	0.0
004	0.0-0.5	1.0	0.0
005	0.0(0.0-1.0)	0.0	0.0
006	1.0(0.5-2.0)	2.0	0.0
007	1.0(0.0-1.0)	1.0	0.0
008	0.0-1.0	1.0-2.0	0.0
009	no data recorded	no data recorded	no data recorded
010	0.0-0.5	1.0	0.0
011	0.0-1.0(0.0-2.0)	2.0	0.0
012	0.0-1.0	1.5(1.0-1.5)	0.0(0.0-1.0)
013	0.5-1.0(0.0-2.0)	2.0	0.0
014	1.0(0.0-1.0)	1.0-2.5	1.0(0.0-1.0)
015	1.0(1.0-2.0)	2.0	0.0
016	1.0-2.0(0.0-2.0)	2.0	0.0
017	1.0(0.0-1.0)	2.0	0.0
018	1.0-2.0(0.5-2.0)	2.0	0.0
019	1.0-2.0	2.0	0.0
020	2.0(0.0-2.5)	2.0	0.0
021	2.0(2.0-3.0)	1.0	0.0
022	2.0(2.0-2.5)	1.0(0.0-1.0)	1.0(0.0-1.0)
023	2.0(1.0-3.0)	1.0-2.0	0.0-1.0
024	3.0(1.0-3.0)	2.0-2.5	0.0-1.0
025	1.0-3.0	1.0	0.0-1.0
026	3.0(1.0-3.0)	2.0(0.0-3.0)	0.0-1.0
027	2.0(1.0-3.0)	1.0	0.0
028	1.0(1.0-1.5)	1.0-2.0	0.0
029	0.5(0.0-1.0)	1.0	0.0
030	0.5	2.0	0.0
031	1.0(0.5-1.0)	1.0	0.0-1.0
032	0.0(0.0-0.5)	1.0	0.0
033	0.5(0.5-1.0)	0.0-1.0	0.0
034	0.0(0.0-0.5)	1.0	0.0
035	0.5(0.5-1.0)	1.0	0.0
036	1.0	1.0	0.0
037	1.0	1.0	0.0
038	1.0	1.0	0.0
039	1.0(1.0-2.5)	2.0	0.0
040	2.0	2.0	0.0
041	1.0	2.0	0.0
042	3.0	2.0	0.0
043	3.0(2.0-3.0)	2.0	0.0
044	2.5(1.5-3.0)	2.0	0.0
045	2.0(2.0-3.0)	1.0	0.0
046	0.0(0.0-2.0)	1.0	0.0
047	1.0(0.0-2.0)	1.0	0.0
048	1.0	2.0	0.0
049	1.0-2.0	1.0	0.0
050	1.0(1.0-2.0)	0.0-1.0	0.0
051	1.0(1.0-2.5)	1.0	0.0

TABLE 2: continued.

(a) Central Section

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
(c) Southern Central Section, September - October 1987			
052	2.0(2.0-3.0)	1.0	0.0
053	1.0	0.0	0.0
054	2.0(1.0-3.0)	1.0	0.0
055	2.0(2.0-3.0)	1.0	0.0
056	2.0(2.0-3.0)	1.0	0.0
057	2.0(2.0-3.0)	1.0	0.0
058	2.0-2.5(2.0-3.0)	1.0	0.0
059	0.0	0.0	0.0
060	0.0-1.0	0.0	0.0
061	0.0-0.5	0.0	0.0
062	0.0-1.0	0.0	0.0
063	0.5	1.0	0.0
064	0.0(0.0-0.5)	0.0	0.0
065	0.0(0.0-0.5)	1.0	0.0
066	0.0	0.0	0.0
067	0.0(0.0-1.0)	0.0	0.0
068	0.0	0.0	0.0
069	0.0	0.0	0.0
070	0.0	0.0	0.0
071	0.0	1.0	0.0
072	0.0	0.0	0.0
073	0.0(0.0-0.5)	1.0	0.0
074	0.0	0.0	0.0
075	1.0(0.0-1.0)	2.0	0.0
076	1.0(0.0-1.0)	1.0	0.0
077	1.0(1.0-2.0)	2.0	0.0
078	1.0(0.0-3.0)	1.0-2.0	0.0-1.0
079	2.0(1.0-2.0)	3.0(2.0-3.0)	1.0(0.0-1.0)
080	1.0(1.0-2.0)	1.0-2.0	0.0
081	3.0(1.0-3.0)	0.0-1.0	0.0
082	1.0-3.0	1.0	0.0
083	2.0(2.0-2.5)	1.0	1.0-2.0
084	2.0(1.0-3.0)	0.0	0.0

TABLE 2: continued.

(b) Mackay/Capricorn Section, November 1986

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
001	0.0-1.0	0.0-1.0	0.0-1.0
002	1.0(0.0-1.0)	1.0	1.0
003	1.0(0.0-1.0)	1.0	1.0
004	0.0(0.0-1.0)	1.0	1.0
005	1.0	1.0	1.0
006	1.0	1.0	1.0
007	1.0	1.0	1.0
008	0.0-1.0	1.0	2.0
009	0.0-1.0	1.0-2.0	1.0(1.0-2.0)
010	1.0(0.0-1.0)	2.0	2.0
011	1.0(0.0-1.0)	1.0-2.0	1.0-2.0
012	0.0-1.0	0.0-2.0	0.0-2.0
013	2.0(1.0-3.0)	2.0	2.0(1.0-2.0)
014	1.0(1.0-3.0)	2.0-2.5	2.0
015	2.0-3.0	2.0	2.0
016	3.0(2.0-3.0)	2.0	2.0
017	2.0(1.0-3.0)	2.0	2.0
018	1.0(0.0-3.0)	2.0	1.0
019	2.0-3.0(1.0-3.0)	1.0-2.0	1.0-2.0
020	1.0	0.0-2.0	0.0-2.0
021	1.0	1.0	0.0-2.0
022	1.0	2.0	2.0
023	1.0	2.0	2.0
024	1.0	2.0	2.0
025	1.0(0.0-1.0)	2.0	2.0
026	0.0-1.0	1.0(0.0-1.0)	1.0
027	0.0	0.0	1.0
028	0.0	0.0	0.0
029	0.0-1.0	1.0	1.0
030	0.0(0.0-1.0)	0.0	1.0
031	1.0(0.0-1.0)	1.0	1.0
032	0.0	0.0	0.0
033	0.0(0.0-1.0)	0.0-1.0	0.0-1.0
034	0.0(0.0-1.0)	0.0	0.0
035	3.0	2.0	2.0
036	1.0(1.0-3.0)	2.0	2.0
037	2.0-3.0	2.0	2.0
038	1.0-2.0	2.0	2.0
039	2.0(1.0-2.0)	2.0	2.0
040	2.0	2.0	2.0
041	2.0(1.0-2.0)	1.0(1.0-2.0)	2.0(1.0-2.0)
042	1.0(0.0-2.0)	2.0	2.0
043	1.0-2.0	2.0	2.0
044	1.0	2.0	2.0
045	2.0(1.0-2.0)	2.0	2.0
046	2.0	2.0	2.0
047	2.0	2.0	2.0
048	2.0	2.0	2.0
049	2.0(1.0-2.0)	1.0	0.0-1.0
050	2.0(0.0-2.0)	2.0	2.0
051	2.0(2.0-2.5)	1.0	1.0
052	2.0(1.0-3.0)	2.0	2.0

TABLE 2: continued.

(b) Mackay/Capricorn Section, November 1986

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
053	2.0(2.0-2.5)	2.0	2.0
054	2.0(1.0-3.0)	2.0	2.0
055	2.5(1.0-3.0)	2.0	1.0
056	1.0-2.5(1.0-3.0)	2.0	2.0
057	2.5(2.0-3.0)	2.0	2.0
058	3.0-3.5	1.0	2.0
059	1.0(1.0-2.0)	1.0	1.0
060	2.0(1.0-3.0)	1.0	1.0
061	2.0(1.0-3.0)	1.0	1.0-2.0
062	2.0-2.5(2.0-3.0)	1.0	1.0
063	2.5	1.0	2.0
064	2.5(2.5-3.0)	2.0	1.0
065	2.0(2.0-2.5)	1.0	1.0
066	2.0(1.0-3.0)	1.0	1.0
067	2.0(1.5-2.0)	0.0(0.0-1.0)	2.0(0.0-2.0)
068	2.0(1.0-2.0)	1.0-2.0	1.0
069	1.0(1.0-2.0)	0.0(0.0-1.0)	1.0(0.0-1.0)
070	1.0(1.0-2.0)	1.0	1.0
071	1.0-2.0(0.0-2.0)	0.0	0.0
072	1.0(0.0-2.0)	1.0	1.0
073	1.0(0.0-2.0)	0.0	0.0
074	2.0(0.0-3.0)	1.0	1.0
075	2.0(1.0-3.0)	2.0	1.0
076	3.0(1.0-3.0)	1.0	2.0
077			
078	these transects not flown due to		
079	tide out in Broad Sound		
080			
081	0.0	1.0	1.0
082	0.0-1.0	0.0(0.0-1.0)	0.0
083	0.0-1.0	2.0	2.0
084	0.0-1.0	0.0-2.0	0.0-2.0
085	1.0(0.0-1.0)	2.0	2.0
086	1.0	1.0-2.0	1.0-2.0
087	0.0-1.0	0.0	1.0
088	1.0(1.0-2.0)	2.0	2.0
089	3.0(1.0-3.0)	1.0(0.0-1.0)	1.0
090	3.0(1.0-3.0)	1.0(0.0-1.0)	1.0(0.0-2.0)
091	3.0(2.0-3.0)	0.0-1.0	0.0-1.0
092	0.0(0.0-0.5)	0.0	0.0
093	0.0(0.0-0.5)	0.0	0.0
094	0.0-0.5	0.0	0.0-1.0
095	0.0(0.0-1.0)	0.0	0.0
096	0.0(0.0-1.0)	0.0-1.0	0.0-1.0
097	0.0(0.0-1.0)	0.0	0.0
098	1.0(0.0-1.0)	0.0-1.0	0.0-1.0
099	1.0(0.0-1.0)	0.0	0.0
100	1.0(0.0-1.0)	1.0	1.0
101	1.0	0.0	1.0
102	1.0(1.0-2.0)	2.0	2.0
103	1.0(1.0-2.0)	1.0-2.0	1.0
104	1.0(1.0-3.0)	2.0	2.0

TABLE 2: continued.

(b) Mackay/Capricorn Section, November 1986

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
105	1.0(1.0-2.0)	2.0	2.0
106	2.0(0.0-2.0)	1.0-2.0	2.0
107	1.0-2.0	1.0-2.0	1.0
108	3.0(3.0-4.0)	2.0	1.0-2.0
109	1.0	0.0	0.0-1.0
110	1.0(0.0-1.0)	0.0	0.0
111	1.0(0.0-1.0)	0.0	0.0-1.0
112	1.0(0.0-1.0)	0.0	0.0(0.0-2.0)
113	1.0(0.0-1.0)	0.0-1.0	0.0-1.0
114	1.0	0.0	0.0-2.0
115	0.0-1.0	1.0(0.0-1.0)	0.0-2.0
116	0.0-1.0	0.0	1.0-2.0
117	0.0	0.0	0.0
118	0.0	0.0	0.0
119	0.0	1.0	1.0
120	0.0-1.0	0.0	1.0
121	0.0	0.0	0.0-1.0
122	0.0	0.0	0.0-2.0
123	0.0-1.0	1.0(0.0-1.0)	1.0(0.0-1.0)
124	0.0	0.0(0.0-1.0)	1.0(1.0-2.0)
125	0.0-1.0	0.0-1.0	0.0-1.0
126	0.0	0.0	0.0
127	2.0(2.0-3.0)	2.0	2.0
128	2.0	2.0	2.0
129	3.0(2.0-3.0)	2.5	2.0
130	2.0(2.0-3.0)	2.0	2.0
131	1.0(1.0-2.0)	2.0	2.0
132	1.0-3.0	1.0-2.0	1.0-2.0
133	1.0	-	0.0
134	0.5(0.5-1.0)	1.0	1.0-2.0
135	0.0	0.0	0.0
136	0.0	0.0	0.0
137	0.0	-	-
138	1.0	1.0	1.0
139	1.0	1.0	0.0-1.0
140	1.0(1.0-2.0)	2.0	2.0
141	-	1.0	2.0
142	2.5-3.0	1.0	1.0
143	-	-	-
144	1.0	1.0-2.0	1.0

TABLE 2: continued.

(c) Cairns Section, October 1987

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
201	0.0-1.0	0.0-1.0	0.0-1.0
202	1.0(0.0-1.0)	1.0	1.0
203	0.5-1.0(0.0-1.0)	1.0(0.0-2.0)	0.0(0.0-1.0)
204	0.0-0.5(0.0-1.0)	1.0(0.0-1.0)	0.0(0.0-1.0)
205	0.5(0.0-1.0)	1.0-2.0	0.0
206	1.0(0.5-2.0)	0.0(0.0-1.0)	0.0(0.0-2.0)
207	1.0(0.5-1.5)	1.0(1.0-2.0)	1.0(0.0-1.0)
208	1.0(1.0-2.0)	1.0(1.0-3.0)	1.0(0.0-2.0)
209	1.0(0.5-2.5)	2.0(1.0-2.0)	1.0(0.0-1.0)
210	2.0(1.0-2.0)	0.0(0.0-2.5)	0.0(0.0-2.0)
211	1.0-2.5	2.0(1.0-2.0)	1.0(0.0-1.0)
212	1.0(1.0-2.5)	2.0	1.0
213	1.0(0.0-1.0)	1.0	1.0
214	1.5	0.0-1.0	0.0.-1.0
215	1.0-1.5	0.0-1.0	1.0
216	1.0-2.0	1.0	1.0
217	1.0-1.5(0.0-1.5)	1.0	1.0
218	1.5(1.0-2.0)	0.0-1.0	1.0
219	1.5(1.0-2.0)	0.0(0.0-1.0)	1.0(0.0-1.0)
220	2.0	0.0-2.0	0.0(0.0-1.0)
221	0.0(0.0-1.0)	0.0-1.0	0.0
222	0.0-0.5	0.0-2.0	0.0
223	0.0(0.0-1.0)	0.0-1.0	0.0
224	1.0(0.0-1.0)	0.0-2.0	0.0-1.0
225	0.5(0.0-1.0)	0.0-1.0	0.0-2.0
226	0.0(0.0-2.0)	0.0-1.0	0.0-1.0
227	1.5(1.5-2.0)	1.0-2.0	1.0-2.0
228	1.5(1.5-2.0)	1.0-2.0	1.0-2.0
229	2.0(1.0-2.0)	0.0-2.0	0.0(0.0-1.0)
230	1.0(0.0-1.0)	0.0-2.0	0.0-1.0
231	1.0(0.0-1.0)	1.0-2.0(0.0-2.0)	0.0-1.0(0.0-2.0)
232	1.0(0.0-1.0)	2.0(1.0-2.0)	1.0(0.0-2.0)
233	1.0(0.0-2.0)	1.0(0.0-2.0)	0.0(0.0-2.0)
234	1.0(0.0-2.0)	1.0	0.0-1.0
235	2.0(0.0-2.5)	1.0(0.0-2.0)	0.0-1.0
236	0.0-1.0(0.0-2.0)	0.0	0.0-1.0
237	1.0(0.0-1.0)	0.0-1.0	0.0-1.0
238	0.0(0.0-1.0)	0.0(0.0-1.0)	0.0(0.0-1.0)
239	0.0-1.0(0.0-2.0)	0.0	0.0-1.0
240	0.0(0.0-1.0)	0.0(0.0-1.0)	0.0(0.0-1.0)
241	0.0-0.5	0.0(0.0-1.0)	0.0(0.0-1.0)
242	0.0-0.5(0.0-1.0)	0.0-1.0	0.0
243	0.0(0.0-0.5)	0.0	0.0-1.0
244	0.0(0.0-0.5)	0.0	0.0
245	0.0(0.0-0.5)	0.0	0.0
246	0.0(0.0-0.5)	0.0-1.0	0.0]
247	0.0(0.0-2.0)	0.0	0.0
248	0.0(0.0-0.5)	1.0	0.0
249	0.0(0.0-0.5)	0.0-1.0	0.0
250	0.5(0.5-1.0)	0.0-1.0	0.0
251	1.0(0.0-1.0)	0.0(0.0-1.0)	0.0
252	1.0(1.0-2.0)	1.0(0.0-1.0)	0.0-1.0

TABLE 2: continued.

(c) Cairns Section, October 1987

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
253	1.0(1.0-2.5)	0.0-1.0	1.0(0.0-2.0)
254	2.0(1.0-3.0)	0.0-2.0	1.0(0.0-2.0)
255	1.5(1.0-3.0)	1.0(0.0-1.0)	1.0(1.0-2.0)
256	1.0(1.0-2.5)	2.0(0.0-2.0)	0.0(0.0-2.0)
257	1.0-2.0(1.0-3.0)	1.0(0.0-1.0)	1.0(0.0-1.0)
258	2.0(2.0-3.0)	1.0(0.0-3.0)	2.0(0.0-2.0)
259	3.0(2.0-3.0)	2.0	2.0
260	2.0-3.0	3.0(2.0-3.0)	2.0
261	1.0(1.0-3.0)	2.5	1.0-2.0
262	3.0(2.0-3.0)	2.0-3.0	2.0
263	3.0(2.5-3.0)	2.5	2.0
264	3.0(2.0-3.0)	2.0(2.0-3.0)	2.0(1.0-2.0)
265	1.0	0.0	0.0
266	2.0	1.0	2.0
267	2.0	0.0-1.0	1.0-2.0
268	2.0	2.0	1.0
269	2.0(2.0-2.5)	2.0	2.0
270	2.0	2.0	1.0
271	3.0	2.0	1.0-2.0
272	2.0	2.0	1.0
273	2.0-3.0	0.0-2.0	1.0-2.0
274	1.0(1.0-2.0)	1.0	1.0
275	1.0	U	U
276	1.0	U	U
277	no data recorded	U	U

U direction of flight unknown

TABLE 3: Raw data for each survey: dugong sightings.

(a) Central Section

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
(a) Northern Central Section, September 1986								
001	2	2	0	0	1	0	0	0
002	2	2	2	0	2	0	0	0
003	2	2	1	1	0	1	0	1
004	2	2	0	0	3	0	1	0
005	2	2	0	0	0	0	0	0
006	2	2	0	0	0	0	0	0
007	2	2	0	0	0	0	0	0
008	2	2	0	0	0	0	0	0
009	2	2	0	0	0	0	0	0
010	2	2	0	0	0	0	0	0
011	2	2	0	1	0	0	0	0
012	2	2	0	0	0	0	0	0
013	2	2	0	0	0	0	0	0
014	2	2	0	0	0	0	0	0
015	2	2	0	0	0	0	0	0
016	1	2		0		0	0	0
017	2	2	0	0	0	0	0	0
018	2	2	0	0	0	0	0	0
019	2	2	1	0	0	0	0	0
020	2	2	0	0	0	0	0	0
021	2	2	0	0	0	0	0	0
022	2	2	0	0	0	0	1	0
023	2	2	0	0	0	0	0	0
024	2	2	0	0	0	0	0	0
025	2	2	0	0	0	0	0	0
026	2	2	0	0	0	0	0	0
027	2	2	0	0	0	0	0	0
028	2	2	0	0	0	0	0	0
029	2	2	0	0	0	0	0	0
030	2	2	0	0	0	0	0	0
031	1	2		0		0	0	0
032	1	2		0		0	0	0
033	1	2		0		0	0	0
034	1	2		0		0	0	0
035	1	2		0		0	0	0
036	1	2		0		0	0	0
037	1	2		0		0	0	0
038	1	2		0		1	0	2
039	1	2		0		0	0	0
040	1	2		0		0	0	0
041	1	2		2		0	0	0
042	1	2		0		0	0	0
043	1	2		0		0	0	0
044	1	2		0		0	0	0
045	1	2		1		0	0	0
046	1	2		0		0	0	0
047	1	2		0		0	0	0
048	1	2		0		0	0	1
049	1	2		0		0	0	0
050	1	2		0		0	0	0
051	2	2	0	0	1	0	0	0

TABLE 3: continued.

(a) Central Section

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
(a) Northern Central Section, September 1986								
052	2	2	1	0	0	0	0	1
053	2	2	1	0	0	0	0	0
054	2	2	0	0	1	0	0	0
055	2	2	0	0	1	0	0	0
056	2	2	0	0	0	0	0	0
057	2	2	0	0	0	1	0	0
058	2	2	0	0	0	0	0	0
059	2	2	0	0	0	0	0	1
060	2	2	0	0	0	0	0	0
061	2	2	0	1	2	0	0	0
062	2	2	0	0	0	0	0	0
063	1	2		0		0	0	0
			8	9	11	5	5	7

TABLE 3: continued.

(a) Central Section

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
(b) Northern Central Section, October 1987								
101	2	2	0	0	0	0	0	0
102	2	2	1	0	0	0	0	0
103	2	2	1	0	1	0	0	0
104	2	2	0	0	0	0	0	1
105	2	2	0	0	0	0	0	0
106	2	2	0	0	1	0	0	1
107	2	2	1	0	1	0	1	0
108	2	2	0	0	0	0	0	0
109	2	2	0	0	0	0	0	0
110	2	2	0	0	0	0	0	0
111	2	2	0	0	0	0	0	0
112	2	2	0	0	0	0	0	0
113	2	2	0	0	0	0	0	0
114	2	2	0	0	0	0	0	0
115	2	2	0	0	0	0	0	0
116	2	2	0	0	0	0	0	0
117	2	2	0	0	0	0	0	0
118	2	2	0	0	0	0	0	0
119	2	2	0	0	0	0	0	0
120	2	2	0	0	0	0	0	0
121	2	2	0	0	0	0	0	0
122	2	2	0	0	0	0	0	0
123	2	2	0	0	0	0	0	0
124	2	2	0	0	0	0	0	0
125	2	2	0	0	0	0	0	0
126	2	2	0	0	0	0	0	0
127	2	2	0	0	0	0	0	0
128	2	2	0	0	0	0	0	0
129	2	2	0	0	0	0	0	0
130	2	2	0	0	0	0	0	0
131	2	2	0	0	0	0	0	0
132	2	2	0	0	0	0	0	0
133	2	2	0	0	0	0	0	0
134	2	2	0	0	0	0	0	0
135	2	2	0	0	0	0	0	0
136	2	2	0	0	0	0	0	0
137	2	2	0	0	0	0	0	0
138	2	2	0	0	0	0	0	0
139	2	2	0	0	0	0	0	0
140	2	2	0	0	0	0	0	0
141	2	2	0	0	0	0	0	0
142	2	2	0	0	0	0	0	0
143	2	2	1	0	0	0	0	0
144	2	2	0	0	0	0	0	0
145	2	2	0	0	0	0	0	0
146	2	2	0	0	0	0	0	0
147	2	2	0	0	0	0	0	0
148	2	2	0	0	0	0	0	0
149	2	2	0	0	0	0	0	0
150	2	2	0	0	1	1	0	0
151	2	2	0	0	0	0	0	0

TABLE 3: continued.

(a) Central Section

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
(b) Northern Central Section, October 1987								
152	2	2	0	0	0	0	0	0
153	2	2	0	0	0	0	0	0
154	2	2	0	0	0	0	0	0
155	2	2	0	0	0	0	0	0
156	2	2	0	1	0	0	0	0
157	2	2	0	0	1	1	1	0
158	2	2	0	0	0	0	0	2
159	2	2	0	0	1	0	0	0
160	2	2	0	0	0	0	0	0
161	2	2	0	0	0	0	0	0
162	2	2	0	0	0	0	0	0
163	2	2	0	0	0	0	0	0
			4	1	6	3[a]	2	6[b]

[a] includes one group of dugongs seen by the starboard mid-seat observer on transects flown in Cleveland Bay that were abandoned due to poor weather and subsequently reflown.

[b] includes two groups of dugongs seen by the starboard observing team on transects flown in Cleveland Bay that were abandoned due to poor weather and subsequently reflown.

TABLE 3: continued.

(a) Central Section

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
(c) Southern Central Section, September - October 1987								
001	2	2	0	0	0	0	0	0
002	2	2	0	0	0	0	0	0
003	2	2	0	0	0	0	0	0
004	2	2	0	0	0	0	0	0
005	2	2	0	0	0	0	0	0
006	2	2	0	0	0	0	0	0
007	2	2	0	0	1	0	0	0
008	2	2	0	0	0	0	0	0
009	2	2	0	0	0	0	0	0
010	2	2	0	0	0	0	0	0
011	2	2	0	0	0	0	0	0
012	2	2	0	0	0	0	0	0
013	2	2	0	0	0	0	0	0
014	2	2	0	0	0	0	0	0
015	2	2	0	0	0	0	0	0
016	2	2	0	0	0	0	0	0
017	2	2	0	0	0	0	0	0
018	2	2	0	0	0	0	0	0
019	2	2	0	0	0	0	0	0
020	2	2	0	0	0	0	0	0
021	2	2	0	0	0	0	0	0
022	2	2	0	0	0	0	0	0
023	2	2	0	0	0	0	0	0
024	2	2	0	0	0	0	0	0
025	2	2	0	0	0	0	0	0
026	2	2	0	0	0	0	0	0
027	2	2	0	0	0	0	0	0
028	2	2	0	0	0	0	0	0
029	2	2	0	0	0	0	0	0
030	2	2	0	0	0	0	0	0
031	2	2	0	0	0	0	0	0
032	2	2	0	0	0	0	0	0
033	2	2	0	0	1	0	0	0
034	2	2	0	0	0	0	0	0
035	2	2	0	0	0	0	0	0
036	2	2	0	0	0	0	0	0
037	2	2	0	0	0	0	0	0
038	2	2	0	0	0	0	0	0
039	2	2	0	0	0	0	0	0
040	2	2	0	0	0	0	0	0
041	2	2	0	0	0	0	0	0
042	2	2	0	0	0	0	0	0
043	2	2	0	0	0	0	0	0
044	2	2	0	0	0	0	0	0
045	2	2	0	0	0	0	0	0
046	2	2	0	0	0	0	0	1
047	2	2	0	0	0	0	0	0
048	2	2	0	0	0	0	0	0
049	2	2	0	0	0	1	0	0
050	2	2	0	0	0	0	0	1
051	2	2	0	0	0	1	0	1

TABLE 3: continued.

(a) Central Section

Transcect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
(c) Southern Central Section, September - October 1987								
052	2	2	0	0	1	0	0	0
053	2	2	0	0	1	0	0	0
054	2	2	0	0	0	0	0	1
055	2	2	0	0	0	0	0	0
056	2	2	0	0	0	0	0	0
057	2	2	0	0	0	0	0	0
058	2	2	0	0	0	0	0	0
059	2	2	0	0	0	0	0	0
060	2	2	0	0	0	0	0	0
061	2	2	0	0	1	0	0	0
062	2	2	1	1	0	0	0	0
063	2	2	0	0	0	0	0	2
064	2	2	0	0	0	0	0	0
065	2	2	0	0	0	0	0	0
066	2	2	0	0	0	0	0	0
067	2	2	0	0	0	0	0	0
068	2	2	0	0	0	0	0	0
069	2	2	0	0	0	0	0	0
070	2	2	0	0	0	0	0	0
071	2	2	0	0	0	0	0	0
072	2	2	0	0	0	0	1	0
073	2	2	0	0	0	0	0	0
074	2	2	0	0	0	0	0	0
075	2	2	0	0	0	0	0	0
076	2	2	1	0	1	0	0	1
077	2	2	1	0	0	0	0	0
078	2	2	0	0	0	0	0	0
079	2	2	0	0	0	0	0	0
080	2	2	0	0	0	0	0	0
081	2	2	0	0	0	0	0	0
082	2	2	0	0	0	0	0	0
083	2	2	0	0	0	0	0	0
084	2	2	0	0	0	0	0	0
			3	1	6	2	1	7

TABLE 3: continued.

(b) Mackay/Capricorn Section, November 1987

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
001	2	2	0	0	0	0	0	0
002	2	2	0	0	0	0	0	0
003	2	2	0	0	0	0	0	0
004	2	2	0	0	0	0	0	0
005	2	2	0	0	0	0	0	0
006	2	2	0	0	0	0	0	1
007	2	2	0	0	0	0	0	0
008	2	2	0	0	0	0	0	0
009	2	2	0	0	0	0	0	0
010	2	2	0	0	0	0	0	0
011	2	2	0	0	0	0	0	1
012	2	2	0	0	0	0	0	1
013	2	2	0	0	0	0	0	0
014	2	2	0	0	0	0	0	0
015	2	2	0	0	0	0	0	0
016	2	2	0	0	0	0	0	0
017	2	2	0	0	0	0	0	0
018	2	2	0	0	0	0	0	0
019	2	2	0	0	0	0	0	0
020	2	2	0	0	0	0	0	0
021	2	2	0	0	0	0	0	0
022	2	2	0	0	0	0	0	0
023	2	2	0	0	0	0	0	0
024	2	2	0	0	0	0	0	0
025	2	2	0	0	0	0	0	1
026	2	2	0	0	0	0	0	0
027	2	2	0	0	0	0	0	0
028	2	2	0	0	0	0	0	0
029	2	2	0	0	0	0	0	0
030	2	2	0	0	0	0	0	0
031	2	2	0	0	0	0	0	0
032	2	2	0	0	0	0	0	0
033	2	2	0	0	0	0	0	1
034	2	2	0	0	0	0	0	0
035	2	2	0	0	0	0	0	0
036	2	2	0	0	0	0	0	0
037	2	2	0	0	0	0	0	0
038	2	2	0	0	0	0	0	0
039	2	2	0	0	0	0	0	0
040	2	2	0	0	0	0	0	0
041	2	2	0	0	0	0	0	0
042	2	2	0	0	0	0	0	0
043	2	2	0	0	0	0	0	0
044	2	2	0	0	0	0	0	0
045	2	2	0	0	0	0	0	0
046	2	2	0	0	0	0	0	0
047	2	2	0	0	0	0	0	0
048	2	2	0	0	0	0	0	0
049	2	2	0	0	0	0	0	0
050	2	2	0	0	0	0	0	0
051	2	2	0	0	0	0	0	0
052	2	2	1	0	0	0	0	0

TABLE 3: continued.

(b) Mackay/Capricorn Section, November 1987

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs: Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
053	2	2	0	0	0	0	0	0
054	2	2	0	0	0	0	0	0
055	2	2	0	0	0	0	0	0
056	2	2	1	0	0	0	0	0
057	2	2	0	0	0	0	0	0
058	2	2	0	0	0	0	0	0
059	2	2	0	0	1	0	0	0
060	2	2	0	1	1	0	0	2
061	2	2	0	1	1	0	0	1
062	2	2	0	0	0	0	0	0
063	2	2	0	0	1	1	0	0
064	2	1	0	0	0		0	
065	2	1	0	1	1		2	
066	2	1	0	0	1		0	
067	2	1	1	1	2		0	
068	2	1	0	0	1		1	
069	2	1	0	0	1		0	
070	2	1	0	0	0		0	
071	2	1	0	1	0		0	
072	2	1	0	0	0		0	
073	2	1	0	0	0		0	
074	2	1	0	0	0		0	
075	2	2	0	0	0	1	0	0
076	2	2	0	0	0	0	0	0
077								
078		transects not flown this survey due to						
079		tide out in Broad Sound.						
080								
081	2	2	0	0	0	0	0	0
082	2	2	0	0	0	0	0	0
083	2	2	0	0	0	0	1	0
084	2	2	0	0	0	0	0	0
085	2	2	0	0	0	0	0	0
086	2	2	0	0	0	0	1	0
087	2	2	0	0	0	0	0	0
088	2	2	0	0	0	0	1	0
089	2	1	0	0	0		0	
090	2	2	0	0	0	0	1	1
091	2	2	0	0	0	0	0	0
092	2	2	0	0	0	0	0	0
093	2	2	0	0	0	0	0	0
094	2	2	0	0	0	0	0	0
095	2	2	0	0	0	0	0	0
096	2	2	0	0	0	0	0	0
097	2	2	0	0	0	0	0	0
098	2	2	0	0	0	0	0	0
099	2	2	0	0	0	0	0	0
100	2	2	0	0	0	0	0	0
101	2	2	0	0	0	0	0	0
102	2	2	0	0	0	0	0	0
103	2	2	0	0	0	0	0	0
104	2	2	0	0	0	0	0	0

TABLE 3: continued.

(b) Mackay/Capricorn Section, November 1987

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
105	2	2	0	0	2	0	1	2
106	2	2	0	0	0	0	0	0
107	2	2	0	0	0	0	0	0
108	2	2	0	0	0	0	0	0
109	2	2	0	0	0	0	0	0
110	2	2	0	0	0	0	0	0
111	2	2	0	0	0	0	0	0
112	2	2	0	0	0	0	0	0
113	2	2	0	0	0	0	0	0
114	2	2	0	0	0	0	0	0
115	2	2	0	0	0	0	0	0
116	2	2	0	0	0	0	0	0
117	2	2	0	0	1	0	0	1
118	2	2	0	0	0	0	0	0
119	2	2	0	0	0	0	0	0
120	2	2	0	0	0	0	0	2
121	2	2	0	0	1	0	0	0
122	2	2	1	0	0	0	0	0
123	2	2	0	0	0	0	0	0
124	2	2	0	0	0	0	0	0
125	2	2	1	0	1	0	0	1
126	2	2	0	0	0	0	0	1
127	2	2	0	0	0	0	0	0
128	2	2	0	0	0	0	0	0
129	2	2	0	0	0	0	0	0
130	2	2	0	0	0	0	0	0
131	2	2	0	0	0	0	0	0
132	2	2	0	0	0	0	0	0
133	2	2	0	0	0	0	0	0
134	2	2	0	0	0	0	0	0
135	2	2	0	1	1	0	0	0
136	2	2	0	0	0	0	0	0
137	2	2	0	0	0	1	0	1
138	2	2	0	0	0	0	0	0
139	2	2	0	0	0	0	0	0
140	2	2	0	0	0	0	0	1
141	2	2	0	0	0	0	0	0
142	2	2	0	1	0	0	0	0
143	2	2	0	0	0	1	0	0
144	2	2	0	0	0	1	0	0
			5	8	16	5	8	18

TABLE 3: continued.

(c) Cairns Section, October 1987

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
201	2	2	0	0	0	0	0	0
202	2	2	0	0	0	0	0	0
203	2	2	0	0	0	0	0	0
204	2	2	0	0	0	0	0	0
205	2	2	0	0	0	0	1	0
206	2	2	0	0	0	0	0	0
207	2	2	0	0	0	0	0	0
208	2	2	0	0	0	0	0	0
209	2	2	0	0	0	0	0	0
210	2	2	0	0	0	0	0	0
211	2	2	0	0	0	0	0	0
212	2	2	0	0	0	0	0	0
213	2	2	0	0	0	0	0	0
214	2	2	0	0	0	0	0	0
215	2	2	0	0	0	0	0	0
216	2	2	0	0	0	0	0	0
217	2	2	0	0	0	0	0	0
218	2	2	0	0	0	0	0	0
219	2	2	0	0	0	0	0	0
220	2	2	0	0	0	0	0	0
221	2	2	0	0	0	0	0	0
222	2	2	0	0	0	0	0	0
223	2	2	0	0	0	0	0	0
224	2	2	0	0	0	0	0	0
225	2	2	0	0	0	0	0	0
226	2	2	0	0	0	0	0	0
227	2	2	0	0	0	0	0	0
228	2	2	0	0	0	0	0	0
229	2	2	0	0	0	0	0	0
230	2	2	0	0	0	0	0	0
231	2	2	0	0	0	0	0	0
232	2	2	0	0	0	0	0	0
233	2	2	0	0	0	0	0	0
234	2	2	0	0	0	0	0	0
235	2	2	0	0	0	0	0	0
236	2	2	0	0	0	0	0	0
237	2	2	0	0	0	0	0	0
238	2	2	0	0	0	0	1	0
239	2	2	0	0	0	0	0	0
240	2	2	0	0	0	0	0	0
241	2	2	0	0	0	0	0	0
242	2	2	0	0	0	0	0	0
243	2	2	0	0	0	0	0	0
244	2	2	0	0	0	0	0	0
245	2	2	0	0	0	0	0	0
246	2	2	0	0	0	0	0	0
247	2	2	0	0	0	0	0	0
248	2	2	0	0	0	0	0	0
249	2	2	0	0	0	0	0	0
250	2	2	0	0	0	0	0	0
251	2	2	0	0	0	0	0	0
252	2	2	0	0	0	0	0	0

TABLE 3: continued.

(c) Cairns Section, October 1987

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
253	2	2	0	0	0	0	0	0
254	2	2	0	0	0	0	0	0
255	2	2	0	0	0	0	0	0
256	2	2	0	0	0	0	0	0
257	2	2	0	0	0	0	0	0
258	2	2	0	0	0	0	0	0
259	2	2	0	0	0	0	0	0
260	2	2	0	0	0	1	0	0
261	2	2	0	0	0	0	0	1
262	2	2	0	0	0	0	0	0
263	2	2	0	0	0	0	0	0
264	2	2	0	0	0	0	0	0
265	2	2	0	0	0	0	0	0
266	2	2	0	1	0	0	0	0
267	2	2	0	0	0	0	0	0
268	2	2	0	0	0	0	0	0
269	2	2	0	0	0	0	0	0
270	2	2	0	0	0	0	0	0
271	2	2	0	0	0	0	0	0
272	2	2	0	0	0	0	0	0
273	2	2	0	0	0	0	0	0
274	2	2	0	0	0	0	0	0
275	2	2	0	0	0	0	0	0
276	2	2	0	0	0	0	0	0
277	2	2	0	0	0	0	0	0
			0[d]	1[d]	0[d]	1[d]	2[d]	1[d]

[d] these sightings constituted to few observations for any correction factors for the Cairns Section to be calculated.

TABLE 4: Raw data used to calculate correction factors for the surveys.

(a) Correction for perception bias

Blocks : lines	No. of groups of dugongs					
	Port			Starboard		
	Mid	Rear	Tandem	Mid	Rear	Tandem
(a) Northern Central Section, September 1986						
9: 16, 31-38; 2: 38; 11	8[a]	9[a]	11[a]	5	2	7
8; 9: 11-14 & 17-30; 10: 51-58, 61, 64	8	6	11	5	2	7
(b) Central Section, September - October 1987						
All blocks and lines	7	2	12	5	3	13
(c) Mackay/Capricorn Section, November 1986						
5: 64-74; 3: 89	5	8	16	5[b]	8[b]	18[b]
1; 2; 3; 4; 5: 50-63, 75 & 138-144; 6: 76, 81-88 & 90-106; 7; 8	5	8	16	5	5	18

[a] port perception correction factor based on port rear-seat observer for rest of the survey while mid-seat observer on training transects.

[b] starboard perception correction factor based on starboard rear-seat observer for rest of the survey while mid-seat observer on training transects.

(b) Correction for availability bias

Blocks : lines	No. of dugongs in groups of less than 10		
	Surface	Under	Total
(a) northern Central Section, September 1986			
All blocks and lines	27	27	54
(b) Central Section, September - October 1987			
All blocks and lines	41	29	70
(c) Mackay/Capricorn Section, November 1986			
All blocks and lines	41	39	80

TABLE 5: Logistics of flight time for each survey.

Date	Transit Time (hrs)	Survey Time (hrs)	Dead Time (hrs)
(a) Northern Central Section, September 1986			
22/09/86	1.6	2.7	0.7
23/09/86	1.2	2.9	1.2
24/09/86	0.9	2.9	0.8
	3.7	8.5	2.7
(b) Central Section, September - October 1987			
29/09/87	1.11	3.37	1.20
30/09/87	2.83	3.44	1.32
1/10/87	1.34	9.49	3.37
5/10/87	0.69	3.03	0.71
6/10/87	1.42	2.52	1.35
7/10/87	1.55	2.73	0.72
21/10/87[a]	0.38	1.44	0.46
	9.32	26.02	9.13
(c) Mackay/Capricorn Section, November 1986			
18/11/86	1.2	1.9	0.5
21/11/86	2.3	3.9	1.2
22/11/86	1.3	4.2	1.0
23/11/86	1.4	4.0	1.2
24/11/86	2.4	4.1	0.9
25/11/86	1.4	2.6	0.6
26/11/86	0.6	0.2	0.0
27/11/86	0.5	2.6	0.3
	11.1	23.5	5.7
(c) Cairns Section, October 1987			
12/10/87	1.36	3.09	0.55
13/10/87	1.78	3.58	0.49
14/10/87	0.70	2.44	0.52
15/10/87	2.53	2.64	0.64
16/10/87	0.71	1.88	0.73
aircraft ferry	2.47	0.00	0.00
	9.55	13.63	2.93

[a] transect numbers 101-110,159,160,162 which were originally flown on the 5/10/87 and abandoned due to very poor weather were reflown on the 21/10/87.

SECTION 3

Raw data tables for dugongs in the survey area in Torres Strait

Section 3: Raw data tables for dugongs in the survey area in Torres Strait.

Table 1: Details of weather conditions encountered during the surveys.

Table 2: Beaufort Sea State and glare (for the north/east and south/west side of the aircraft) for each transect.

Table 3: Raw data for the surveys: dugong sightings.

Table 4: Raw data used to calculate correction factors for each survey.

Table 5: Logistics of flight time for each survey.

TABLE 1: Details of weather conditions encountered during the surveys.

Date	Session	Wind Speed (knots)	Wind Direction	Cloud Cover (oktas)	Cloud Height (ft)	Beaufort Sea State mode(range)	Glare[1] North/East mode(range)	Glare[1] South/West mode(range)	Tide Time
(a) November 1987									
10/11/87	1	10	E	1	5000	2.0(1.0-3.0)	1.0(0.0-1.0)	2.0(0.0-2.5)	Low 0232
	2	12-15	E	2	1000	2.0(1.0-4.0)	0.5-1.0(0.0-1.0)	0.5(0.0-1.0)	High 1750
11/11/87	1	5	E	6	12000	1.0(0.5-1.0)	0.0(0.0-1.0)	0.0(0.0-1.0)	Low 0258
	2	10	E	8	10000	2.5(1.0-3.0)	0.0(0.0-0.5)	0.0-1.0	High 1142
12/11/87	1	0	-	1,5	800,20000	0.5(0.0-1.0)	0.0(0.0-0.5)	0.5-1.0	Low 0324
	2	5	NE	4	20000	0.0(0.0-1.5)	0.0	0.0(0.0-1.0)	High 1127
13/11/87	1	<5	V	3,3	1000,20000	0.5(0.0-1.0)	0.0(0.0-1.0)	0.0(0.0-1.0)	Low 0349
	2	5	N	3	1500	0.0(0.0-2.0)	1.0(0.0-2.0)	1.0(0.0-2.5)	High 1126
14/11/87	1	10	NE	4,3	1000,20000	0.0(0.0-1.0)	1.0(0.0-2.0)	0.0	Low 0411
	2	8	NE	3,4	1200,12000	2.0(0.0-3.0)	1.0(0.0-1.5)	2.0(0.0-2.0)	High 1132
16/11/87	1	10	NE	3,2	1000,18000	2.0(1.0-3.0)	0.5(0.0-2.0)	1.0(0.5-2.0)	Low 0442
	2	12	NE	2,2	1500,18000	2.0-3.0(0.0-3.0)	1.0(0.0-1.5)	2.0(0.0-2.5)	High 1142
18/11/87	1	10	E	3,5	1000,20000	2.0(0.0-4.0)	1.0(0.0-1.5)	1.0(0.0-2.5)	Low 0451
	2	15	NE	2,4	1500,20000	2.0(2.0-3.0)	1.5(0.5-1.5)	2.5(1.0-2.5)	High 1135
19/11/87	1	8	E	3,1	1500,20000	2.0-2.5(1.0-2.5)	2.5(2.0-3.0)	0.0	Low 0452
	2	10	NE	-	-	1.0(0.0-2.0)	2.0(0.0-3.0)	0.5(0.0-3.0)	High 1138
20/11/87	1	10	E	-	-	1.0(0.0-2.0)	3.0(0.0-3.0)	0.0(0.0-3.0)	Low 0453
	2	10	E	3,2	1500,20000	2.0(1.0-4.0)	2.5(0.0-2.5)	2.0(0.0-2.0)	High 1156
21/11/87	1	8	NE	3,2	1500,20000	1.0(0.0-2.5)	2.0(0.0-3.0)	0.0	Low 0454
	2	8	E	3,2	1500,18000	1.0(0.0-3.0)	2.0(0.0-3.0)	0.0(0.0-3.0)	High 1226
22/11/87	1	10	E	2,4	1000,12000	1.0(0.0-2.5)	0.0(0.0-2.0)	1.0(0.5-2.0)	Low 0444
(b) March 1988									
4/03/88	1	10	W	2	2000	1.0(0.5-2.0)	1.0(1.0-1.5)	1.0(0.5-1.5)	Low 0348
	2	10	W	1	15000	1.0(0.5-2.0)	1.0(0.0-2.0)	0.5(0.0-1.0)	High 1238
5/03/88	1	<5	W	1,4	2000,15000	0.5(0.0-1.5)	0.0(0.0-0.5)	0.0(0.0-0.5)	Low 0404
	2	5-10	W	1,4	2000,15000	2.0(0.0-3.0)	1.0(0.0-2.0)	1.0(0.0-1.5)	High 1149
6/03/88	1	10	W	2,6	2000,15000	2.5(1.0-3.0)	1.0(0.5-2.0)	1.0(0.0-2.0)	Low 0426
	2	10	W	3,2	2200,15000	2.5(1.0-3.0)	1.0(0.5-2.0)	1.0(0.0-2.0)	High 1216
7/03/88	1	10	W	6	15000	2.5(1.0-3.0)	1.0(0.0-2.0)	2.0(0.0-2.0)	Low 0438
	2					1.0(0.0-1.0)	1.0(0.0-1.5)	0.0(0.0-1.0)	
	3	10	WNW	5,6	1500,15000	2.0(1.0-3.0)	0.0(0.0-2.0)	0.0(0.0-1.0)	High 1156
11/03/88	1	5	NE	1,8	1000,10000	2.0(0.0-2.5)	0.0-1.0(0.0-1.5)	0.0-1.0(0.0-1.5)	Low 0256
	2	8	E	3,8	1500,10000	1.0(0.0-2.5)	1.0(0.0-2.5)	0.5(0.0-2.0)	High 0923
									Low 1643

[1] 0 = no glare
1 = 0 $\leq$ 25% field of view glare affected
2 = 25 $\leq$ 50% field of view glare affected
3 = > 50% field of view glare affected

TABLE 2: Beaufort Sea State and glare (for the north/east and south/west sides of the aircraft) for each transect.

Scale : 0 = no glare
1 = 0 ≤ 25% field of view glare affected
2 = 25 ≤ 50% field of view glare affected
3 = > 50% field of view glare affected

(a) November 1987

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
Block 0[1]			
001	2.5(1.0-2.5)	2.0-3.0	0.0
002	2.5(1.0-2.5)	2.5-3.0	0.0
003	2.0(1.0-2.5)	2.5	0.0
004	2.0-2.5(1.0-2.5)	2.0-2.5	0.0
005	2.0(1.0-2.5)	2.5	0.0
006	2.5(1.0-2.5)	2.0-2.5	0.0
007	2.0(1.0-2.5)	2.0-2.5	0.0
008	0.0(0.0-0.5)	1.0-1.5	0.0
009	0.0(0.0-1.0)	1.0	0.0
010	0.0(0.0-0.5)	1.0(0.0-1.5)	0.0
011	0.0-0.5	2.0(0.5-2.0)	0.0
012	0.5	0.5(0.0-1.0)	0.0
Block 1[1]			
101	1.0(1.0-1.5)	2.0(0.0-2.5)	0.5(0.0-0.5)
102	1.0(1.0-3.0)	2.5(0.0-2.5)	0.0(0.0-2.0)
103	1.0(1.0-2.5)	3.0(0.0-3.0)	0.5-3.0
104	1.5(0.0-2.0)	2.0(0.0-2.0)	0.0
105	0.0(0.0-0.5)	3.0(0.0-3.0)	0.0
106	0.0-2.0	2.0(0.0-2.0)	0.0
107	1.0(0.0-2.0)	0.0-3.0	0.0
108	1.0(0.5-2.5)	2.0	0.0
109	1.0-2.5	2.5(0.0-3.0)	0.0
110	2.0(2.0-2.5)	2.0(0.0-2.0)	0.0
111	1.0(1.0-2.0)	1.5(0.0-2.0)	2.5(0.0-2.5)
112	1.0(1.0-2.0)	1.0	2.0
113	2.0	2.0	2.0
114	2.0(1.5-2.0)	3.0(0.0-3.0)	0.5(0.0-0.5)
115	2.0	3.0(0.0-3.0)	0.0
116	1.0(0.0-2.0)	3.0	0.0
117	2.0(1.0-2.0)	2.5-3.0	0.0
118	1.5(1.0-2.0)	0.0-3.0	0.0-3.0
119	1.0-2.0	0.0-3.0	0.0
120	2.0(1.0-4.0)	2.0	2.0
121	2.5(2.0-2.5)	2.5(2.0-2.5)	1.0(1.0-2.0)
122	1.0(1.0-1.5)	2.5	0.0
123	1.0(0.0-2.0)	3.0(0.0-3.0)	0.0
124	1.0	3.0(0.5-3.0)	0.0
125	0.5(0.0-0.5)	0.0-3.0	0.0
126	1.0(0.5-1.0)	2.5(0.0-2.5)	0.0
127	1.0(0.5-1.0)	3.0(1.0-3.0)	0.0
128	0.5-1.0	2.0	0.0
129	1.5(0.0-2.0)	1.0(0.0-2.0)	0.0-3.0

TABLE 2: continued

(a) November 1987

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
132	1.0(0.0-1.0)	2.0	0.5-1.0
133	1.0(1.0-2.0)	2.5-3.0	0.0
134	2.0(1.0-2.5)	2.5	0.0
135	1.0-2.5	2.5(2.0-3.0)	0.0
136	1.0	3.0	1.5
137	0.5-1.0	2.0	1.5
Block 2[2]			
201	1.0	0.0	0.0
202	1.0	0.0(0.0-0.5)	0.5(0.0-0.5)
203	1.0	0.0	0.0
204	1.0	0.5	1.0
205	1.0(0.5-1.0)	0.5-1.0(0.0-1.0)	0.0(0.0-0.5)
206	2.0(1.0-2.5)	0.0	0.5
207	2.5(1.0-2.5)	0.5	1.0
208	2.5(1.0-3.0)	0.0	0.0
209	2.0(1.0-3.0)	0.5	1.0-1.5
210	2.0(1.0-2.0)	0.0-0.5	1.0
211	3.0(1.0-3.0)	0.0-1.0	0.0-1.5
212	1.0(0.5-2.0)	0.0-1.0	0.5-2.0
213	2.0(1.0-2.5)	0.5(0.0-0.5)	1.5(1.0-2.0)
214	0.5(0.0-1.0)	0.0	0.5
215	1.0(0.5-1.0)	0.5	1.0
216	0.5(0.0-1.0)	0.0	0.5
217	1.0(0.0-1.0)	0.5	0.5
218	1.0(0.0-1.0)	0.0	0.5-1.0
219	0.5(0.0-0.5)	0.0	1.0
220	0.5(0.0-1.0)	0.0	1.0
221	1.5(0.0-1.5)	0.0	0.0-1.0
222	0.0(0.0-0.5)	0.0	0.0
223	0.0(0.0-0.5)	0.0	0.0
224	2.0(0.0-3.0)	1.0-1.5	2.0
225	1.5(0.0-2.0)	0.5(0.0-1.5)	2.0(0.0-2.0)
226	2.0(2.0-3.0)	1.0	2.0
227	1.0(0.5-2.0)	2.0(0.5-2.0)	0.5(0.5-1.0)
228	2.0(2.0-2.5)	2.0	0.5
Block 3[2]			
301	0.5(0.0-1.0)	0.0	0.0
302	0.5(0.0-0.5)	0.0-0.5	0.0-1.0
303	0.5(0.0-0.5)	0.0	0.5-1.0
304	0.0-0.5	0.0-0.5	0.0
305	0.5(0.5-1.0)	0.0(0.0-1.0)	0.0-1.0
306	1.0(0.5-2.0)	1.0(0.5-2.0)	0.5(0.5-1.0)
307	1.0(0.0-1.0)	1.0-2.0(0.0-2.0)	0.5(0.0-1.0)
308	0.5(0.0-1.5)	1.0	2.0
309	0.5(0.5-1.0)	0.0(0.0-2.0)	1.0(0.0-2.5)
310	2.0(2.0-3.0)	1.0(1.0-1.5)	1.0-2.0
311	2.0-2.5(1.5-3.0)	1.0-1.5	2.0
312	2.0(0.0-2.5)	0.5-1.0(0.0-1.0)	2.0(0.0-2.0)

TABLE 2: continued

(a) November 1987

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
315	2.0(1.0-3.0)	1.0(0.5-1.0)	2.0(1.5-2.0)
316	1.0(1.0-3.0)	0.0	0.0-0.5
Block 4[2]			
401	2.0(1.0-2.0)	0.0-0.5	0.5-2.0
402	2.0(1.5-3.0)	1.0	2.0
403	2.0(2.0-2.5)	1.0	2.0(1.5-2.0)
404	3.0(1.0-3.0)	0.0-1.0(0.0-1.5)	1.5(0.5-2.5)
405	2.0(1.0-3.0)	0.5(0.0-0.5)	1.5(0.0-1.5)
406	0.5(0.0-1.0)	1.0(0.0-1.0)	2.0(1.0-2.0)
407	0.5(0.0-0.5)	1.0(0.0-2.0)	0.0-1.5
Block 5[2]			
501	2.0(1.0-3.0)	0.0	1.0
502	2.0-2.5(1.0-4.0)	1.0	1.0
503	2.0(1.5-3.0)	1.0	1.0-1.5
504	2.0(2.0-2.5)	1.0	1.0-2.0
505	2.0(1.0-2.5)	1.0(0.5-1.0)	1.0-2.5
506	1.5(1.0-2.5)	0.5-1.0	1.0-1.5
507	2.0(1.5-2.5)	0.5-1.5	0.5-2.0
508	2.0	1.0	2.0
509	2.0(2.0-4.0)	1.0	1.0
510	1.0-3.0	1.0	0.0-1.0
511	2.5(1.0-3.0)	1.5	1.5
512	2.5(1.0-3.0)	0.0	1.0
513	2.0-2.5	1.5	1.0-1.5
514	2.5(2.0-3.0)	1.5	0.5
515	2.0-2.5(1.0-2.5)	0.0-1.0	1.5(0.0-1.5)
516	2.0(0.02.0)	1.0	2.0
Block 6[2]			
601	2.0(2.0-2.5)	1.5(0.5-1.5)	1.0-2.5
602	2.0-2.5	1.5	2.5
603	2.0(2.0-2.5)	1.0-2.0	1.0-2.0
604	2.0(2.0-2.5)	0.0	1.0
605	1.0-2.0	0.5	0.5
606	1.0(0.0-1.0)	0.0	1.5
607	1.0(1.0-2.0)	0.5-2.0	2.0
608	1.0(1.0-2.0)	0.0	1.0
609	1.0(0.5-1.0)	0.0	1.0
610	1.0(1.0-2.5)	0.0	1.0
611	2.0(2.0-2.5)	0.0	1.0

1 Transects in these blocks flown north-south, thus glare is for the east and west sides of the aircraft.

2 Transects in these blocks flown east-west, thus glare is for the north and south sides of the aircraft.

TABLE 2: continued

(b) March 1988

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
Block 2[2]			
201	1.0(1.0-1.5)	1.0	1.0
202	1.0	1.0-1.5	1.5
203	0.5-1.0(0.5-1.5)	1.0	1.0
204	0.5(0.5-1.5)	1.0	1.0
205	0.5(0.5-2.0)	1.0	0.5
206	1.0	1.0	0.0-1.0
207	1.0(1.0-1.5)	0.0-2.5	0.5(0.0-0.5)
208	1.0(0.5-2.0)	0.5-1.0	0.5-1.0
209	0.5(0.5-1.0)	0.5	0.0
210	0.5(0.5-1.0)	0.0-0.5	0.0-0.5
211	0.5-1.0(0.0-1.0)	0.0	0.0
212	0.5(0.0-1.5)	0.0-0.5	0.0
213	0.5-1.0	0.0	0.0
220	2.5(2.0-3.0)	1.0-1.5	1.0
221	2.0(1.0-3.0)	0.0-1.5	0.0-1.5
222	2.0(0.0-3.0)	1.0	1.0
223	2.5(1.0-2.5)	0.0(0.0-2.0)	0.0(0.0-1.5)
224	2.0(1.0-2.5)	0.0-1.5	0.0-1.5
225	1.5-2.0	1.0	0.5-1.0
226	1.0-3.0	1.0	0.0
227	2.0(1.5-3.0)	1.0-2.0	0.0
228	1.0(1.0-2.0)	1.0	2.0
Block 3[2]			
303	2.5(2.0-2.5)	1.0(0.5-1.0)	1.0
304	2.5(2.0-2.5)	1.0	1.0
305	2.5(1.0-3.0)	1.0	2.0
306	2.0(1.5-3.0)	1.0-2.0	0.0
307	1.0(1.0-2.5)	2.0	2.0
308	1.0-2.5	1.0-2.0	1.0
309	1.0-2.0	1.0	0.0-2.0
310	1.0-1.5	0.5-1.0	0.5-1.0
311	1.0(1.0-2.0)	0.0-1.0	0.5-1.5
312	1.0(0.0-2.5)	0.5	0.5
313	1.0(0.0-1.5)	0.5	0.5
Block 4[2]			
401	2.0(1.0-2.5)	0.0-0.5	0.0(0.0-1.5)
402	2.0(2.0-2.5)	1.0	0.0
403	2.0(2.0-2.5)	0.0-1.0	0.5-1.0
404	2.0(2.0-2.5)	1.0	0.0
405	2.0(1.0-2.5)	0.0-1.0	1.0
406	2.0(0.0-2.5)	1.5	0.5
407	2.0(1.5-2.5)	1.0-2.0	1.0(0.5-2.0)
Block 5[2]			
501	2.0(1.0-3.0)	0.0(0.0-1.5)	1.0(0.0-1.0)
502	2.5(2.0-2.5)	2.0	0.5
503	2.0(1.5-2.0)	0.0-1.0	0.0-0.5

TABLE 2: continued

(b) March 1988

Transect No.	Beaufort Sea State mode(range)	Glare North/East mode(range)	Glare South/West mode(range)
510	2.0-2.5(1.0-2.5)	0.5-2.0	0.0-2.0
511	1.0-2.5	1.0	1.0
512	1.0-2.5	1.5	1.0
513	1.5-2.0	2.0	1.0
Block 6[2]			
602	0.5-1.0	0.0	0.0
603	1.0	1.5	1.0
604	0.0-1.0	0.0-1.0	0.0
605	1.0(0.5-1.0)	1.0	0.0
606	0.0-1.0	0.0	0.0
607	0.5(0.5-1.0)	1.0	0.0
608	1.0	1.0	0.5
609	1.0(0.5-1.0)	1.0	0.0
610	1.0(0.0-1.0)	0.5	1.0
611	1.0(0.0-1.0)	0.0	0.0

[1] Transects in these blocks flown north-south, thus glare is for the east and west sides of the aircraft.

[2] Transects in these blocks flown east-west, thus glare is for the north and south sides of the aircraft.

TABLE 3: Raw data for each survey: dugong sightings.

(a) November 1987

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
001	2	2	0	0	0	0	0	0
002	2	2	0	0	0	0	0	0
003	2	2	0	0	0	0	0	0
004	2	2	0	0	0	0	0	0
005	2	2	0	0	0	0	0	0
006	2	2	0	0	0	0	0	0
007	2	2	0	0	0	0	0	0
008	2	2	0	0	0	0	0	0
009	2	2	0	0	0	0	0	0
010	2	2	0	0	0	0	0	0
011	2	2	0	0	0	0	0	0
012	2	2	0	0	0	0	0	0
101	2	2	0	0	0	0	0	0
102	2	2	0	0	0	0	0	0
103	2	2	0	0	0	0	0	0
104	2	2	0	0	0	0	0	0
105	2	2	0	0	0	0	0	0
106	2	2	0	0	1	0	0	0
107	2	2	0	0	1	0	1	1
108	2	2	0	1	3	0	0	0
109	2	2	0	0	0	0	0	1
110	2	2	0	0	0	0	0	0
111	2	2	0	0	0	0	0	0
112	2	2	0	0	0	0	0	0
113	2	2	0	0	0	2	0	0
114	2	2	0	0	0	0	0	0
115	2	2	0	0	0	0	0	0
116	2	2	0	0	0	0	0	0
117	2	2	0	0	0	0	0	0
118	2	2	0	0	0	0	0	0
119	2	2	0	0	0	0	0	0
120	2	2	0	0	0	1	0	0
121	2	2	0	0	0	0	0	0
122	2	2	0	0	0	0	0	0
123	2	2	0	0	0	0	0	1
124	2	2	0	1	1	0	0	0
125	2	2	0	0	0	0	0	0
126	2	2	0	0	0	0	0	0
127	2	2	0	0	0	0	0	1
128	2	2	0	1	1	0	0	0
129	2	2	0	0	1	0	0	0
130	2	2	1	0	0	1	0	0
131	2	2	0	0	0	0	0	0
132	2	2	0	1	0	0	0	1
133	2	2	0	0	0	0	0	0
134	2	2	0	0	1	0	0	0
135	2	2	0	0	0	0	0	1
136	2	2	0	0	0	1	0	0
137	2	2	0	0	0	0	0	0
201	2	1	0	2	6		19	

TABLE 3: continued.

(a) November 1987

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
204	2	1	5	3	7		9	
205	2	1	1	0	4		3	
206	2	1	1	0	3		0	
207	2	1	0	1	1		2	
208	2	1	0	1	0		0	
209	2	2	0	0	0	0	0	2
210	2	2	0	0	4	0	2	0
211	2	2	0	0	0	3	1	0
212	2	2	0	0	0	0	0	0
213	2	2	1	1	3	2	2	1
214	2	2	0	0	1	0	1	2
215	2	2	0	0	0	1	2	3
216	2	2	0	0	0	1	0	1
217	2	2	0	1	1	0	1	0
218	2	2	0	0	0	1	0	2
219	2	2	0	0	1	0	0	0
220	2	2	0	0	0	0	0	1
221	2	2	0	0	0	0	0	0
222	2	2	0	0	2	0	0	3
223	2	2	2	2	4	2	2	0
224	2	2	0	0	0	0	0	0
225	2	2	1	1	0	1	0	1
226	2	2	0	0	0	0	0	0
227	2	2	0	1	0	0	0	2
228	2	2	0	0	1	0	2	2
301	2	2	0	0	2	0	0	7
302	2	2	0	1	1	0	0	1
303	2	2	0	0	1	0	1	4
304	2	2	0	0	1	0	0	1
305	2	2	0	1	0	0	2	2
306	2	2	0	0	0	0	0	0
307	2	2	0	0	0	0	0	0
308	2	2	0	0	1	0	0	0
309	2	2	0	0	1	0	0	0
310	2	2	0	0	0	0	0	0
311	2	2	0	0	0	0	0	0
312	2	2	0	0	1	0	0	0
313	1	1	0				1	
314	1	1	0				0	
315	1	1	0				0	
316	1	1	0				0	
401	2	2	0	1	0	0	2	1
402	2	2	0	0	0	0	0	0
403	2	2	0	0	2	0	0	0
404	2	2	0	0	0	0	0	0
405	2	2	0	0	0	1	0	1
406	2	2	0	0	0	1	0	0
407	2	2	0	0	0	0	0	0
501	2	2	0	0	0	0	0	0
502	2	2	0	0	0	0	0	0

TABLE 3: continued.

(a) November 1987

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
505	2	2	0	0	0	0	0	0
506	2	2	0	0	0	0	0	0
507	2	2	0	0	0	0	0	0
508	2	2	0	0	0	0	0	0
509	2	2	0	0	0	0	0	1
510	2	2	0	0	0	0	0	0
511	2	2	0	0	0	0	0	0
512	2	2	0	0	0	0	0	0
513	2	2	0	0	0	0	0	0
514	2	2	0	0	0	0	0	0
515	2	2	0	0	0	0	0	0
516	2	2	0	0	0	0	0	0
601	2	2	0	0	0	0	0	0
602	2	2	0	0	0	0	0	0
603	2	2	0	0	0	0	0	0
604	2	2	0	0	0	0	0	0
605	2	2	0	0	0	0	0	0
606	2	2	0	0	0	0	0	0
607	2	2	0	0	0	0	0	0
608	2	2	0	0	0	0	0	0
609	2	2	0	0	0	0	0	0
610	2	2	0	0	0	0	0	0
611	2	2	0	0	0	0	0	0
			12[1]	23	65	18	69[2]	46

[1] includes transects 313 to 316 which were not used in the calculation of the port perceptual correction factor.

[2] includes transects 201 to 208 and 313 to 316 which were not used in the calculation of the starboard perceptual correction factor.

TABLE 3: continued.

(b) March 1988

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
201	1	1	2				4	
202	1	1	8				8	
203	1	1	1				2	
204	1	1	3				2	
205	1	1	2				5	
206	2	1	4	1	3		4	
207	2	1	0	3	5		1	
208	2	1	1	3	3		5	
209	2	2	1	0	1	0	1	0
210	2	2	0	0	2	0	0	0
211	2	2	0	0	1	0	0	0
212	2	2	0	0	0	2	1	0
213	2	2	0	0	0	0	0	0
220	2	2	0	0	0	0	0	0
221	2	2	1	0	0	1	0	0
222	2	2	0	0	0	0	0	0
223	2	2	0	0	0	0	0	2
224	2	2	0	0	0	0	0	0
225	2	2	0	0	0	0	0	0
226	2	2	2	1	2	0	2	1
227	2	2	0	0	0	0	2	2
228	2	2	0	0	1	0	0	0
303	2	2	1	2	0	1	0	0
304	2	2	0	0	0	2	1	0
305	2	2	0	0	1	0	0	0
306	2	2	0	0	0	0	0	1
307	2	2	1	0	0	0	0	0
308	2	2	0	0	0	0	0	0
309	2	2	0	0	0	0	0	0
310	2	2	0	0	1	0	0	1
311	2	2	0	0	0	0	0	0
312	2	2	0	0	0	0	0	0
313	2	2	1	1	1	0	1	5
401	2	2	0	0	0	0	0	0
402	2	2	0	0	0	0	0	0
403	2	2	1	0	0	0	0	0
404	2	2	0	0	0	0	0	0
405	2	2	0	0	0	0	0	0
406	2	2	0	0	0	0	0	0
407	2	2	0	0	0	0	0	0
501	2	2	0	0	0	0	0	0
502	2	2	0	0	0	0	0	0
503	2	2	0	0	0	0	0	0
504	2	2	0	0	0	0	0	0
509	2	2	0	0	0	0	0	0
510	2	2	0	0	0	0	0	0
511	2	2	0	0	0	0	0	0
512	2	2	0	0	0	0	0	0
513	2	2	0	0	0	0	0	0
602	2	2	0	0	0	0	0	0

TABLE 3: continued.

(b) March 1988

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
605	2	2	0	0	0	0	0	0
606	2	2	0	0	0	0	0	0
607	2	2	0	0	0	0	0	0
608	2	2	0	0	0	0	0	0
609	2	2	0	0	0	0	0	0
610	2	2	0	0	0	0	0	0
611	2	2	0	0	0	0	0	0
			29[3]	11	21	6	33[4]	12

[3] includes transects 201 to 205 which were not used in the calculation of the port perceptual correction factor.

[4] includes transects 201 to 208 which were not used in the calculation of the starboard perceptual correction factor.

TABLE 4: Raw data used to calculate correction factors for the surveys.

(a) Correction for perception bias

Blocks : lines	No. of groups of dugongs Port			Starboard		
	Mid	Rear	Tandem	Mid	Rear	Tandem
(a) November 1987						
3: 13-16	12[1]	23[1]	65[1]	18[2]	69[2]	46[2]
2: 1-8	12	23	65	18[2]	68[2]	46[2]
0; 1; 2: 9-28; 3: 1-12; 4; 5; 6	12	23	65	18	19	46
(b) March 1988						
2: 1-5	29[1]	11[1]	21[1]	6[2]	33[2]	12[2]
2: 6-8	13	11	21	6[2]	18[2]	12[2]
2: 9-28; 3: 3-13; 4; 5: 1-4, 9-13; 6: 2-11	13	11	21	6	8	12

[1] port perception correction factor based on port mid-seat observer for rest of the survey while rear-seat observer on training transects.

[2] starboard perception correction factor based on starboard rear-seat observer for rest of the survey while mid-seat observer on training transects.

(b) Correction for availability bias

Blocks : lines	No. of dugongs in groups of less than 10 Surface	Under	Total
(a) November 1987			
All blocks and lines	141	170	311
(b) March 1988			
All blocks and lines	69	92	161

TABLE 5: Logistics of flight time for each survey.

Date	Transit Time (hrs)	Survey Time (hrs)	Dead Time (hrs)
(a) November 1987			
10/11/87	1.21	2.07	0.27
11/11/87	1.98	2.98	0.15
12/11/87	1.65	3.30	0.73
13/11/87	0.97	3.68	0.63
14/11/87	2.22	2.71	0.63
16/11/87	0.88	3.30	1.08
18/11/87	1.55	2.06	0.57
19/11/87	1.81	3.06	0.43
20/11/87	1.78	3.39	0.79
21/11/87	2.01	3.14	0.43
22/11/87	1.07	3.14	0.28
aircraft ferry	9.80	0.00	0.00
	26.93	31.38	5.99
(b) March 1988			
4/03/88	1.47	2.93	0.29
5/03/88	2.24	3.58	0.39
6/03/88	1.74	2.98	0.80
7/03/88	1.83	2.34	1.24
11/03/88	1.12	3.57	0.63
aircraft ferry	13.90	0.00	0.00
	22.30	15.40	3.35

SECTION 4

Raw data tables for turtles in the survey area from the tip of Cape York south to Cape Bedford

Section 4: Raw data tables for turtles in the survey area from the tip of Cape York south to Cape Bedford.

Table 1: Raw data for the surveys: turtle sightings.

TABLE 1: Raw data for the surveys: turtle sightings.

(a) ßlocks 1 - 4, November 1984

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of turtles Port Rear	No. of groups of turtles Starboard Rear
001	1	1	3	3
002	1	1	5	8
003	1	1	3	1
004	1	1	0	0
005	1	1	3	1
006	1	1	5	3
007	1	1	9	9
008	1	1	6	3
009	1	1	4	5
010	1	1	14	18
011	1	1	15	12
012	1	1	25	23
013	1	1	16	12
014	1	1	2	4
015	1	1	0	1
016	1	1	0	1
017	1	1	2	1
018	1	1	2	1
019	1	1	0	0
020	1	1	0	0
021	1	1	0	0
022	1	1	0	0
023	1	1	0	1
024	1	1	0	0
025	1	1	3	3
026	1	1	1	3
027	1	1	0	0
028	1	1	1	2
029	1	1	2	1
030	1	1	3	4
031	1	1	5	5
032	1	1	0	1
033	1	1	3	4
034	1	1	2	1
035	1	1	0	0
036	1	1	5	4
037	1	1	7	1
038	1	1	2	3
039	1	1	3	2
040	1	1	3	2
			154	143

TABLE 1: continued.

(b) Blocks 6 - 13, April 1985

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs Port Rear	Starboard Mid	Starboard Rear	Starboard Tandem
001	1	2	1	1	5	0
002	1	2	1	1	0	1
003	1	2	2	3	0	1
004	1	2	2	0	1	2
005	1	2	1	2	1	3
006	1	2	2	1	1	0
007	1	2	0	1	1	0
008	1	2	4	1	1	0
009	1	2	1	2	1	1
010	1	2	2	1	0	1
011	1	2	0	1	0	0
012	1	2	1	0	0	0
013	1	2	0	0	1	0
014	1	2	1	0	1	0
015	1	2	0	0	0	0
016	1	2	1	1	0	0
017	1	2	2	0	0	3
018	1	2	2	0	1	0
019	1	2	1	0	2	1
020	1	2	1	0	0	0
021	1	2	0	0	0	0
022	1	2	0	0	0	0
023	1	2	1	0	0	0
024	1	2	0	0	0	1
025	1	2	0	0	0	0
026	1	2	0	0	0	0
027	1	2	0	0	0	0
028	1	2	4	4	0	1
029	1	2	6	0	2	0
030	1	2	0	0	1	0
031	1	2	2	1	1	6
032	1	2	1	1	0	0
033	1	2	1	2	1	2
034	1	2	3	0	0	1
035	1	2	2	0	0	1
036	1	2	0	0	0	1
037	1	2	0	0	0	1
038	1	2	0	0	0	0
039	1	2	1	0	0	0
040	1	2	0	1	0	2
041	1	2	1	2	1	1
042	1	2	1	1	1	1
043	1	2	2	1	1	4
044	1	2	3	3	0	0
045	1	2	0	0	1	1
046	1	2	0	0	0	0
047	1	2	2	1	5	0
048	1	2	0	0	1	0
049	1	2	4	3	1	1
050	1	2	0	0	0	1
051	1	2	0	0	0	0
052	1	2	0	1	0	0

TABLE 1: continued.

(b) Blocks 6 - 13, April 1985

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Rear	Starboard Mid	Rear	Tandem
053	1	2	0	1	0	0
054	1	2	1	1	0	0
055	1	2	0	0	0	3
056	1	2	1	0	0	1
057	1	2	8	4	0	13
			69	44	32	55

TABLE 1: continued.

(c) Blocks 1 - 4, November 1985

Transect No.	No. of observers Port	No. of observers Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
001	2	2	0	0	0	1	0	0
002	2	2	0	0	0	1	1	2
003	2	2	2	0	2	0	0	0
004	2	2	1	1	0	1	1	0
005	2	2	0	0	2	0	0	0
006	2	2	0	0	1	0	0	0
007	2	2	0	0	0	0	0	0
008	2	2	1	0	0	2	0	0
009	2	2	1	0	1	0	0	0
010	2	2	3	1	1	0	0	0
011	2	2	3	1	1	0	0	0
012	2	2	0	5	1	2	0	2
013	2	2	3	1	3	3	1	0
014	2	2	3	1	2	2	2	4
015	2	2	2	1	2	0	1	0
016	2	2	3	1	0	3	0	0
017	2	2	0	0	0	0	0	0
018	2	2	2	3	1	2	0	2
019	2	2	6	3	4	6	6	1
020	2	2	3	9	5	3	6	10
021	2	2	3	7	8	8	3	3
022	2	2	2	7	6	8	4	7
023	2	2	9	2	6	4	2	1
024	2	2	0	0	0	1	1	1
025	2	2	4	3	4	6	0	3
026	2	2	0	1	2	2	1	0
027	2	2	2	1	1	0	1	0
028	2	2	0	3	5	3	0	1
029	2	2	0	0	1	3	1	0
030	2	2	1	0	1	0	0	1
031	2	2	0	1	0	0	0	2
032	2	2	0	0	0	1	0	0
033	2	2	0	1	2	2	0	1
034	2	2	0	1	5	1	1	2
			54	54	67	65	32	43

TABLE 1: continued.

(d) Block 5, November 1985

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
001	2	1	0	0	1		0	
002	2	1	0	1	1		2	
003	2	1	2	1	4		4	
004	2	1	0	0	0		3	
005	2	1	2	3	5		9	
006	2	1	2	1	6		6	
007	2	1	1	0	0		2	
008	2	1	2	0	2		2	
009	2	2	2	3	3	5	3	3
010	2	2	4	2	4	6	0	3
011	2	2	5	0	9	5	2	2
012	2	2	6	4	7	5	5	4
013	2	2	7	6	17	6	3	8
014	2	2	8	6	5	7	8	15
015	2	2	3	5	15	3	3	5
016	2	2	6	2	21	7	3	15
017	2	2	9	3	7	3	1	6
018	2	2	1	0	3	3	2	3
019	2	2	0	2	2	2	2	0
020	2	2	1	1	1	2	2	2
021	2	2	1	2	0	2	1	1
022	2	2	1	4	1	0	1	1
023	2	2	3	5	1	4	0	0
			66	51	115	60	63[a]	68

[a] includes transects 1-8, which were not used in the calculation of starboard perception correction factor.

TABLE 1: continued.

(e) Blocks 6 - 13, November 1985

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Port Rear	Port Tandem	Starboard Mid	Starboard Rear	Starboard Tandem
001	2	2	0	1	2	2	0	2
002	2	2	0	2	0	0	1	0
003	2	2	5	1	2	5	2	3
004	2	2	0	0	1	0	2	3
005	2	2	1	0	3	1	0	2
006	2	2	1	0	0	0	0	0
007	2	2	0	0	2	1	0	2
008	2	2	0	0	1	0	1	3
009	2	2	1	7	0	0	6	0
010	2	2	0	0	0	1	1	0
011	2	2	0	0	0	0	0	0
012	2	2	1	0	0	1	1	0
013	2	2	0	1	1	0	0	3
014	2	2	1	1	1	1	1	4
015	2	2	0	1	2	1	0	3
016	2	2	1	1	0	0	1	3
017	2	2	1	0	5	0	0	2
018	2	2	1	0	1	0	0	1
019	2	2	0	1	1	2	0	2
020	2	2	0	2	0	0	0	1
021	2	2	3	0	0	1	0	1
022	2	2	0	0	0	1	1	1
023	2	2	1	2	0	2	0	1
024	2	2	0	1	2	0	3	0
025	2	2	0	1	2	3	4	2
026	2	2	1	0	0	0	0	0
027	2	2	1	2	7	0	0	6
028	2	2	4	0	1	1	0	2
029	2	2	4	2	5	4	4	2
030	2	2	2	4	10	0	3	10
031	2	2	3	5	12	4	2	11
032	2	2	2	0	7	3	2	7
033	2	2	2	6	8	2	2	4
034	2	2	3	2	7	5	2	10
035	2	2	2	4	9	6	3	5
036	2	2	2	2	8	1	1	3
037	2	2	2	3	4	0	2	1
038	2	2	3	1	2	2	5	9
039	2	2	8	0	11	0	3	9
040	2	2	3	0	28	1	8	20
041	2	2	3	4	18	1	7	11
042	2	2	1	2	5	0	4	7
043	2	2	4	1	10	3	5	12
044	2	2	1	0	6	1	0	7
045	2	2	1	0	2	0	0	3
046	2	2	2	0	2	2	0	3
047	2	2	11	3	10	4	2	10
048	2	2	4	3	5	0	5	8
049	1	2		12		1	1	4
050	1	2		2		0	0	0
051	1	2		1		0	0	0
052	1	2		0		0	0	0

TABLE 1: continued.

(e) Blocks 6 - 13, November 1985

Transect No.	No. of observers Port	Starboard	No. of groups of dugongs Port Mid	Rear	Tandem	Starboard Mid	Rear	Tandem
053	1	2		2		0	1	0
054	1	2		10		0	1	1
055	1	2		2		0	0	1
056	1	2		2		1	1	0
057	1	2		5		5	6	11
			86	102[b]	203	69	94	217

b includes transects 49-57, which were not used in the calculation of port perception correction factor.

SECTION 5

Listing of computer programmes used for the collection and analysis of aerial census data

CONTENTS

Section 5.1

Description of how to set-up the input data files

and how to use the programmes.

Introduction

The programmes in this manual were developed for the analysis of aerial survey data collected using the methodology of Marsh and Sinclair (in review). The final output consists of an estimate of overall density and population size for the survey region.

Use of the programmes

Survey data are recorded in real time during the survey using an EPSON HX-20 personal computer programmed as a data-logger and timer, and using a two-track tape recording system (see Marsh and Sinclair, in review). Data recorded on micro-cassette by the EPSON HX-20 are transferred to a main-frame computer (a Digital DECsystem 10 computer) where the additional data obtained from the two-track tape records are edited into the transferred files.

The sighting information recorded by the EPSON HX-20 (see Section 5.2 for a listing of the data-logging programme) is as follows:

i) Takeoff (code 'S') - takeoff time, takeoff date, altimeter reading at takeoff, cloud cover and cloud height for two levels, wind speed and direction, visibility and any comments about conditions/location etc;

ii) Transect start (code 'R') - transect start time, transect number (000 to 999), transect direction (N,E,S or W), nominal flight height (feet) and cloud cover;

iii) Beaufort sea state (code 'B') - time of record, beaufort sea state, transect number and direction;

iv) Glare (code 'G') - time of record, glare on port side of aircraft, glare on starboard side of aircraft, transect number and direction;

v) Height (code 'H') - time of record, altimeter height of aircraft, transect number and direction;

vi) Dugong sighting (code 'D') - time of sighting, observer ('PM' = port mid-seat, 'PR' = port rear-seat, 'PT' = port team, 'SM' = starboard mid-seat, 'SR' = starboard rear-seat, 'ST' = starboard team), number of animals, number of calves, number of animals at the surface, position in transect ('T' = top third, 'M' = middle third, 'B' = bottom third), transect number and direction;

vii) Turtle sighting (code 'T') - time of sighting, observer, number of animals, number at surface, position in transect, transect number and direction;

viii) Shark sighting (code 'K') - as for turtle sighting;

ix) Ray sighting (code 'Y') - as for turtle sighting;

x) Seasnake sighting (code 'N') - as for turtle sighting;

xi) Cetacean sighting (code 'C') - time of sighting, observer, number of animals, number of calves, number at surface, position in transect, species, reliability of sighting ('U' = uncertain, 'P' = probable, 'C' = certain), transect number and direction;

xii) Whale sighting (code 'W') - as for cetacean sighting;

xiii) Plume sighting (code 'X') - time of sighting, observer, number of plumes, species producing the plumes, transect number and direction;

xiv) Plankton sighting (code 'P') - time of sighting, observer, colour of plankton, transect number and direction;

xv) Map reference (code 'M') - time of position, map reference (from chart), side of aircraft, distance to object (e.g. an island), transect number and direction;

xvi) Comment (code 'A') - time of comment, comment, transect number and direction;

xvii) Transect finish (code 'F') - time of finish, transect number, transect direction and cloud cover;

xviii) Landing (code 'L') - time of landing, altimeter reading at landing, altimeter drift since takeoff.

Once editing of the transferred files is completed they are combined into a single data file (called 'SURVEY.DAT') using an appropriate system programme. It is important to ensure that the format of all records of the same type is identical and corresponds to the format utilized by the user programmes. (The formats are given in the programmes).

File 'SURVEY.DAT' is split into a series of separate data files, each containing all records of a single type for the whole survey, using programme SPLIT (see Section 5.3 for listing). As written, programme SPLIT, extracts the following records from the file 'SURVEY.DAT':

i) Takeoff and corresponding landing time (these should be in the sequence takeoff time then landing time in file 'SURVEY.DAT' for each flight interval) and writes them to file 'SURSL.DAT';

ii) Transect start and corresponding finish time (these should be in the sequence start time then finish time in file 'SURVEY.DAT' for each transect) and writes them to file 'SURRF.DAT';

iii) Height, which is written to file 'SURH.DAT';

iv) Beaufort sea state, which is written to file 'SURB.DAT';

v) Glare, which is written to file 'SURG.DAT';

vi) Dugong sightings, which are written to file 'SURD.DAT'.

Other records, e.g. turtle sightings etc., can be extracted from the file 'SURVEY.DAT' by modifying programme SPLIT appropriately.

The file 'SURSL.DAT' can now be printed and the information it contains used to (i) draw up tables of the weather conditions encountered during the survey, (ii) calculate total flight time during the survey, and (iii) calculate the drift in altimeter readings for each flight interval so that the error in altimeter readings for each transect can be interpolated.

The file 'SURRF.DAT' containing the transect start and finish times is used by programme TRAN (see Section 5.5 for listing) to calculate transect flight time, transect mid time and transect flight speed for each transect. To calculate transect flight speed, programme TRAN also requires that transect length be input. This information is contained in the file 'LENGTH.DAT' which the user creates with transect numbers in columns 2 to 4 and transect length (in kilometers) in columns 6 to 10 (FORTRAN FORMAT 1X,I3,1X,F5.1). **Note that the order of the transect lengths in file 'LENGTH.DAT' must be the same as the transect order in file 'SURRF.DAT'.**

The other files output by programme SPLIT can be utilized as follows:

a) 'SURH.DAT', containing the aircraft heights along each transect is read by programme HEIGHT (see Section 5.4 for listing), which calculates the mean height at which each transect was flown and outputs the results to file 'HEIGHT.DAT'. These means are uncorrected for altimeter drift during the flights and must be corrected using the appropriate interpolations (calculated from the information in file 'SURSL.DAT');

b) 'SURB.DAT' containing the Beaufort Sea State data for each transect which can be used to determine the modal Beaufort Sea State for each transect;

c) 'SURG.DAT' containing glare data for each transect which can be used to determine the modal glare for each transect; and

d) 'SURD.DAT' containing the dugong sightings for each transect and is used by programme DIST (see Section 5.6 for listing) in determining the position of each sighting, the number of groups seen by each individual observer and each tandem team, the total number of dugongs seen, the number of calves seen, the number seen at the surface and the number seen under the surface.

After execution of programme SPLIT and creation of file 'LENGTH.DAT', programme TRAN can be executed to produce the output file 'TRAN.DAT', which, with file 'SURD.DAT', is used by programme DIST to determine the position of each dugong sighting and the parameters necessary to calculate the correction factors.

File 'TRAN.DAT' contains the following data for each transect:

a) transect number;

b) transect direction;

c) transect length;

d) start time in hours, minutes and seconds;

e) start time in seconds from midnight;

f) mid time in hours, minutes and seconds;

g) mid time in seconds from midnight;

h) finish time in hours, minutes and seconds;

i) finish time in seconds from midnight;

j) speed at which transect was flown; and

k) elapsed flight time on transect in decimal hours.

Execution of programme DIST is the next step in the calculation of population size and density. The output from programme DIST consists of three files: 'DIST.DAT', containing transect number, distance from the northern or western end of transect in kilometers and the number of animals sighted at that point; 'CORFAC.DAT', containing the number of groups sighted to port and starboard, number of dugongs, number of calves, number at the surface and number under the surface for each transect, plus, the total number of groups seen by each observer and tandem team and the total numbers of dugongs, calves, surface and under surface animals; and 'INPUT.DAT', which contains the total numbers of groups seen by each observer and tandem team, the total numbers of surface and under surface animals, and the sum and sum-squared of group sizes, for input to programme FACTOR (see Section 5.7 for listing), which calculates the perceptual and availability correction factors and the mean group size (with associated coefficients of variation) for use in programme POPUL (see Section 5.8 for listing). Output in the first two files is labelled.

Programme FACTOR does not require any user editing of the input file prior to execution. Once file 'INPUT.DAT' has been created by programme DIST, programme FACTOR can be executed. Output is to file 'CORREC.DAT' and consists of the port and starboard perceptual correction factors with associated coefficients of variation, the availability correction factor with its coefficient of variation and the mean group size with its coefficient of variation. Output in file 'CORREC.DAT' is labelled.

Before programme POPUL (the final programme in this manual, which calculates the population size and density for the survey area) can be executed the input file 'POPIN.DAT', containing the input data for programme POPUL, has to be created.

The data contained in file 'POPIN.DAT' is as follows:

- number of transects flown in the survey region
- nominal flight height
- nominal transect width
- total area of survey region
- length of survey region perpendicular to transect direction
- availability correction factor
- coefficient of variation for availability correction factor
- mean group size
- coefficient of variation for mean group size
- port perceptual correction factor
- coefficient of variation for port perceptual correction factor
- starboard perceptual correction factor
- coefficient of variation for starboard perceptual correction factor
- and for each transect
  - transect number
  - transect length
  - actual transect height (from corrected mean heights)
  - number of groups of animals seen to port
  - number of groups of animals seen to starboard

The fortran format for file 'POPIN.DAT' is

```
1X,I3,1X,F5.1,1X,F5.3,1X,F8.1,1X,F5.1,/,8(1X,F6.4),/,1X,I3,4(1X,F5.1)
```

Once file 'POPIN.DAT' has been created programme POPUL can be executed, with the output going to file 'POPOUT.DAT'. The output consists of:

- for each transect
  - transect number
  - transect area
  - corrected number of animals sighted to port
  - corrected number of animals sighted to starboard
- the population density estimate for the survey region
- the population estimate for the survey region
- the standard error for the population estimate (corrected for the errors associated with the correction factors and mean group size estimate)

Programme POPUL uses the Ratio Method (Jolly, 1969 and Caughley and Grigg, 1981) and incorporates the errors in estimating the perceptual and availability correction factors and mean group size (Marsh and Sinclair, in review).

If the survey region is stratified into a number of blocks, a separate population and density estimate is calculated for each block, by creating file 'POPIN.DAT' such that it contains data for the transects within the block. A more precise estimate will be obtained using correction factors based on the entire survey.

Acknowledgements

The basic programme used by the EPSON HX-20 was developed by Lachlan Marsh.

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Jolly, G.M. 1969. Sampling methods for aerial census of wildlife populations. E. Afr. agric. For. J. 34:46-49.

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Section 5.2

Listing of Basic programme for the

EPSON HX-20 personal computer

```
10 DEFSTRA-H,T:OPEN"O",1,"CAS0:AERIAL.DAT"
20 INPUT">> ",C:IFC=""THEN22ELSEF=C
22 IFF="D"THEN60
24 IFF="V"THEN110
26 IFF="T"THEN200
28 IFF="C"THEN250
30 IFF="X"THEN300
32 IFF="F"THEN350
34 IFF="H"THEN400
36 IFF="B"THEN450
38 IFF="E"THEN500
40 IFF="R"THEN550
42 IFF="W"THEN600
43 IFF="Y"THEN1050
44 IFF="M"THEN650
45 IFF="P"THEN1000
46 IFF="Z"THEN   20
47 IFF="N"THEN950
48 IFF="S"THEN700
49 IFF="K"THEN900
50 IFF="Q"THEN CLOSE:END
51 IFF="A"THEN850
52 IFF="L"THEN750
53 IFF="G"THEN800
55 SOUND15,10:PRINT"INVALID ENTRY":GOTO20
60 LINEINPUT"Observer ",A:B="D*"+TIME$+"*"+A+"*"
70 LINEINPUT"#Group ",A:B=B+A+"*"
80 LINEINPUT"#Calves ",A:B=B+A+"*"
90 LINEINPUT"Position: ",A:B=B+A+"*"
100 LINEINPUT"#Surface ",A:B=B+A+"*"+TN+"*"+TD
102 LPRINTB:PRINT#1,B:GOTO20
110 LINEINPUT"Photographer ",A:B="V*"+TIME$+"*"+A+"*"
120 LINEINPUT"Frames ",A:B=B+A+"*"
130 LINEINPUT"Overlap ",A:B=B+A+"*"
140 LINEINPUT"Blank ",A:B=B+A+"*"+TN+"*"+TD
150 LPRINTB:PRINT#1,B:GOTO20
200 LINEINPUT"Observer ",A:B="T*"+TIME$+"*"+A+"*":LINEINPUT"# group ",A:B=B+A+"*":LINEINPUT"# surface ",A:B=B+A+"*":LINEINPUT"pos in col ",A:B=B+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
250 LINEINPUT"Observer ",A:B="C*"+TIME$+"*"+A+"*":LINEINPUT"# group ",A:B=B+A+"*":LINEINPUT"# calves ",A:B=B+A+"*":LINEINPUT"# surface ",A:B=B+A+"*"
255 LINEINPUT"pos in col ",A:B=B+A+"*":LINEINPUT"genus ",A:B=B+A+"*":LINEINPUT"Reliability ",A:B=B+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
300 LINEINPUT"Observer ",A:B="X*"+TIME$+"*"+A+"*":LINEINPUT"# plumes ",A:B=B+A+"*":LINEINPUT"Species? ",A:B=B+A+"*"+TN+"*"+TD
305 LPRINTB:PRINT#1,B
350 LINEINPUT"Cloud cover ",A:B="F*"+TIME$+"*"+TN+"*"+TD+"*"+A:LPRINTB:PRINT#1,B:GOTO20
400 LINEINPUT"Height ",A:B="H*"+TIME$+"*"+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
450 LINEINPUT"Beaufort ",A:B="B*"+TIME$+"*"+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
500 LINEINPUT"Substrate ",A:B=B+A+"*":LINEINPUT"Seagrass ",A:B="E*"+TIME$+"*"+B+A+"*"+TN+"*"+TD
505 LPRINTB:PRINT#1,B:GOTO20
550 LINEINPUT"Transect # ",TN:B=TN+"*":LINEINPUT"Transect dir. ",TD:B=B+TD+"*":LINEINPUT"Nom. ht ",A:B=B+A+"*"
555 LINEINPUT"Cloud cover ",A:B=B+A+"*"
560 LINEINPUT"Start ",A:B="R*"+TIME$+"*"+B:LPRINTB:PRINT#1,B:GOTO20
600 LINEINPUT"Observer ",A:B="W*"+TIME$+"*"+A+"*":LINEINPUT"# group ",A:B=B+A+"*":LINEINPUT"# calves ",A:B=B+A+"*":LINEINPUT"# surface ",A:B=B+A+"*"
605 LININPUT"pos in col ",A:B=B+A+"*":LINEINPUT"species ",A:B=B+A+"*":LINEINPUT"reliability ",A:B=B+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
650 LINEINPUT"Map ref. ",A:B=A+"*":LINEINPUT"Side ",A:B=B+A+"*":LINEINPUT"Distance ",A:B="M*"+TIME$+"*"+B+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
700 LINEINPUT"Altimeter ",A:B=A+"*":LINEINPUT"Cloud Cov.1 ",A:B=B+A+"*":LINEINPUT"Cloud ht ",A:B=B+A+"*":LINEINPUT"Cloud cov. 2 ",A:B=B+A+"*":LINEINPUT"Cloud ht ",A:B=B+A+"*"
710 LINEINPUT"Windspeed ",A:B=B+A+"*":LINEINPUT"Wind dir. ",A:B=B+A+"*":LINEINPUT"Air vis. ",A:B=B+A+"*":LINEINPUT"Comments ",A:B=B+A
720 LINEINPUT"Takeoff ",A:IFA<>"TO" THEN720 ELSE B="S*"+TIME$+"*"+DATE$+"*"+B:LPRINTB:PRINT#1,B:GOTO20
750 LINEINPUT"Altimeter ",A:B="L*"+TIME$+"*"+A:LINEINPUT"Alt. dif. ",A:B=B+"*"+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:CLOSE:END
800 LINEINPUT"glare port ",A:B="G"+"*"+TIME$+"*"+A+"*":LINEINPUT"glare starbd",A:B=B+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
850 LINEINPUT"Comment: ",A:B="A*"+TIME$+"*"+A+"*"+TN+"*"+TD
855 LPRINTB:PRINT#1,B:GOTO20
900 LINEINPUT"Observer ",A:B="K*"+TIME$+"*"+A+"*":LINEINPUT"Number ",A:B=B+A+"*":LINEINPUT"# surface ",A:B=B+A+"*":LINEINPUT"pos in col ",A:B=B+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
950 LINEINPUT"Observer ",A:B="N*"+TIME$+"*"+A+"*":LINEINPUT"Number ",A:B=B+A+"*":LINEINPUT"# surface ",A:B=B+A+"*":LINEINPUT"pos in col ",A:B=B+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
1000 LINEINPUT"Observer: ",A:B=A+"*":LINEINPUT"Colour: ",A:B=B+A+"*"+TN+"*"+TD:B="P*"+TIME$+"*"+B
1005 LPRINTB:PRINT#1,B:GOTO20
1050 LINEINPUT"Observer ",A:B="Y*"+TIME$+"*"+A+"*":LINEINPUT"Number ",A:B=B+A+"*":LINEINPUT"# surface ",A:B=B+A+"*":LINEINPUT"pos in col ",A:B=B+A+"*"+TN+"*"+TD:LPRINTB:PRINT#1,B:GOTO20
```

Section 5.3

Listing of programme SPLIT

```
      PROGRAM SPLIT
C
C     PROGRAMME SPLIT IS DESIGNED TO SPLIT THE RAW DATA FILE
C     'SURVEY.DAT' INTO A SERIES OF SEPARATE FILES, EACH CONTAINING
C     SIGHTINGS OF A SINGLE CLASSIFICATION. THE EXCEPTIONS TO THIS
C     ARE THE DATA FILES FOR TRANSECT START AND FINISH TIMES AND DAILY
C     TAKEOFF AND LANDING TIMES.
C
C     DEFINE THE CHARACTER VARIABLES USED IN PROGRAMME SPLIT
C       ID   - A SINGLE CHARACTER VARIABLE IDENTIFYING THE SIGHTING
C              TYPE
C       TEXT - A STRING CHARACTER VARIABLE CONTAINING THE REST OF THE
C              SIGHTING INFORMATION
C
      CHARACTER ID*1,TEXT*70
C
C     ASSOCIATE THE INPUT AND OUTPUT FILE NAMES WITH A FORTRAN LOGICAL
C     NUMBER
C
      OPEN(UNIT=01,FILE='SURVEY.DAT) !RAW DATA INPUT FILE
      OPEN(UNIT=02,FILE='SURSL.DAT') !TAKEOFF AND LANDING TIMES
      OPEN(UNIT=03,FILE='SURRF.DAT') !TRANSECT START AND FINISH TIMES
      OPEN(UNIT=04,FILE='SURH.DAT')  !AIRCRAFT HEIGHTS ALONG TRANSECTS
      OPEN(UNIT=05,FILE='SURB.DAT')  !BEAUFORT SEA STATE ALONG
C                                     TRANSECTS
      OPEN(UNIT=06,FILE='SURG.DAT')  !GLARE ALONG TRANSECTS
      OPEN(UNIT=07,FILE='SURD.DAT')  !DUGONG SIGHTINGS
C
C     READ IN SIGHTING RECORD
C
10    READ(01,20,END=9999)ID,TEXT
20    FORMAT(A1,A70)
C
C     IDENTIFY SIGHTING TYPE, WRITE TO OUTPUT FILE AND READ IN NEXT
C     SIGHTING, IF END OF FILE STOP AND EXIT.
C
      IF(ID.EQ.'S'.OR.ID.EQ.'L')THEN
        WRITE(02,20)ID,TEXT
        GO TO 10
      ELSE IF(ID.EQ.'R'.OR.ID.EQ.'F')THEN
        WRITE(03,20)ID,TEXT
        GO TO 10
      ELSE IF(ID.EQ.'H')THEN
        WRITE(04,20)ID,TEXT
        GO TO 10
      ELSE IF(ID.EQ.'B')THEN
        WRITE(05,20)ID,TEXT
        GO TO 10
      ELSE IF(ID.EQ.'G')THEN
        WRITE(06,20)ID,TEXT
        GO TO 10
      ELSE IF(ID.EQ.'D')THEN
        WRITE(07,20)ID,TEXT
        GO TO 10
      END IF
      GO TO 10
9999  STOP
      END
```

Section 5.4

Listing of programme HEIGHT

```
      PROGRAM HEIGHT
C
C     PROGRAMME HEIGHT CALCULATES UN CORRECTED MEAN FLIGHT ALTITUDE FOR
C     EACH TRANSECT.
C
C     DEFINE THE VARIABLES TO BE USED IN PROGRAMME HEIGHT
C       TN     - TRANSECT NUMBER OF FIRST RECORD IN FILE
C       TNN    - TRANSECT NUMBER OF NEXT RECORD IN FILE
C       HT     - HEIGHT OF FIRST RECORD IN FILE
C       HTN    - HEIGHT OF NEXT RECORD IN FILE
C       HEIGHT - SUM OF THE HEIGHTS FOR EACH TRANSECT
C       N      - NUMBER OF RECORDS FOR EACH TRANSECT
C       MEAN   - MEAN HEIGHT FOR EACH TRANSECT
C
      INTEGER HT,HTN,HEIGHT,MEAN,N,TN,TNN
C
C     ASSOCIATE INPUT AND OUTPUT FILE NAMES WITH FORTRAN LOGICAL
C     NUMBERS
C
      OPEN(UNIT=01,FILE='SURH.DAT')    !INPUT FILE
      OPEN(UNIT=02,FILE='HEIGHT.DAT') !OUTPUT FILE
C
C     READ IN FIRST RECORD AND SET COUNTER TO TWO AND SUM OF HEIGHTS TO
C     FIRST HEIGHT PLUS 450 (AIRCRAFT IS AT A HEIGHT OF 450 FEET AT THE
C     START OF EACH TRANSECT ON THE DUGONG SURVEYS)
C
      READ(01,'(11X,I3,1X,I3)')HT,TN
      N=2
      HEIGHT=HT+450
C
C     READ IN NEXT RECORD
C
10    READ(01,'(11X,I3,1X,I3)',END=9999)HTN,TNN
C
C     TEST IF THIS RECORD HAS SAME TRANSECT NUMBER AS PREVIOUS RECORD.
C     IF YES THEN INCREMENT COUNTER BY ONE AND ADD HEIGHT TO SUM OF
C     HEIGHTS AND READ IN NEXT RECORD. IF NO THEN CALCULATE AND OUTPUT
C     MEAN HEIGHT FOR THE PREVIOUS TRANSECT, RESET COUNTER, SET NEW
C     TRANSECT NUMBER AND SUM OF HEIGHTS TO NEW HEIGHT
C
      IF(TNN.EQ.TN)THEN
        N=N+1
        HEIGHT=HEIGHT+HTN
      ELSE
        MEAN=HEIGHT/N
        WRITE(02,'(1X,I3,1X,I3)')TN,MEAN
        N=2
        HEIGHT=HTN+450
        TN=TNN
      END IF
      GO TO 10
C
C     IF LAST RECORD HAS BEEN READ OUTPUT INFORMATION FOR LAST TRANSECT
C
9999  MEAN=HEIGHT/N
      WRITE(02,'(1X,I3,1X,I3)')TN,MEAN
      STOP
      END
```

Section 5.5

Listing of programme TRAN

```
      PROGRAM TRAN
C
C     DEFINE THE VARIABLES USED IN PROGRAMME TRAN
C       TNS    - TRANSECT NUMBER OF START TIME
C       TNF    - TRANSECT NUMBER OF FINISH TIME
C       TNL    - TRANSECT NUMBER OF LENGTH MEASUREMENT
C       TD     - DIRECTION OF FLIGHT ON TRANSECT
C       HRS    - START TIME HOUR
C       HRM    - MID TIME HOUR
C       HRF    - FINISH TIME HOUR
C       MINS   - START TIME MINUTE
C       MINM   - MID TIME MINUTE
C       MINF   - FINISH TIME MINUTE
C       SECS   - START TIME SECOND
C       SECM   - MID TIME SECOND
C       SECF   - FINISH TIME SECOND
C       START  - START TIME IN SECONDS
C       MID    - MID TIME IN SECONDS
C       FINISH - FINISH TIME IN SECONDS
C       LEN    - TRANSECT LENGTH IN KILOMETERS
C       SPEED  - FLIGHT SPEED IN K/SEC
C       TIME   - TRANSECT FLIGHT TIME IN DECIMAL HOURS
C
      INTEGER TNS,TNF,TNL,HRS,MINS,SECS,HRF,MINF,SECF,HRM,MINM,SECM,
     +START,FINISH,MID
      REAL LEN,SPEED,TIME
      CHARACTER TD*1
C
C     ASSOCIATE INPUT AND OUTPUT FILES WITH FORTRAN LOGICAL NUMBERS
C
      OPEN(UNIT=01,FILE='SURRF.DAT')
      OPEN(UNIT=02,FILE='LENGTH.DAT')
      OPEN(UNIT=03,FILE='TRAN.DAT')
C
C     READ IN START AND FINISH TIMES FOR EACH TRANSECT AND CHECK THAT
C     TIMES ARE FOR THE SAME TRANSECT
C
10    READ(01,20,END=999)HRS,MINS,SECS,TNS,TD,HRF,MINF,SECF,TNF
20    FORMAT(2X,I2,1X,I2,1X,I2,1X,I3,1X,A1/2X,I2,1X,I2,1X,I2,1X,I3)
      IF(TNS.NE.TNF)THEN
        WRITE(*,'(''ERROR IN INPUT FILE 'SURRF.DAT'')')
        STOP
      END IF
C
C     READ IN LENGTH DATA AND CHECK THAT LENGTH IS FOR SAME TRANSECT AS
C     START AND FINISH TIMES
C
      READ(02,'(1X,I3,1X,F5.1)')TNL,LEN
      IF(TNL.NE.TNS)THEN
        WRITE(*,'(''ERROR IN INPUT FILE LENGTH.DAT''/
     +  ''CHECK ORDER OF TRANSECT NUMBERS WITH SURRF.DAT'')')
        STOP
      END IF
C
C     CALCULATE MID TIME AND SPEED FOR EACH TRANSECT AND OUTPUT TO
C     TRAN.DAT
C
      START=HRS*3600+MINS*60+SECS
```

```
      FINISH=HRF*3600+MINF*60+SECF
      MID=START+(FINISH-START)/2
      HRM=MID/3600
      MINM=(MID-HRM*3600)/60
      SECM=MID-HRM*3600-MINM*60
      SPEED=LEN/(FINISH-START)
      TIME=FLOAT(FINISH-START)/3600.0
      WRITE(04,40)TNS,TD,LEN,HRS,MINS,SECS,START,HRM,MINM,SECM,
     +MID,HRF,MINF,SECF,FINISH,SPEED,TIME
40    FORMAT(1X,I3,1X,A1,1X,F5.1,3(1X,I2,':',I2,':',I2,1X,I6),
     +1X,F8.6,1X,F5.2)
C
C     READ IN DATA FOR NEXT TRANSECT
C
      GO TO 10
999   STOP
      END
```

Section 5.6

Listing of programme DIST

```
      PROGRAM DIST
C
C     PROGRAMME DIST CALCULATES A NUMBER OF PARAMETERS USED IN THE
C     POPULATION MODEL. THESE ARE:
C       A) THE DISTANCE FROM THE NORTHERN/WESTERN END ON EACH TRANSECT
C          OF EACH ANIMAL SIGHTING;
C       B) THE NUMBER OF GROUPS SEEN BY:   i)PORT MID-SEAT OBSERVER
C                                         ii)STARBOARD MID-SEAT OBSERVER
C                                        iii)PORT REAR-SEAT OBSERVER
C                                         iv)STARBOARD REAR-SEAT OBSERVER
C                                          v)BOTH PORT OBSERVERS
C                                         vi)BOTH STARBOARD OBSERVERS
C          FOR THE WHOLE SURVEY;
C       C) THE NUMBER OF GROUPS SEEN BY THE PORT SIDE TANDEM TEAM AND BY
C          THE STARBOARD SIDE TANDEM TEAM ON EACH TRANSECT; AND
C       D) THE TOTAL NUMBER OF ANIMALS AT THE SURFACE AND UNDER THE
C          SURFACE FOR THE WHOLE SURVEY.
C
C     DEFINE THE VARIABLES USED IN PROGRAMME DIST:
C       TN     - TRANSECT NUMBER
C       TNN    - TRANSECT NUMBER OF SIGHTING RECORD
C       START  - START TIME FOR EACH TRANSECT IN SECONDS
C       FINISH - FINISH TIME FOR EACH TRANSECT IN SECONDS
C       HR     - HOUR OF SIGHTING ON TRANSECT
C       MIN    - MINUTE OF SIGHTING ON TRANSECT
C       SEC    - SECOND OF SIGHTING ON TRANSECT
C       SIGHT  - TIME OF SIGHTING IN SECONDS
C       ELAP   - ELAPSED TIME OF SIGHTING FROM NORTHERN/WESTERN END
C                OF TRANSECT IN SECONDS
C       SPEED  - SPEED AT WHICH TRANSECT FLOWN
C       DIST   - DISTANCE OF SIGHTING FROM NORTHERN/WESTERN END OF
C                TRANSECT IN KILOMETERS
C       NUMBER - NUMBER OF ANIMALS FOR EACH SIGHTING
C       TRNNUM - NUMBER OF ANIMALS ON TRANSECT
C       TOTNUM - TOTAL NUMBER OF ANIMALS SIGHTED
C       SUMSQ  - SUM-OF-SQUARES OF THE NUMBER OF ANIMALS PER SIGHTING
C       SURF   - NUMBER OF ANIMALS AT SURFACE FOR EACH SIGHTING
C       TRNSUR - NUMBER OF ANIMALS AT SURFACE ON TRANSECT
C       TRNUND - NUMBER OF ANIMALS UNDER SURFACE ON TRANSECT
C       TOTSUR - TOTAL NUMBER OF ANIMALS AT SURFACE
C       TOTUND - TOTAL NUMBER OF ANIMALS UNDER THE SURFACE
C       PORT   - NUMBER OF GROUPS SEEN ON PORT SIDE ON TRANSECT
C       STAR   - NUMBER OF GROUPS SEEN ON STARBOARD SIDE ON TRANSECT
C       TOTPM  - TOTAL NUMBER OF GROUPS SEEN BY PORT MID-SEAT OBSERVER
C       TOTPR  - TOTAL NUMBER OF GROUPS SEEN BY PORT REAR-SEAT OBSERVER
C       TOTPB  - TOTAL NUMBER OF GROUPS SEEN BY PORT TANDEM TEAM
C       TOTSM  - TOTAL NUMBER OF GROUPS SEEN BY STARBOARD MID-SEAT OBSERVER
C       TOTSR  - TOTAL NUMBER OF GROUPS SEEN BY STARBOARD REAR-SEAT OBSERVER
C       TOTSB  - TOTAL NUMBER OF GROUPS SEEN BY STARBOARD TANDEM TEAM
C       PORTM  - NUMBER OF GROUPS SEEN BY PORT MID-SEAT OBSERVER ON
C                TRANSECT
C       PORTR  - NUMBER OF GROUPS SEEN BY PORT REAR-SEAT OBSERVER ON
C                TRANSECT
C       PORTB  - NUMBER OF GROUPS SEEN BY PORT TANDEM TEAM ON TRANSECT
C       STARM  - NUMBER OF GROUPS SEEN BY STARBOARD MID-SEAT OBSERVER ON
C                TRANSECT
C       STARR  - NUMBER OF GROUPS SEEN BY STARBOARD REAR-SEAT OBSERVER ON
C                TRANSECT
```

```
C       STARB  - NUMBER OF GROUPS SEEN BY STARBOARD TANDEM TEAM ON TRANSECT
C       OBSER  - IDENTITY OF OBSERVER
C       TD     - DIRECTION TRANSECT FLOWN
C
      INTEGER TN,START,FINISH,HR,MIN,SEC,SIGHT,ELAP,NUMBER,TOTNUM,
     +SURF,TOTSUR,TOTUND,PORT,STAR,TOTPM,TOTPR,TOTPB,
     +TOTSM,TOTSR,TOTSB,TRNNUM,TRNSUR,TRNUND,SUMSQ,TNN,
     +PORTM,PORTR,PORTB,STARM,STARR,STARB
      REAL SPEED,DIST
      CHARACTER OBSER*2,TD*1
C
C     SET TOTAL SUMMATION VARIABLES TO ZERO
C
      TOTPM=0
      TOTPR=0
      TOTPB=0
      TOTSM=0
      TOTSR=0
      TOTSB=0
      TOTNUM=0
      SUMSQ=0
      TOTSUR=0
      TOTUND=0
C
C     ASSOCIATE INPUT AND OUTPUT FILES WITH FORTRAN LOGICAL NUMBERS
C
      OPEN(UNIT=01,FILE='TRAN.DAT')    !TRANSECT DESCRIPTION FILE
      OPEN(UNIT=02,FILE='SURD.DAT')    !ANIMAL SIGHTING FILE
      OPEN(UNIT=03,FILE='DIST.DAT')    !SIGHTING DISTANCE FILE
      OPEN(UNIT=04,FILE='CORFAC.DAT')  !CORRECTION FACTOR RAW DATA FILE
      OPEN(UNIT=05,FILE='INPUT.DAT')   !CORRECTION FACTOR RAW DATA FILE
C
C     WRITE HEADINGS FOR OUTPUT FILES
C
      WRITE(03,'('' TRANSECT DISTANCE NUMBER '')')
      WRITE(04,'('' TRANSECT          PORT        STAR        NUMBER    SURF
     +   UNDER''/''           M    R    B    M    R    B'')')
C
C     READ IN FIRST RECORD FROM TRANSECT DESCRIPTION FILE
C
      READ(01,5)TN,TD,START,FINISH,SPEED
5     FORMAT(1X,I3,1X,A1,16X,I6,10X,I6,17X,F8.6)
C
C     SET TRANSECT VARIABLES TO ZERO
C
      PORT=0
      STAR=0
      PORTM=0
      PORTR=0
      PORTB=0
      STARM=0
      STARR=0
      STARB=0
      TRNNUM=0
      TRNUND=0
      TRNSUR=0
C
C     READ IN FIRST SIGHTING
```

```
C
      10    READ(02,15,END=999)HR,MIN,SEC,OBSER,NUMBER,SURF,TNN
15    FORMAT(2X,I2,1X,I2,1X,I2,1X,A2,1X,I1,1X,I1,3X,I3)
C
C     CALCULATE TIME OF SIGHTING, TEST THAT SIGHTING IS ON THIS TRANSECT
C     AND FALLS WITHIN THE START AND FINISH TIMES
20    SIGHT=HR*3600+MIN*60+SEC
      IF(TNN.EQ.TN.AND.SIGHT.GE.START.AND.SIGHT.LE.FINISH)THEN
C
C     CALCULATE ELAPSED TIME AND DISTANCE OF SIGHTING FROM NORTHERN/
C     WESTERN END OF TRANSECT AND OUTPUT TO DIST.DAT
C
        IF(TD.EQ.'E')THEN
          ELAP=SIGHT-START
        ELSEIF(TD.EQ.'W') THEN
          ELAP=FINISH-SIGHT
        ELSEIF(TD.EQ.'N') THEN
          ELAP=FINISH-SIGHT
        ELSEIF(TD.EQ.'S') THEN
          ELAP=SIGHT-START
        ELSEIF(TD.EQ.'U') THEN
          ELAP=0.0
        ELSE
          WRITE(*,'(''AN ERROR EXISTS IN TRANSECT DIRECTION''/
     +               ''FOR A SIGHTING ON TRANSECT '',I3)')TNN
          STOP
        END IF
        DIST=ELAP*SPEED
        WRITE(03,25)TNN,DIST,NUMBER
25    FORMAT(4X,I3,5X,F5.1,4X,I2)
C
C     CALCULATE NUMBER OF GROUPS SEEN BY EACH OBSERVER, NUMBER OF ANIMALS,
C     NUMBER AT SURFACE AND NUMBER UNDER THE SURFACE ON EACH TRANSECT
C
        IF(OBSER.EQ.'PM')THEN
          PORT=PORT+1
          TOTPM=TOTPM+1
          PORTM=PORTM+1
        ELSEIF(OBSER.EQ.'PR')THEN
          PORT=PORT+1
          TOTPR=TOTPR+1
          PORTR=PORTR+1
        ELSEIF(OBSER.EQ.'PT')THEN
          PORT=PORT+1
          TOTPB=TOTPB+1
          PORTB=PORTB+1
        ELSEIF(OBSER.EQ.'SM')THEN
          STAR=STAR+1
          TOTSM=TOTSM+1
          STARM=STARM+1
        ELSEIF(OBSER.EQ.'SR')THEN
          STAR=STAR+1
          TOTSR=TOTSR+1
          STARR=STARR+1
        ELSEIF(OBSER.EQ.'ST')THEN
          STAR=STAR+1
          TOTSB=TOTSB+1
          STARB=STARB+1
```

```
          ELSE
            WRITE(05,'(''ERROR IN OBSERVER ID IN SIGHTING ON''
     +                 '' TRANSECT '',I3)')TNN
            STOP
          END IF
          TRNNUM=TRNNUM+NUMBER
          TOTNUM=TOTNUM+NUMBER
          SUMSQ=SUMSQ+NUMBER**2
          TRNSUR=TRNSUR+SURF
          TOTSUR=TOTSUR+SURF
          TRNUND=TRNUND+NUMBER-SURF
          TOTUND=TOTUND+NUMBER-SURF
C
C       READ IN NEXT SIGHTING
C
          GO TO 10
C
        ELSEIF(TNN.EQ.TN)THEN
          WRITE(05,'('' AN ERROR EXISTS IN SIGHTING TIME ON''
     +              /'' TRANSECT # ''I3)')TNN
          STOP
C
C       IF SIGHING DID NOT MATCH PRESENT TRANSECT DATA; OUTPUT TRANSECT
C       TOTALS DATA TO CORFAC.DAT, RESET TRANSECT TOTALS VARIABLES, AND
C       READ IN TRANSECT DATA FOR NEXT TRANSECT
C
        ELSE
          WRITE(04,30)TN,PORTM,PORTR,PORTB,STARM,STARR,STARB,
     +    TRNNUM,TRNSUR,TRNUND
30        FORMAT(4X,I3,3X,I3,2X,I3,2X,I3,2X,I3,2X,I3,2X,I3,2X,
     +    I5,3X,I5,3X,I5)
          PORT=0
          STAR=0
          PORTM=0
          PORTR=0
          PORTB=0
          STARM=0
          STARR=0
          STARB=0
          TRNNUM=0
          TRNSUR=0
          TRNUND=0
          READ(01,5)TN,TD,START,FINISH,SPEED
          GO TO 20
        END IF
C
C       IF LAST SIGHTING HAS BEEN READ OUTPUT LAST TRANSECT DATA AND
C       INDIVIDUAL OBSERVER GROUP TOTALS TO CORFAC.DAT
999       WRITE(04,30)TN,PORTM,PORTR,PORTB,STARM,STARR,STARB,
     +    TRNNUM,TRNSUR,TRNUND
        WRITE(04,'(/''           PORT                      STARBOARD''/
     +''      MID    REAR    BOTH     MID     REAR    BOTH NUMBER SUMSQ ''
     +'' SURFACE  UNDER'')')
        WRITE(04,40)TOTPM,TOTPR,TOTPB,TOTSM,TOTSR,TOTSB,TOTNUM,SUMSQ,
     +TOTSUR,TOTUND
40      FORMAT(10(1X,I6))
        WRITE(05,40)TOTPM,TOTPR,TOTPB,TOTSM,TOTSR,TOTSB,TOTNUM,SUMSQ,
     +TOTSUR,TOTUND
```

```
      STOP
      END
```

Section 5.7

Listing of programme FACTOR

```
      PROGRAM FACTOR
C
C     THIS PROGRAMME CALCULATES THE CORRECTION FACTORS USED BY PROGRAMME
C     POPUL IN ESTIMATING DENSITY AND POPULATION SIZE.
C
C     INPUT DATA IS READ FROM FILE 'INPUT.DAT' (A SINGLE RECORD FILE
C     CONTAINING THE TOTAL NUMBER OF GROUPS SEEN BY THE PORT AND STARBOARD
C     OBSERVERS, THE TOTAL NUMBER OF ANIMALS SIGHTED, THE SUM-OF-SQUARES
C     OF THE TOTAL NUMBER OF ANIMALS SIGHTED, THE TOTAL NUMBER OF ANIMALS
C     AT THE SURFACE AND THE TOTAL NUMBER OF ANIMALS UNDER THE SURFACE).
C
C     VARIABLES USED IN PROGRAMME FACTOR ARE:
C       TOTPM  - TOTAL NUMBER OF GROUPS SEEN BY PORT MID-SEAR OBSERVER
C       TOTPR  - TOTAL NUMBER OF GROUPS SEEN BY PORT REAR-SEAR OBSERVER
C       TOTPB  - TOTAL NUMBER OF GROUPS SEEN BY PORT TANDEM TEAM
C       TOTSM  - TOTAL NUMBER OF GROUPS SEEN BY STARBOARD MID-SEAR OBSERVER
C       TOTSR  - TOTAL NUMBER OF GROUPS SEEN BY STARBOARD REAR-SEAT OBSERVER
C       TOTSB  - TOTAL NUMBER OF GROUPS SEEN BY STARBOARD TANDEM TEAM
C       TOTSUR - TOTAL NUMBER OF ANIMALS AT THE SURFACE
C       TOTUND - TOTAL NUMBER OF ANIMALS UNDER THE SURFACE
C       TOTNUM - TOTAL NUMBER OF ANIMALS SIGHTED
C       SUMSQ  - SUM-OF-SQUARES OF TOTAL NUMBER OF ANIMALS SIGHTED
C       TOTGP  - TOTAL NUMBER OF GROUPS
C       PCFP   - PERCEPTUAL CORRECTION FACTOR PORT TEAM
C       CVPCFP - ASSOCIATED COEFFICIENT OF VARIATION
C       PCFS   - PERCEPTUAL CORRECTION FACTOR STARBOARD TEAM
C       CVPCFS - ASSOCIATED COEFFICIENT OF VARIATION
C       ACF    - AVAILABILITY CORRECTION FACTOR
C       CVACF  - ASSOCIATED COEFFICIENT OF VARIATION
C       RMGS   - MEAN GROUP SIZE
C       CVMGS  - ASSOCIATED COEFFICIENT OF VARIATION
C
C     ASSOCIATE INPUT AND OUTPUT FILES WITH FORTRAN LOGICAL NUMBERS
C
      OPEN(UNIT=01,FILE='INPUT.DAT')    !INPUT FILE
      OPEN(UNIT=02,FILE='OUTPUT.DAT')   !OUTPUT FILE
C
C     READ IN THE CORRECTION FACTOR RAW DATA
C
      READ(01,10)TOTPM,TOTPR,TOTPB,TOTSM,TOTSR,TOTSB,TOTNUM,SUMSQ,
     +TOTSUR,TOTUND
10    FORMAT(10(1X,F6))
C
C     CALCULATE PORT AND STARBOARD PERCEPTUAL CORRECTION FACTORS AND
C     ASSOCIATED COEFFICIENTS OF VARIATION
C
      PCFP=((TOTPM+TOTPB)*(TOTPR+TOTPB))/(TOTPB*(TOTPM+TOTPR+TOTPB))
      CVPCFP=((TOTPM+TOTPR)/(TOTPM+TOTPR+TOTPB))*
     +       SQRT(TOTPM*TOTPR/(TOTPB*(TOTPM+TOTPB)*(TOTPR+TOTPB)))
      PCFS=((TOTSM+TOTSB)*(TOTSR+TOTSB))/(TOTSB*(TOTSM+TOTSR+TOTSB))
      CVPCFS=((TOTSM+TOTSR)/(TOTSM+TOTSR+TOTSB))*
     +       SQRT(TOTSM*TOTSR/(TOTSB*(TOTSM+TOTSB)*(TOTSR+TOTSB)))
C
C     CALCULATE AVAILABILITY CORRECTION FACTOR AND ASSOCIATED COEFFICIENT
C     OF VARIATION
C
      PU=TOTSUR/(TOTSUR+TOTUND)
      PS=80.0/480.0
```

```
      ACF=PU/PS
      CVACF=SQRT(((1-PU)/(PU*(TOTSUR+TOTUND)))+((1-PS)/(PS*480.0)))
C
C     CALCULATE MEAN GROUP SIZE AND ASSOCIATED COEFFICIENT OF VARIATION
C
      TOTGP=TOTPM+TOTPR+TOTPB+TOTSM+TOTSR+TOTSB
      RMGS=TOTNUM/TOTGP
      CVMGS=SQRT((SUMSQ-(TOTNUM**2/TOTGP))/(TOTGP-1))/SQRT(TOTGP)
C
C     OUTPUT CORRECTION FACTORS
C
      WRITE(02,'(''        PORT         STARBOARD    AVAILABILITY MEAN
     + GROUP SIZE''/4(''    CF      CV  '')')
      WRITE(02,'(8(1X,F6.4))')PCFP,CVPCFP,PCFS,CVPCFS,ACF,CVACF,RMGS,
     +CVRMGS
      STOP
      END
```

Section 5.8

Listing of programme POPUL

```
      PROGRAM POPUL
C
C     PROGRAMME POPUL CALCULATES AN ESTIMATE OF DENSITY AND POPULATION
C     SIZE FOR THE SURVEY AREA USING THE RATIO METHOD (JOLLY, 1969 AND
C     CAUGHLEY AND GRIGG, 1981).
C
C     DEFINE THE VARIABLES USED IN PROGRAMME POPUL
C       NT     - NUMBER OF TRANSECTS
C       TN     - TRANSECT NUMBER
C       TH     - CORRECTED HEIGHT AT WHICH TRANSECT FLOWN
C       TL     - TRANSECT LENGTH
C       NGP    - NUMBER OF GROUPS SEEN ON PORT SIDE
C       NGS    - NUMBER OF GROUPS SEEN ON STARBOARD SIDE
C       PCP    - PORT PERCEPTUAL CORRECTION FOR EACH TRANSECT
C       CVPCP  - COEFFICIENT OF VARIATION OF THE PORT PERCEPTUAL
C                CORRECTION FACTOR FOR EACH TRANSECT
C       PCS    - STARBOARD PERCEPTUAL CORRECTION FOR EACH TRANSECT
C       CVPCS  - COEFFICIENT OF VARIATION OF THE STARBOARD PERCEPTUAL
C                CORRECTION FACTOR FOR EACH TRANSECT
C       ACF    - ACAILABILITY CORRECTION FACTOR
C       CVACF  - COEFFICIENT OF VARIATION OF AVAILABILITY CORRECTION
C                FACTOR
C       MGS    - MEAN GROUP SIZE
C       CVMGS  - COEFFICIENT OF VARIATION OF MEAN GROUP SIZE
C       NUMBP  - CORRECTED NUMBER OF ANIMALS PER TRANSECT ON THE PORT SIDE
C       NUMBS  - CORRECTED NUMBER OF ANIMALS PER TRANSECT ON THE STARBOARD
C                SIDE
C       HEIGHT - NOMINAL HEIGHT AT WHICH TRANSECT FLOWN
C       WIDTH  - NOMINAL WIDTH OF TRANSECT
C       TAREA  - CORRECTED AREA OF TRANSECT
C       SAREA  - AREA OF SURVEY REGION
C       PZL    - LENGTH OF SURVEY REGION PERPENDICULAR TO TRANSECTS
C       TT     - TOTAL NUMBER OF POSSIBLE TRANSECTS IN SURVEY AREA
C       SUMZ   - SUM OF TRANSECT AREAS
C       SUMZP  - SUM OF TRANSECT AREAS ON THE PORT SIDE
C       SUMZS  - SUM OF TRANSECT AREAS ON THE STARBOARD SIDE
C       SUMZ2  - SUM OF TRANSECT AREAS SQUARED
C       SUMY   - SUM OF CORRECTED NUMBER OF ANIMALS PER TRANSECT
C       SUMYP  - SUM OF CORRECTED NUMBER OF ANIMALS PER TRANSECT ON THE
C                PORT SIDE
C       SUMYS  - SUM OF CORRECTED NUMBER OF ANIMALS PER TRANSECT ON THE
C                STARBOARD SIDE
C       SUMY2  - SUM OF CORRECTED NUMBER OF ANIMALS PER TRANSECT SQUARED
C       SUMZY  - SUM OF TRANSECT AREA TIMES CORRECTED NUMBER OF ANIMALS
C                PER TRANSECT
C       SY2    - VARIANCE BETWEEN ANIMALS COUNTED IN ALL TRANSECTS
C       SZ2    - VARIANCE BETWEEN THE AREAS OF ALL TRANSECTS
C       SZY    - COVARIANCE BETWEEN ANIMALS COUNTED AND THE AREA OF EACH
C                TRANSECT
C       RHAT   - RATIO OF CORRECTED NUMBER OF ANIMALS COUNTED TO AREA
C                SEARCHED (DENSITY) FOR SURVEY REGION
C       RHATP  - RHAT FOR PORT SIDE ONLY
C       RHATS  - RHAT FOR STARBOARD SIDE ONLY
C       YHAT   - POPULATION ESTIMATE FOR SURVEY REGION
C       YHATP  - YHAT FOR PORT SIDE ONLY
C       YHATS  - YHAT FOR STARBOARD SIDE ONLY
C       SEY    - STANDARD ERROR OF THE POPULATION ESTIMATE (YHAT)
```

```
      INTEGER NT,TN(50)
      REAL TH(50),NGP(50),NGS(50),PCP(50),CVPCP(50),PCS(50),CVPCS(50),
     +ACF,CVACF,MGS,HEIGHT,TT,TL(50),CVMGS,+TAREA(50),SAREA,PZL,
     +WIDTH,SUMZP,SUMZS,SUMZ2,SUMYP,SUMYS,TN(50),RHATP,SY2,SZ2,SZY,
     +YHATP,VARY,NUMBP(50),SUMY,SUMY2,SUMZ,SUMZY,RHATS,YHATS,
     +NUMBS(50),RHAT,YHAT,SEY
      CHARACTER*40 FILE1,FILE2
C
C     ASSOCIATE INPUT AND OUTPUT FILES WITH FORTRAN LOGICAL NUMBERS
C
      OPEN(UNIT=01,FILE='POPIN.DAT')  !INPUT FILE
      OPEN(UNIT=02,FILE='POPOUT.DAT') !OUTPUT FILE
C
C     READ IN ALL DATA FROM INPUT FILE
C
      READ(01,*)NT,HEIGHT,WIDTH,SAREA,PZL,ACF,CVACF,MGS,CVMGS,PCP,
     +CVPCP,PCS,CVPCS
      READ(01,*)(TN(I),TL(I),TH(I),NGP(I),NGS(I),I=1,NT)
C
C     CALCULATE CORRECTED AREA OF EACH TRANSECT AND SUMS OF AREAS
C
      DO 3 I=1,NT
      TAREA(I)=TL(I)*WIDTH*TH(I)/HEIGHT
      SUMZ=SUMZ+TAREA(I)
      SUMZP=SUMZP+TAREA(I)/2
      SUMZS=SUMZS+TAREA(I)/2
      SUMZ2=SUMZ2+TAREA(I)**2
3     CONTINUE
C
      CALCULATE MAXIMUM POSSIBLE NUMBER OF TRANSECTS IN SURVEY REGION
C
      TT=PZL/WIDTH
C
C     CALCULATE CORRECTED NUMBER OF ANIMALS PER TRANSECT AND SUMS OF
C     NUMBERS
C
      DO 4 I=1,NT
      NUMBP(I)=MGS*NGP(I)*PCP(I)*ACF
      SUMYP=SUMYP+NUMBP(I)
      NUMBS(I)=MGS*NGS(I)*PCS(I)*ACF
      SUMYS=SUMYS+NUMBS(I)
      SUMY=SUMY+NUMBP(I)+NUMBS(I)
      SUMY2=SUMY2+(NUMBP(I)+NUMBS(I))**2
      SUMZY=SUMZY+TAREA(I)*(NUMBP(I)+NUMBS(I))
4     CONTINUE
C
C     CALCULATE SZ2, SY2 AND SZY
C
      SZ2=(SUMZ2-SUMZ**2/NT)/(NT-1)
      SY2=(SUMY2-SUMY**2/NT)/(NT-1)
      SZY=(SUMZY-SUMZ*SUMY/NT)/(NT-1)
C
C     CALCULATE RHAT, YHAT, VARY AND SEY

      RHATP=SUMYP/SUMZP
      YHATP=RHATP*SAREA/2
      RHATS=SUMYS/SUMZS
      YHATS=RHATS*SAREA/2
```

```
      RHAT=SUMY/SUMZ
      VARY=(TT*(TT-NT)/NT)*(SY2-2*RHAT*SZY+RHAT**2*SZ2)
      VARY=VARY+YHATP**2*(CVPCP**2+CVACF**2+CVMGS**2)+
     +          YHATS**2*(CVPCS**2+CVACF**2+CVMGS**2)
      YHAT=RHAT*SAREA
      SEY=SQRT(VARY)
C
C     OUTPUT TRANSECT DATA, DENSITY AND POPULATION ESTIMATE
C
      WRITE(02,'(''TRANSECT HEIGHT   AREA    NUMBER OF GROUPS''/
     +''   NO     (FT)    (SQ.KM)  PORT    STARBOARD'')')
      WRITE(02,40)(TN(I),TH(I),TAREA(I),NUMBP(I),NUMBS(I),I=1,NT)
40    FORMAT(3X,I3,4X,F5.1,2X,F7.1,2X,F5.1,1X,F5.1)
      WRITE(02,'(/''R^ ='',T40,1X,F8.5)')RHAT
      WRITE(02,'(/''POPULATION TOTAL ='',T40,F10.1)')YHAT
      WRITE(02,'(/''POPULATION STANDARD ERROR ='',T40,F10.1)')SEY
      STOP
      END
```

RESEARCH PUBLICATION No.21

Part 5

Maps detailing the distribution of dugongs and sea turtles for use in rezoning the Great Barrier Reef Marine Park

SECTION 1

Dugong sightings and density distribution maps in the Great Barrier Reef Marine Park from Torres Strait south to Cape Bedford

Section 1: Dugong sightings and density distribution maps in the Great Barrier Reef Marine Park from Torres Strait south to Cape Bedford.

Figure 1: The Torres Strait survey area showing the numbers and positions of the transects and dugong sightings in November 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 2: The Torres Strait survey area showing the numbers and positions of the transects and dugong sightings in March 1988. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 3: The survey area from Hunter Point to Campbell Point showing the numbers and positions of the transects and dugong sightings in April 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed. Square symbols indicate dugongs observed during test transects.

Figure 4: The survey area from Hunter Point to Campbell Point showing the numbers and positions of the transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 5: The distribution of dugong density in the survey area from Hunter Point to Campbell Point in April 1985 showing the numbers and positions of the transects with an overlay of the GBRMPA zoning plan for this area.

Figure 11: The survey area from Campbell Point to Cape Melville (Princess Charlotte Bay) showing the numbers and positions of the transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 12: The distribution of dugong density in the survey area from Campbell Point to Cape Melville (Princess Charlotte Bay) in November 1985 with an overlay of the GBRMPA zoning plan for this area.

Figure 13: Incidental dugong sightings between Cape Grenville and Cape Melville in relation to areas protected by MNPA zoning or above.

Figure 14: The distribution of known seagrass beds in the survey area from Campbell Point to Cape Melville (Princess Charlotte Bay) with an overlay of the GBRMPA zoning plan for this area. The ground-truthed seagrass data are from Coles *et al.*, (1985).

Figure 15: The survey area from Cape Melville to Cape Bedford showing the numbers and positions of the transects and dugong sightings in November 1984. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 16: The survey area from Cape Melville to Cape Bedford showing the numbers and positions of the transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 17: The distribution of dugong density in the survey area from Cape Melville to Cape Bedford in November 1984 with an overlay of the GBRMPA zoning plan for this area.

Figure 18: The distribution of dugong density in the survey area from Cape Melville to Cape Bedford in November 1985 with an overlay of the GBRMPA zoning plan for this area.

Figure 19: Incidental dugong sightings between Cape Melville and Cape Tribulation in relation to areas protected by MNPA zoning or above.

Figure 20: The distribution of known seagrass beds in the survey area from Cape Melville to Cape Bedford with an overlay of the GBRMPA zoning plan for this area. The ground-truthed seagrass data are from Coles *et al.*, (1985).

Figure 21: The Starcke River survey area showing the numbers and positions of the intensive transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed. The distribution of seagrass beds is also shown. The ground-truthed seagrass data are from Coles *et al.*, (1985).

Reference:

Coles, R.G., Lee Long, W.J., and Squire, L.C. (1985) Areas of seagrass beds and prawn nursery grounds on the Queensland coast between Cape York and Cairns. Queensland Department of Primary Industries Information Series Q185017.

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PZ - Preservation Zone

X - excluded from the GBRMP

Note: the zones drawn on the overlays and maps following are based on the Great Barrier Reef Marine Park Authority's Zoning Information releases and are approximate only.

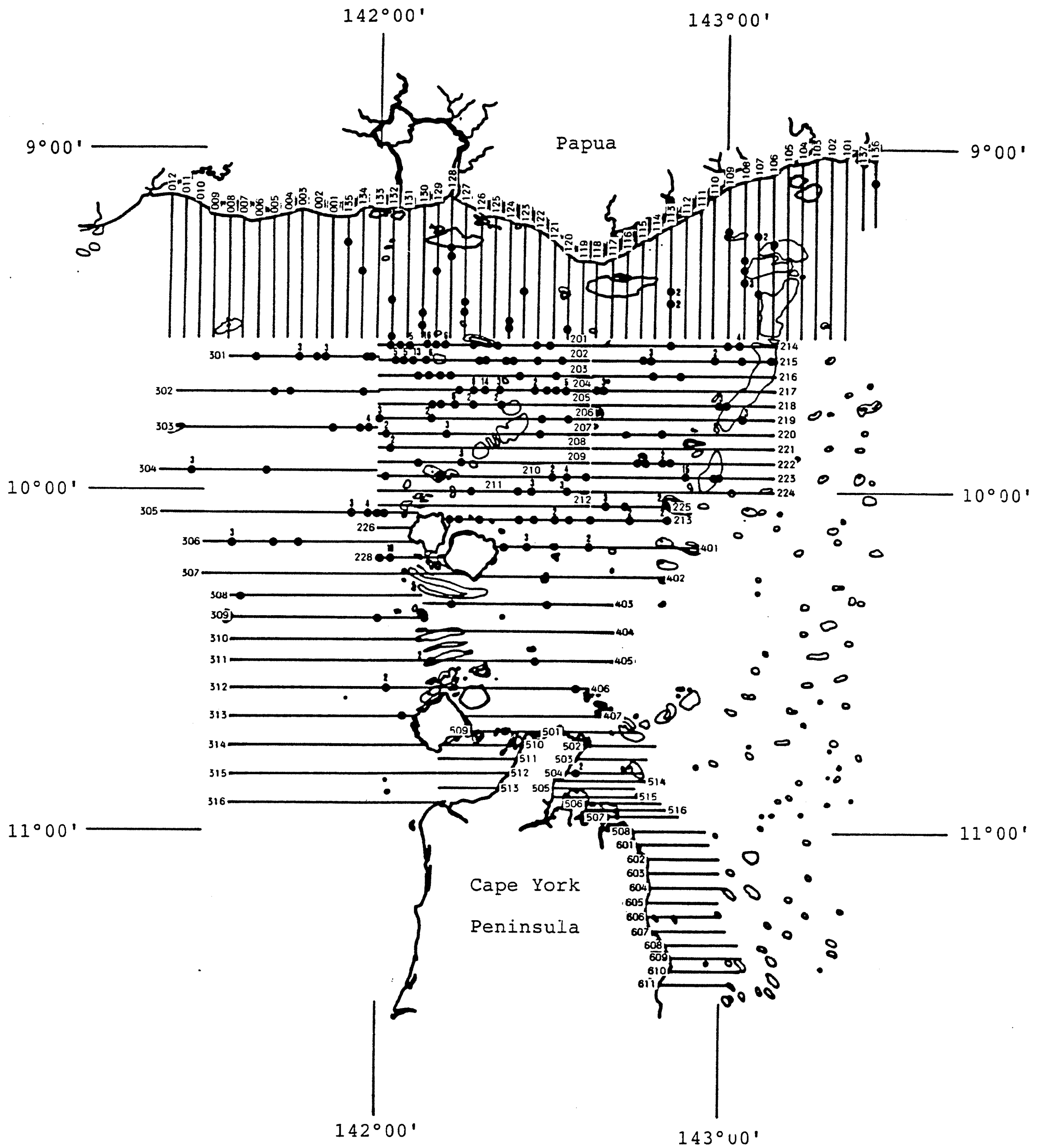

Figure 1: The Torres Strait survey area showing the numbers and positions of the transects and dugong sightings in November 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

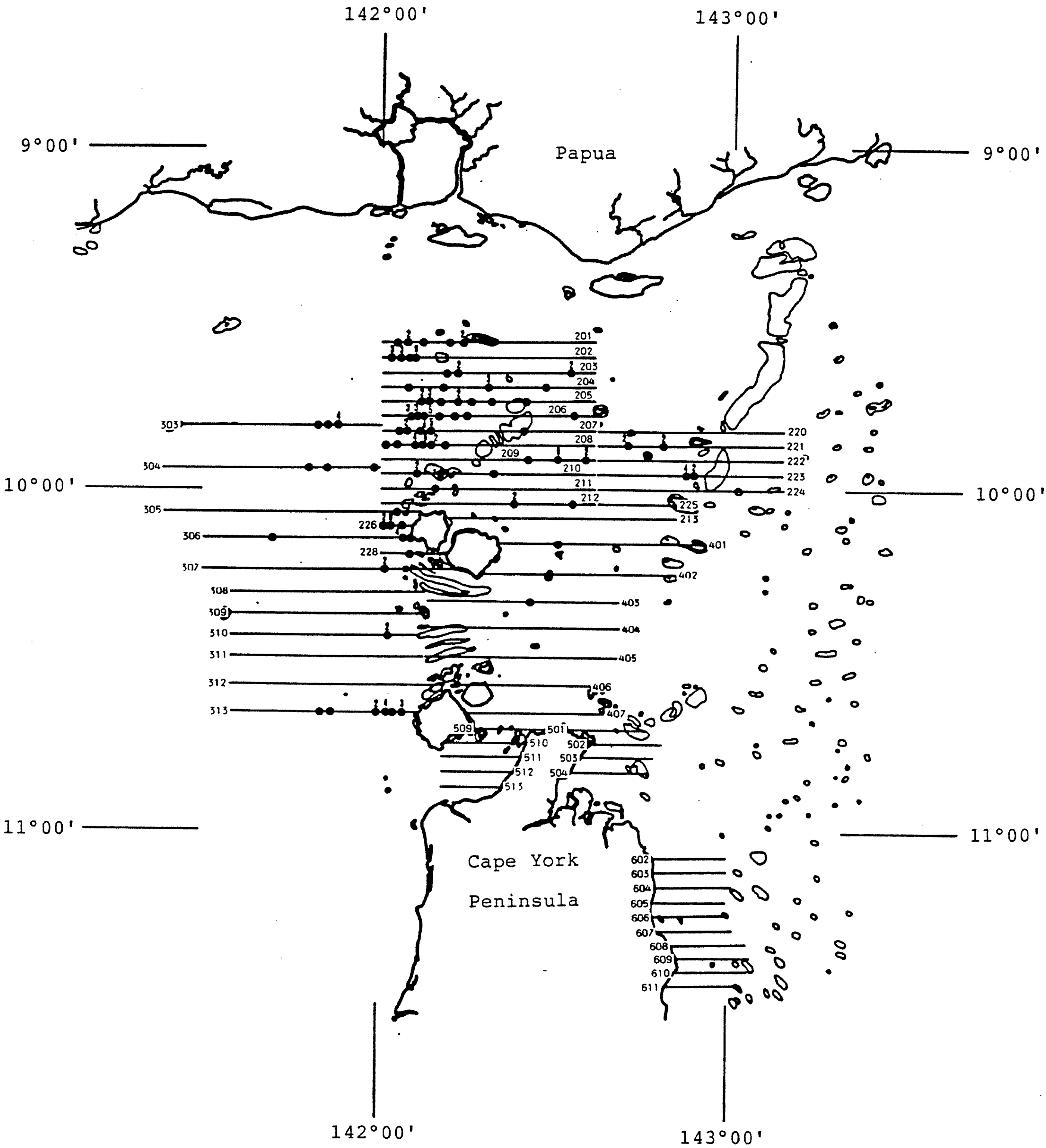

Figure 2: The Torres Strait survey area showing the numbers and positions of the transects and dugong sightings in March 1988. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

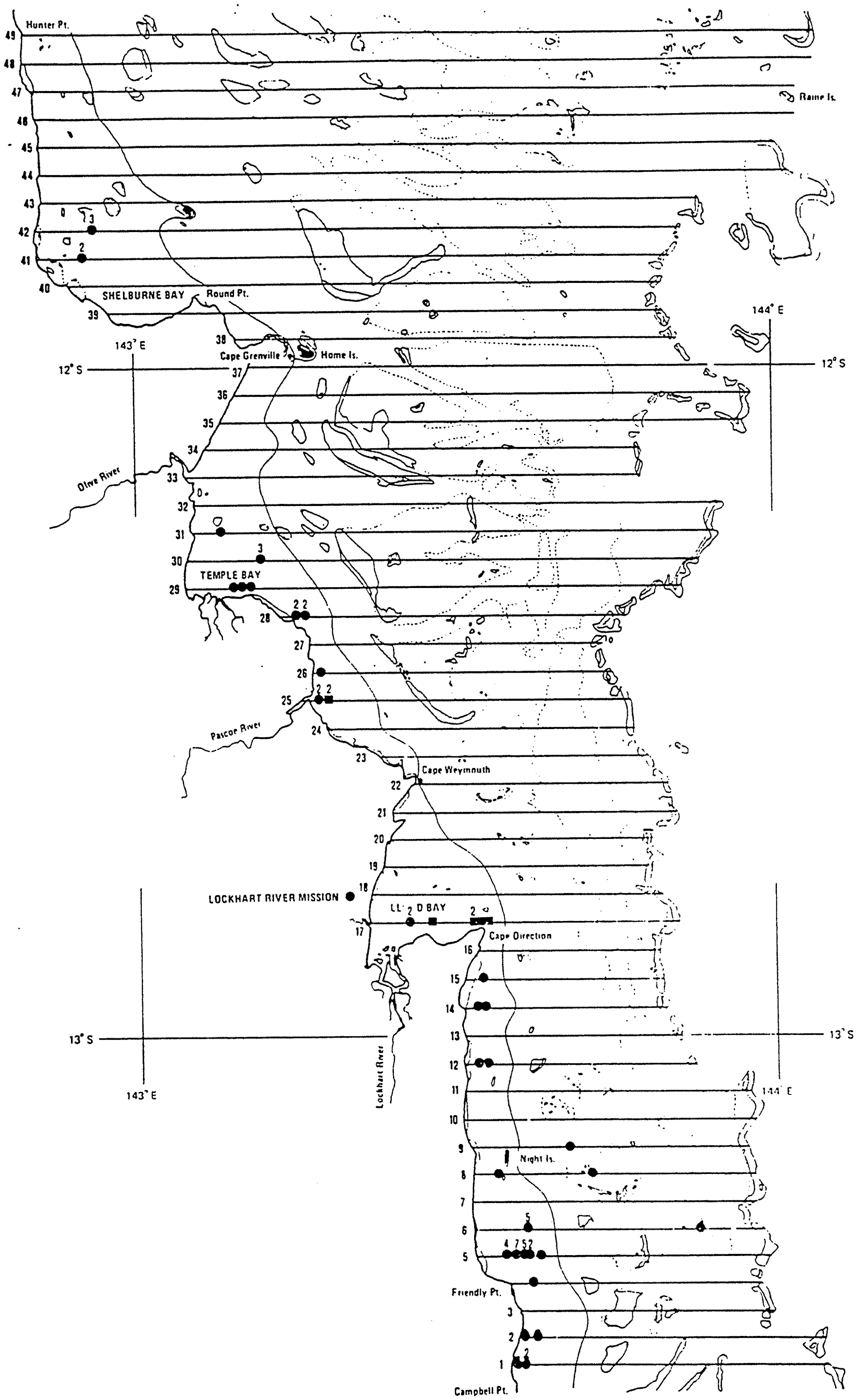

Figure 3: The survey area from Hunter Point to Campbell Point showing the numbers and positions of the transects and dugong sightings in April 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed. Square symbols indicate dugongs observed during test transects.

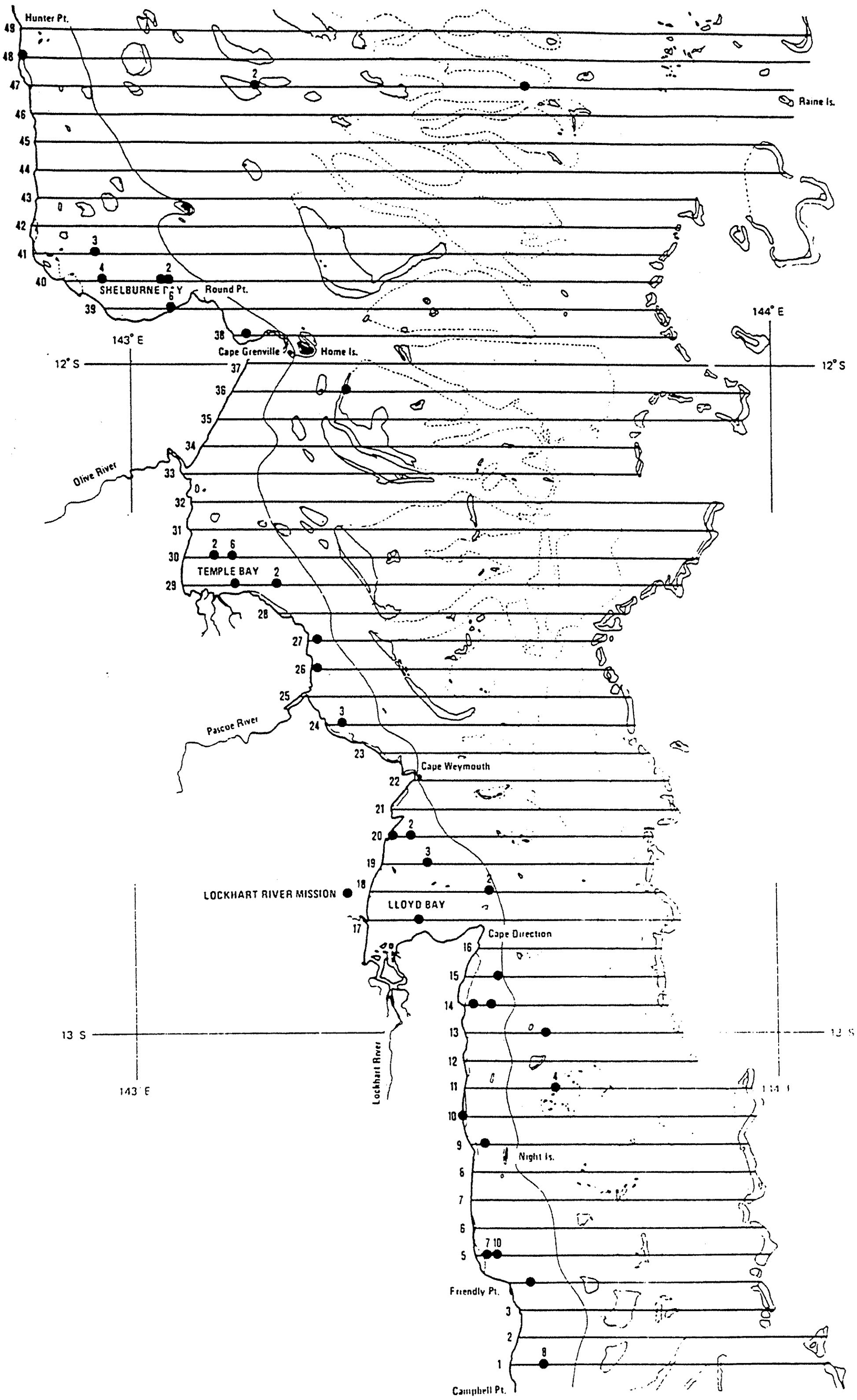

Figure 4: The survey area from Hunter Point to Campbell Point showing the numbers and positions of the transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

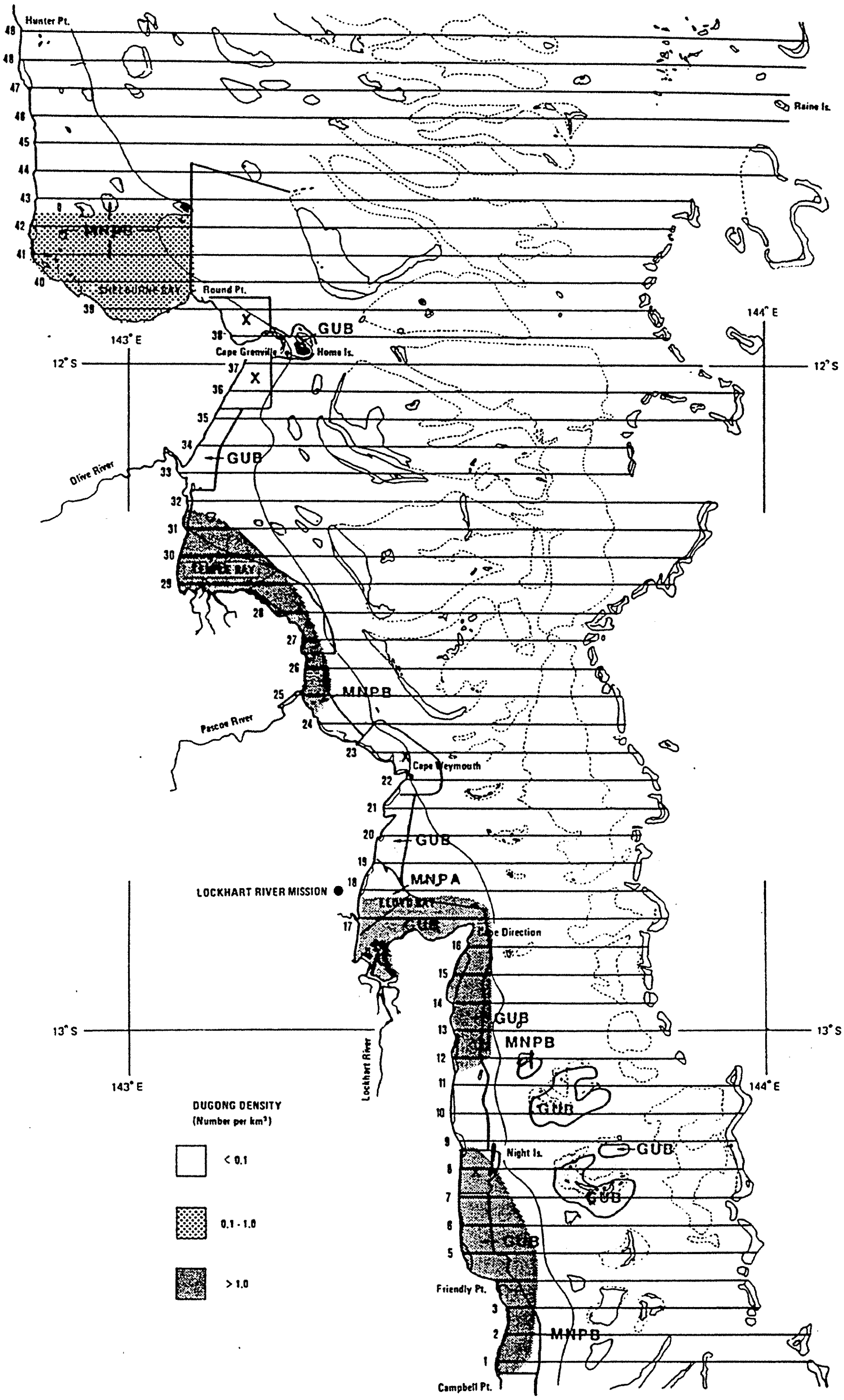

Figure 5: The distribution of dugong density in the survey area from Hunter Point to Campbell Point in April 1985, showing the numbers and positions of the transects with an overlay of the GBRMPA zoning plan for this area.

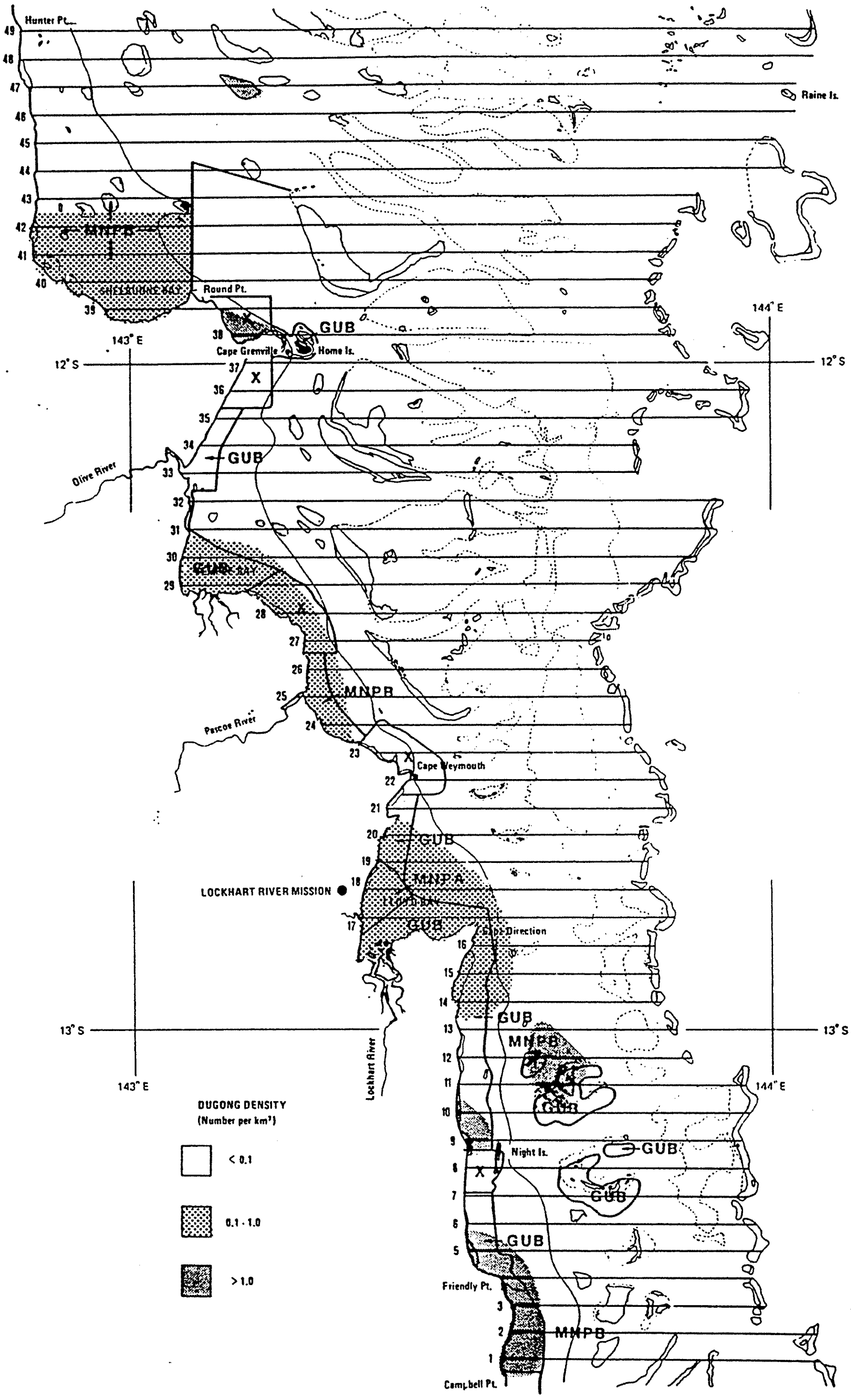

Figure 6: The distribution of dugong density in the survey area from Hunter Point to Campbell Point in November 1985 showing the numbers and positions of the transects with an overlay of the GBRMPA zoning plan for this area.

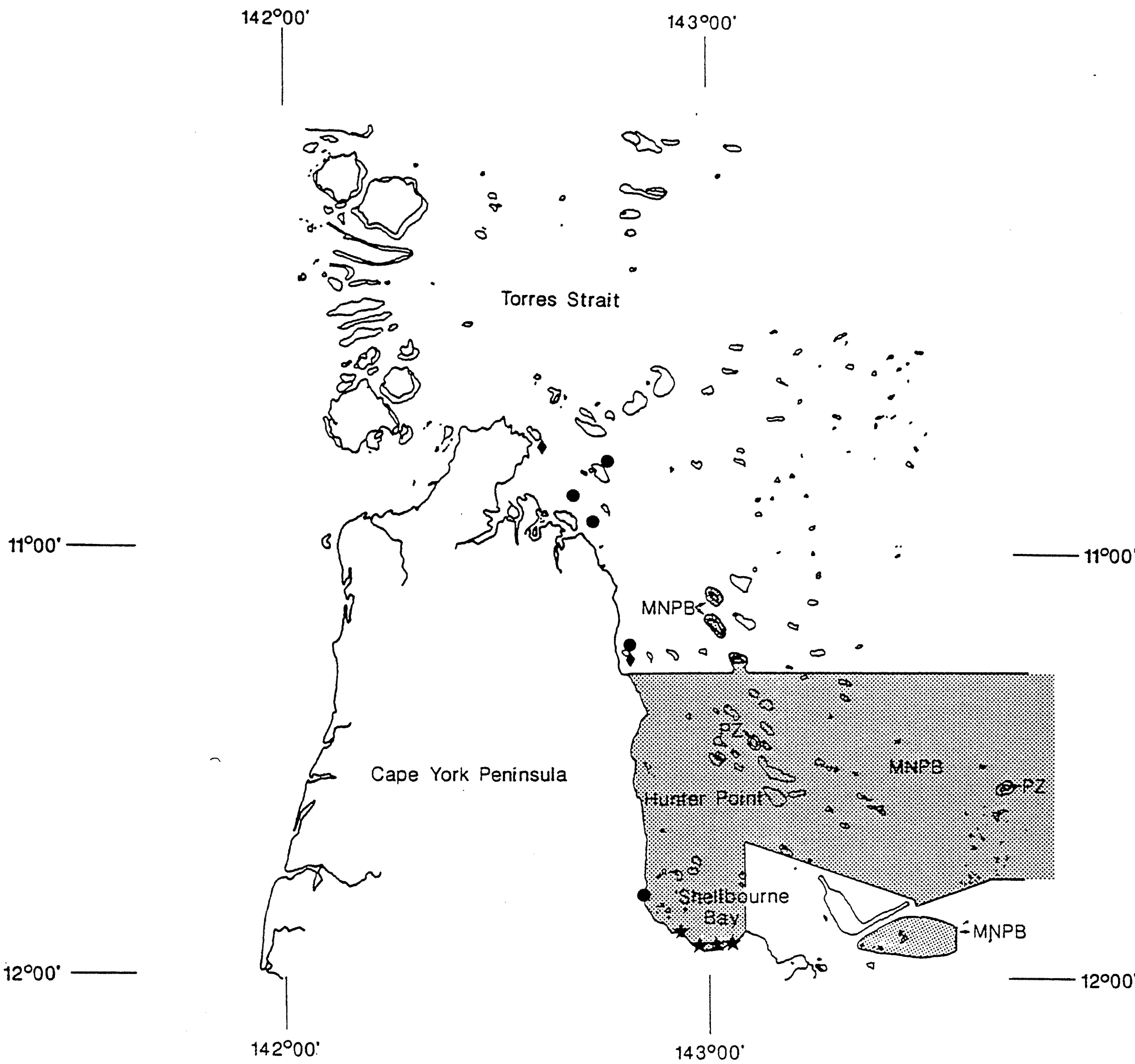

Figure 7: Incidental dugong sightings between the northern tip of Cape York Peninsula and Cape Grenville in relation to areas protected by MNPA zoning or above.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

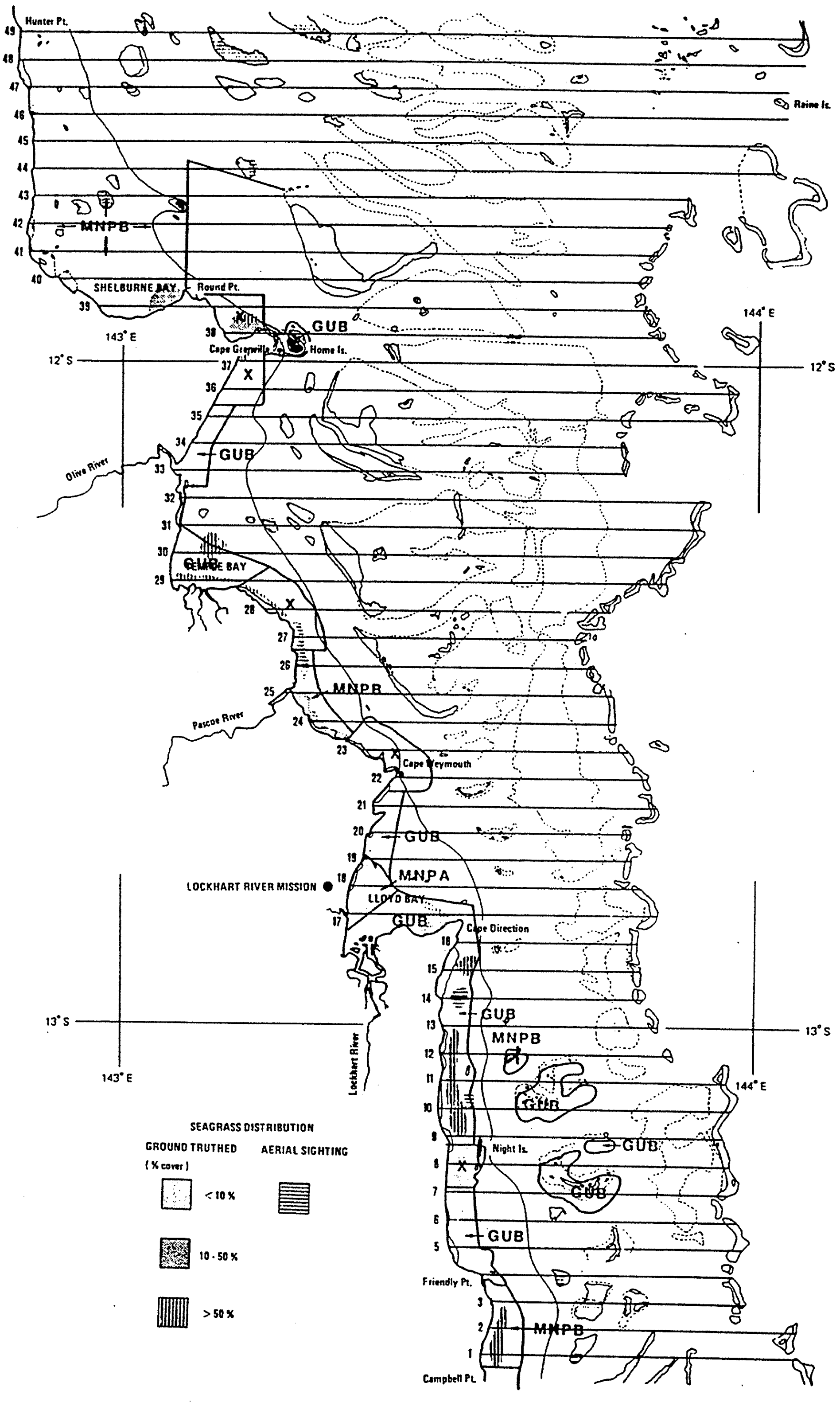

Figure 8: The distribution of known seagrass beds in the survey area from Hunter Point to Campbell Point with an overlay of the GBRMPA zoning plan for this area. The ground-truthed seagrass data are from Coles *et al.*, (1985).

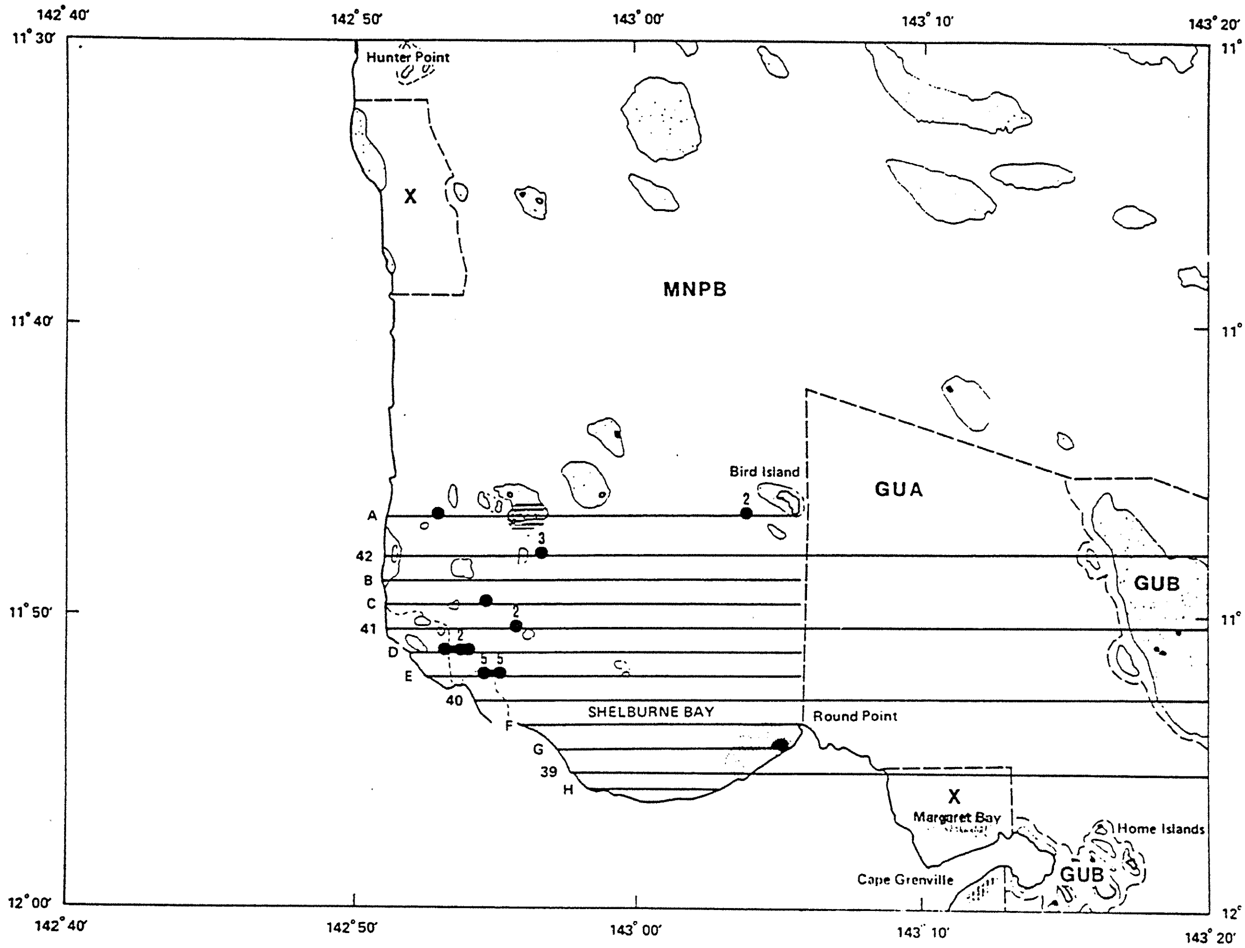

Figure 9: The Shelburne Bay survey area showing the numbers and positions of the intensive transects and dugong sightings in April 1985. The numbers associated with the sightings do not necessarily reflect the sizes of actual groupings observed. The GBRMPA zoning and the distribution of seagrass beds are also shown. The ground-truthed seagrass data are from Coles *et al.*, (1985).

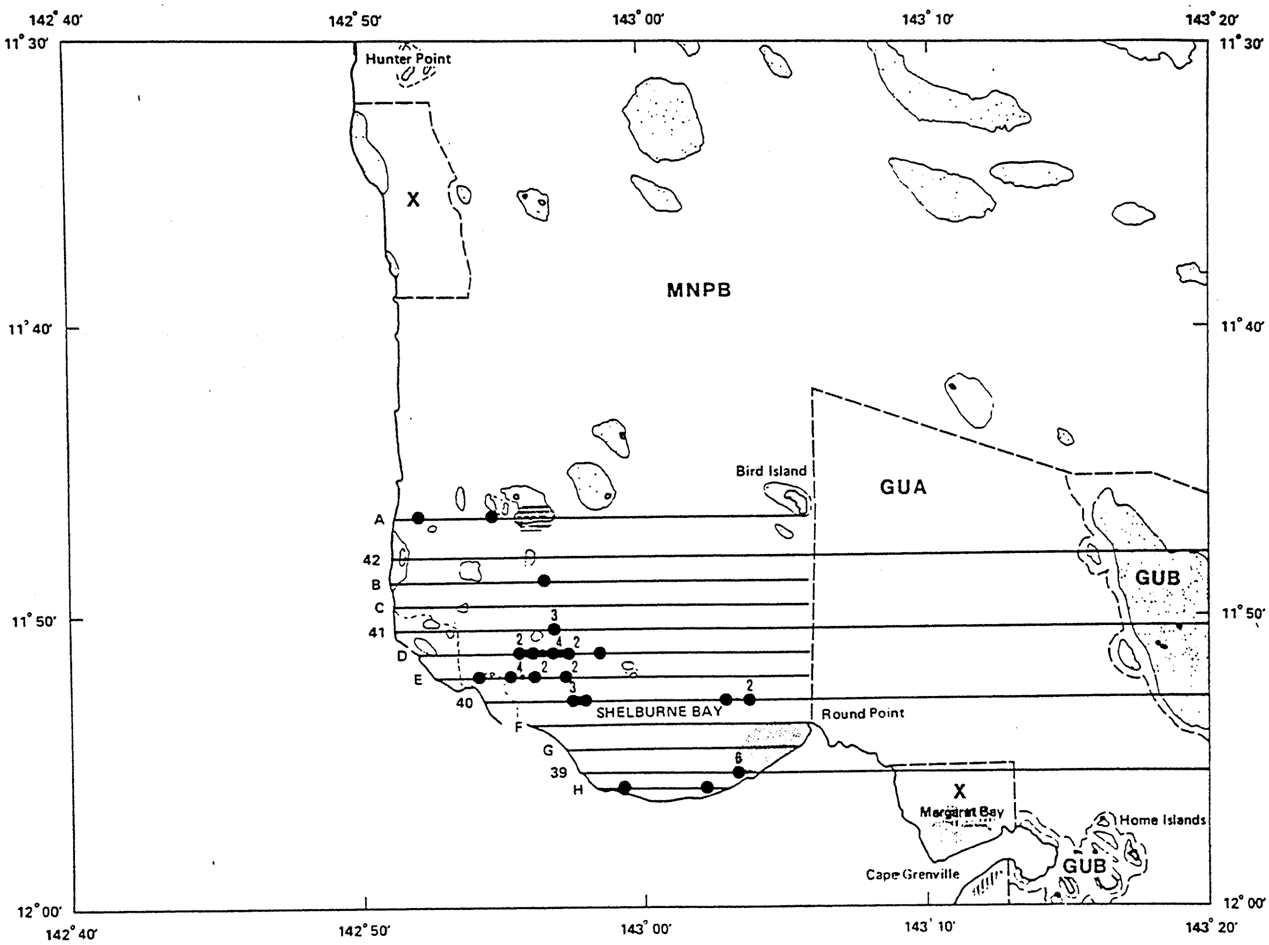

Figure 10: The Shelburne Bay survey area showing the numbers and positions of the intensive transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of actual groupings observed. The GBRMPA zoning and the distribution of seagrass beds are also shown. The ground-truthed seagrass data are from Coles *et al.*, (1985).

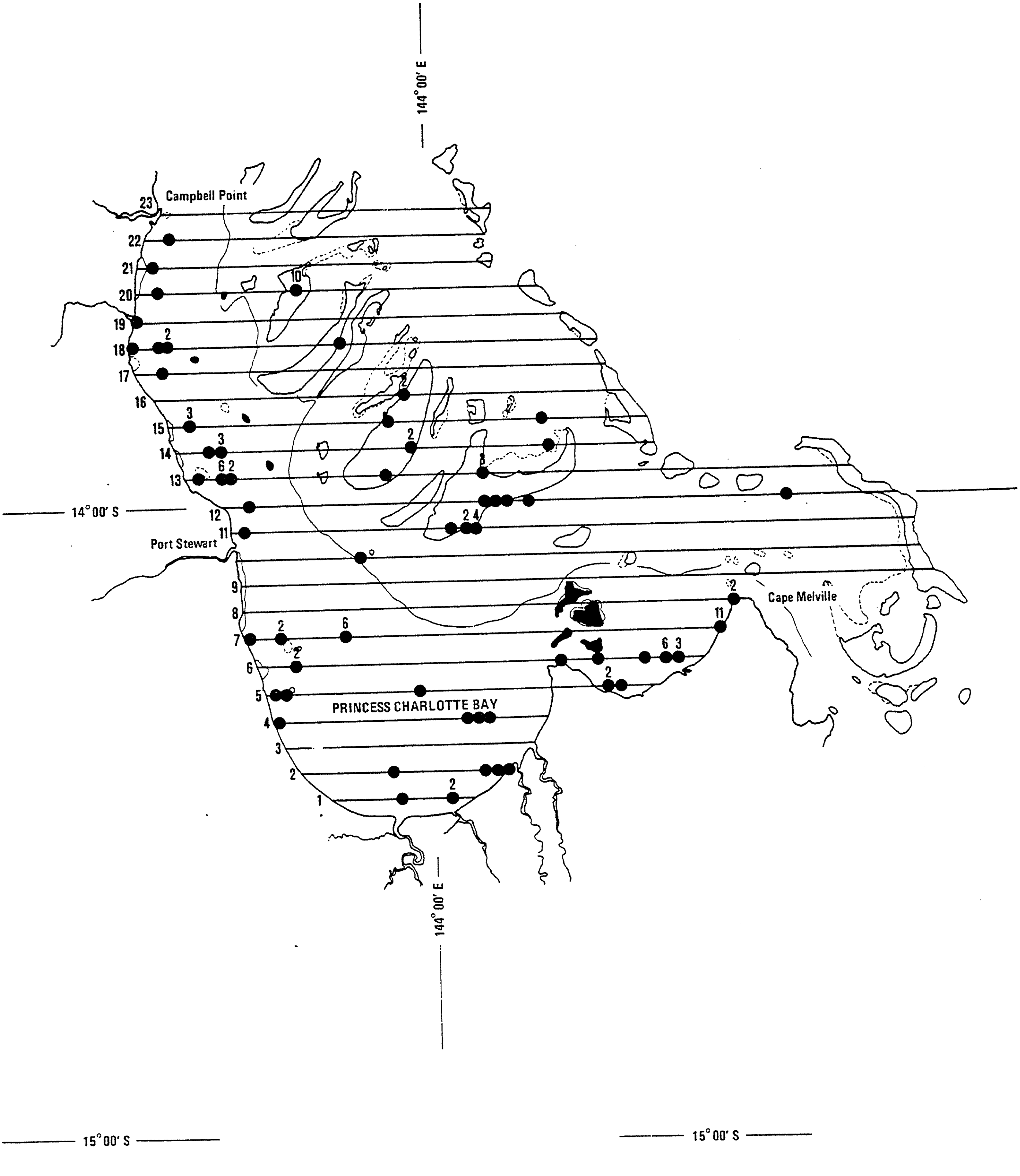

Figure 11: The survey area from Campbell Point to Cape Melville (Princess Charlotte Bay) showing the numbers and positions of the transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

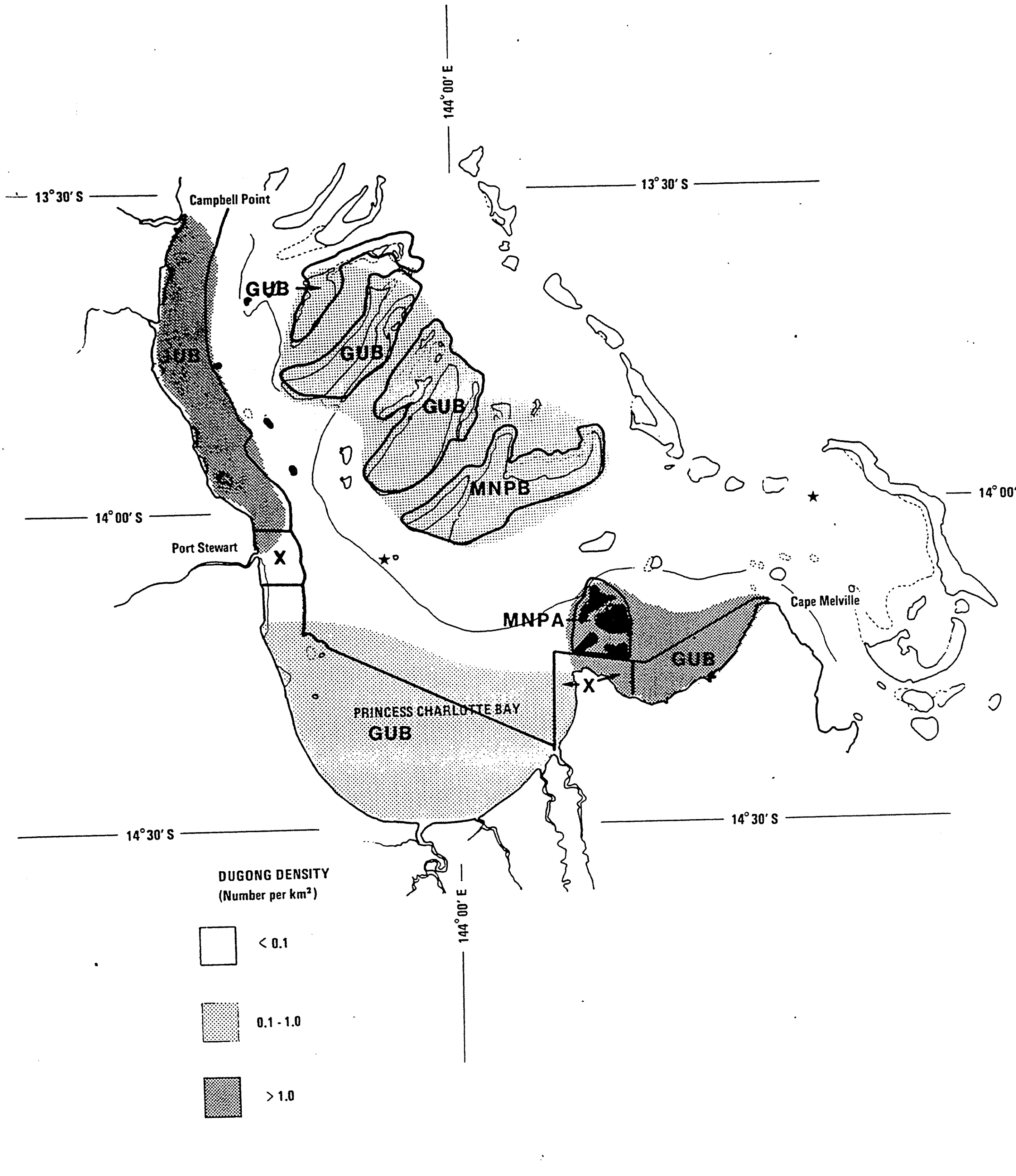

Figure 12: The distribution of dugong density in the survey area from Campbell Point to Cape Melville (Princess Charlotte Bay) in November 1985 with an overlay of the GBRMPA zoning plan for this area.

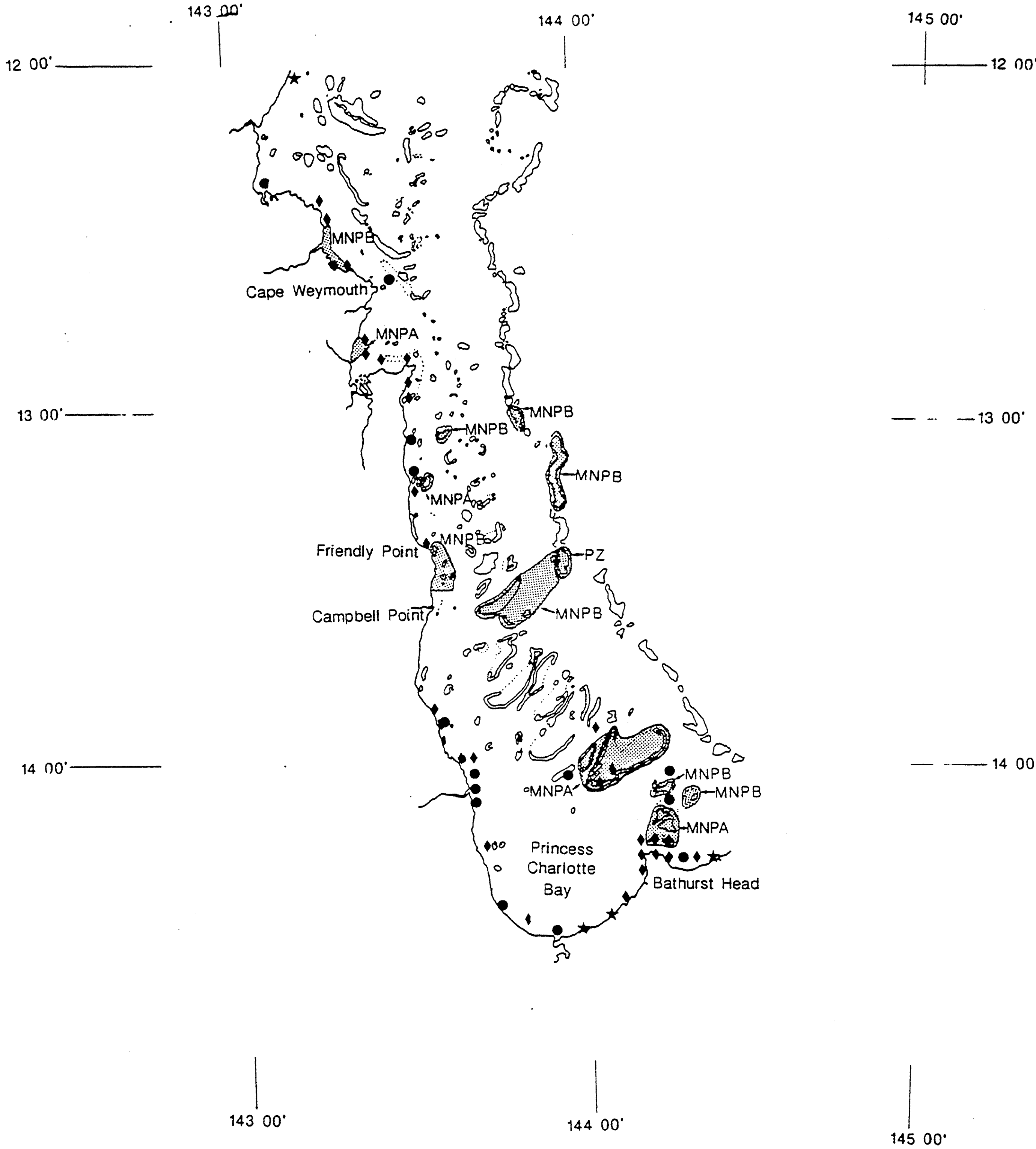

Figure 13: Incidental dugong sightings between Cape Grenville and Cape Melville in relation to areas protected by MNPA zoning or above.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

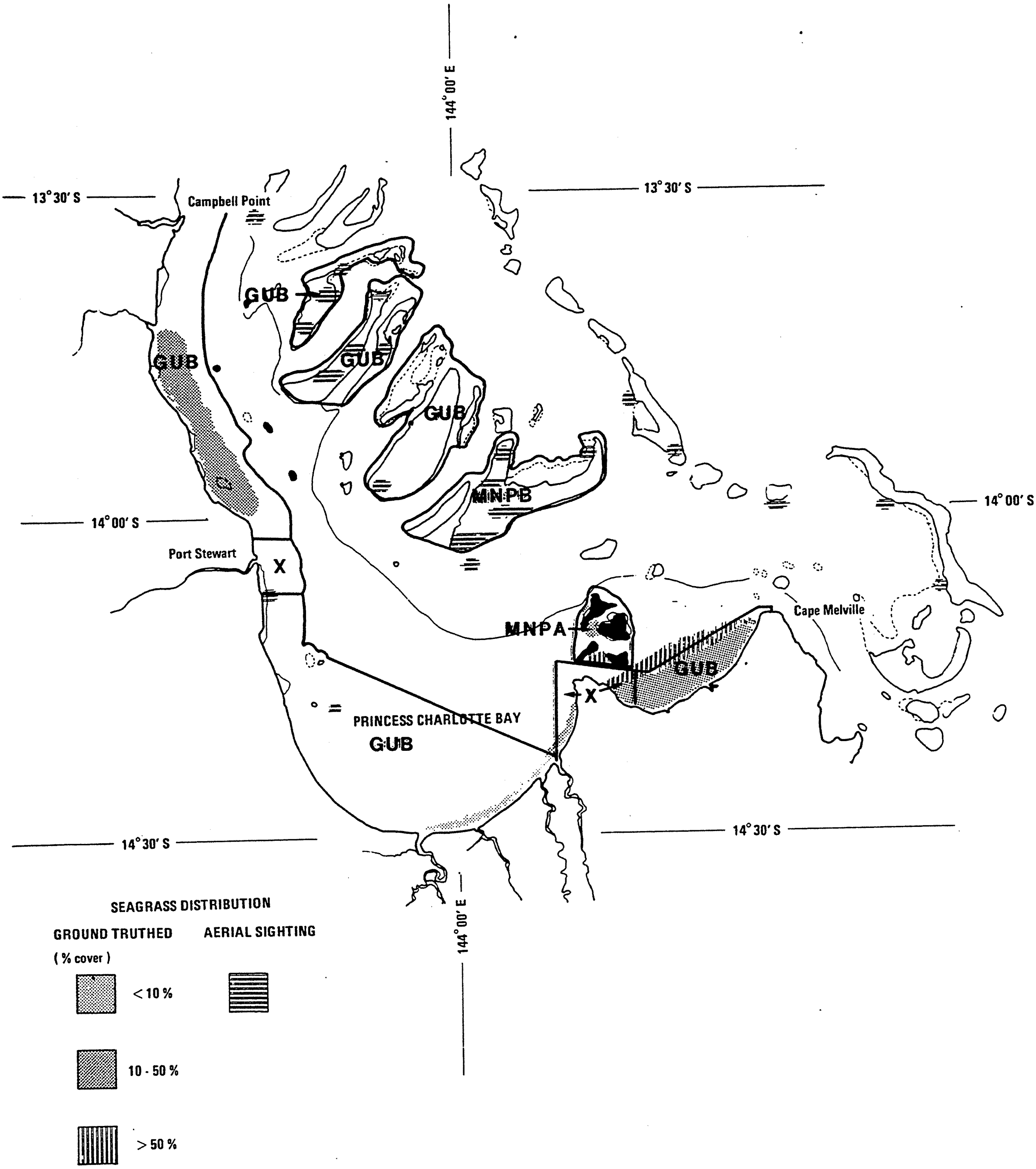

Figure 14: The distribution of known seagrass beds in the survey area from Campbell Point to Cape Melville (Princess Charlotte Bay) with an overlay of the GBRMPA zoning plan for this area. The ground-truthed seagrass data are from Coles *et al.*, (1985).

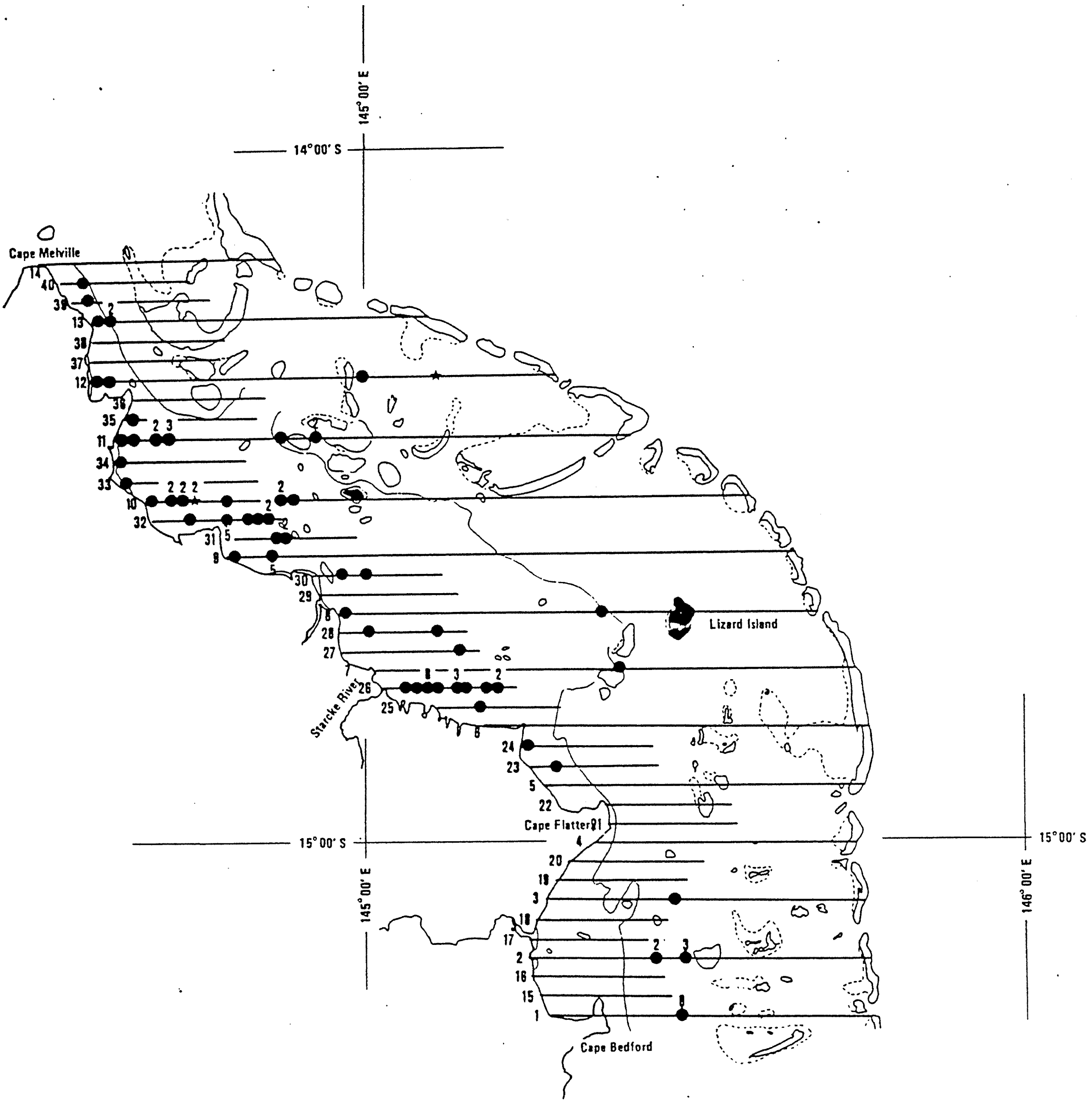

Figure 15: The survey area from Cape Melville to Cape Bedford showing the numbers and positions of the transects and dugong sightings in November 1984. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

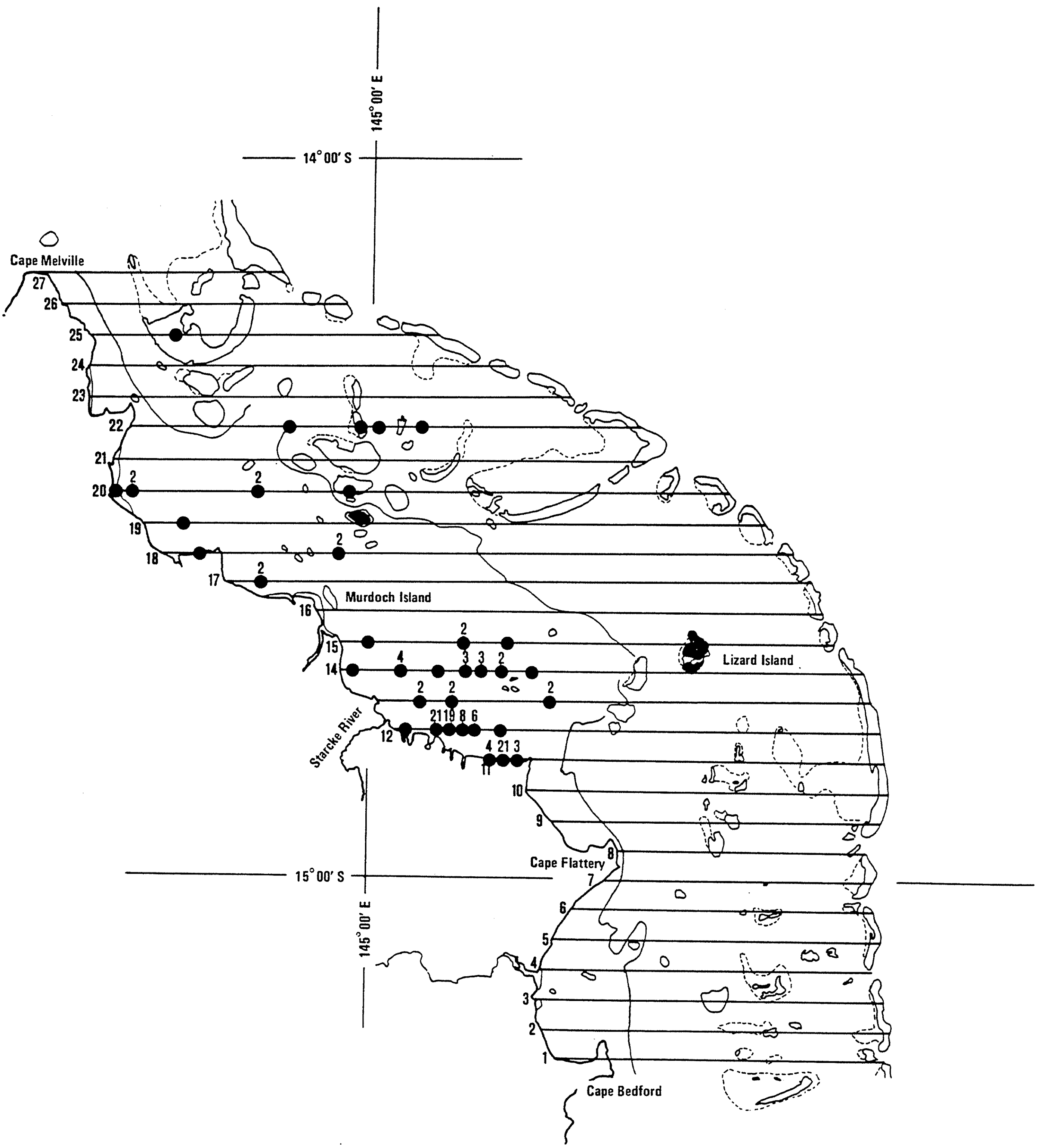

Figure 16: The survey area from Cape Melville to Cape Bedford showing the numbers and positions of the transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

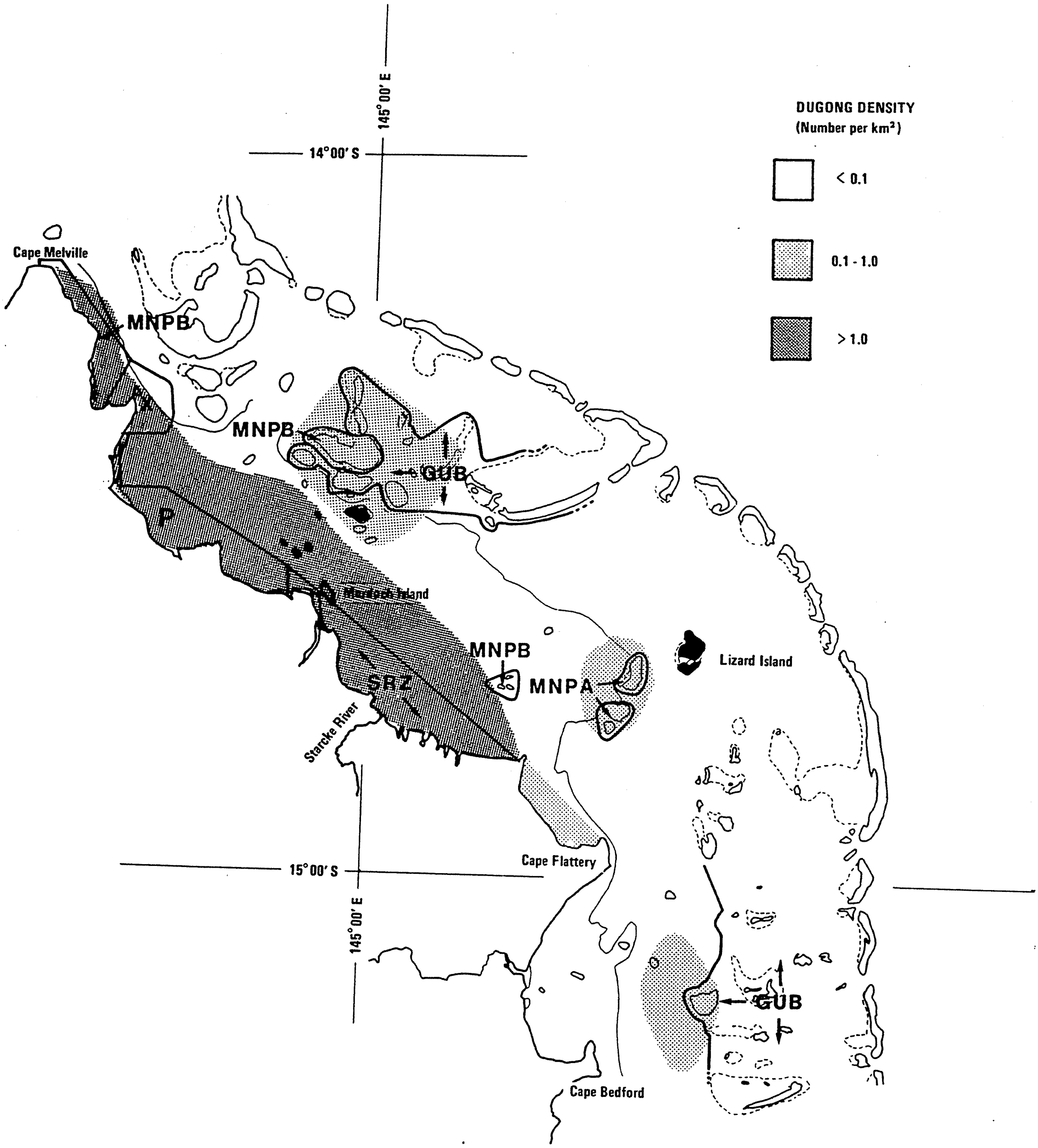

Figure 17: The distribution of dugong density in the survey area from Cape Melville to Cape Bedford in November 1984 with an overlay of the GBRMPA zoning plan for this area.

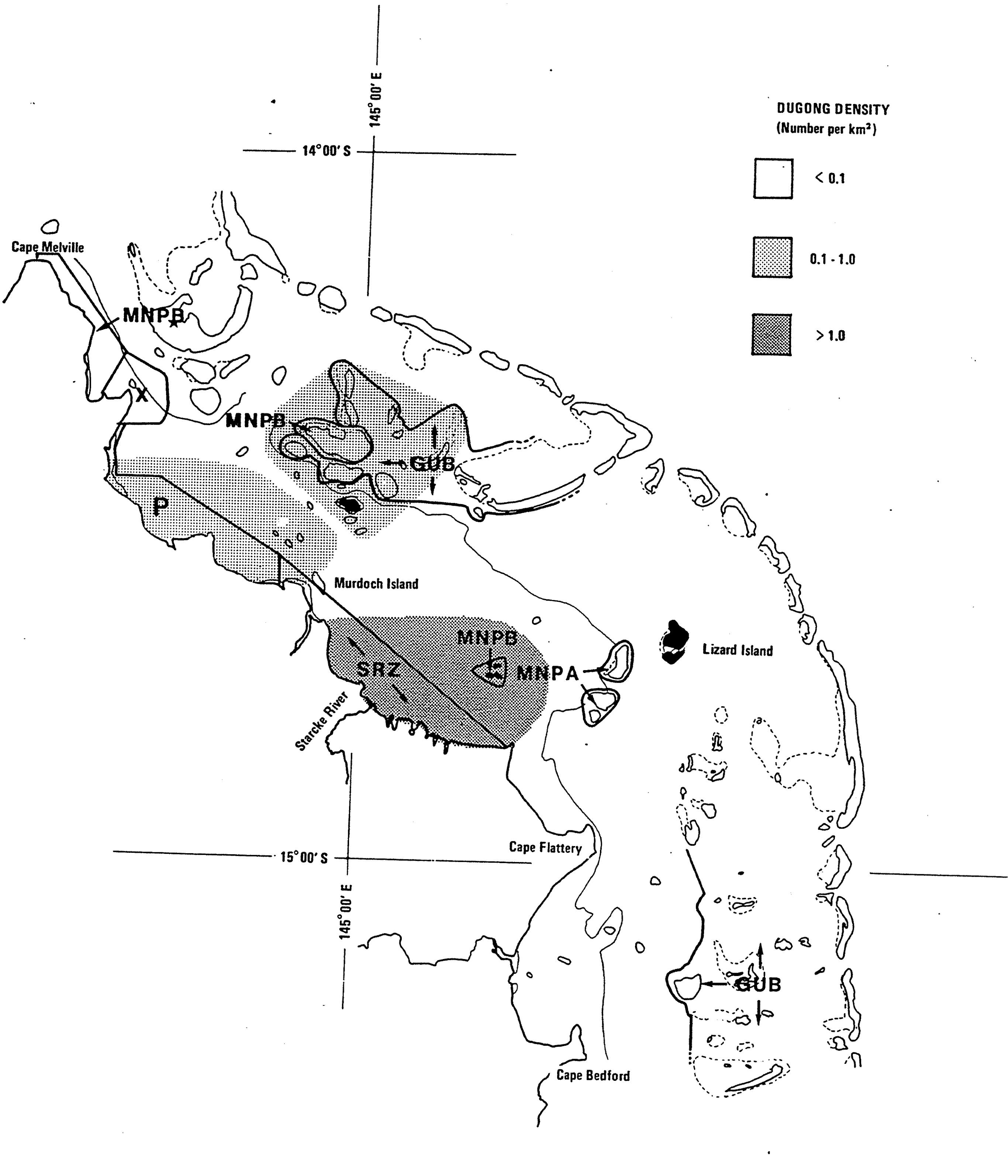

Figure 18: The distribution of dugong density in the survey area from Cape Melville to Cape Bedford in November 1985 with an overlay of the GBRMPA zoning plan for this area.

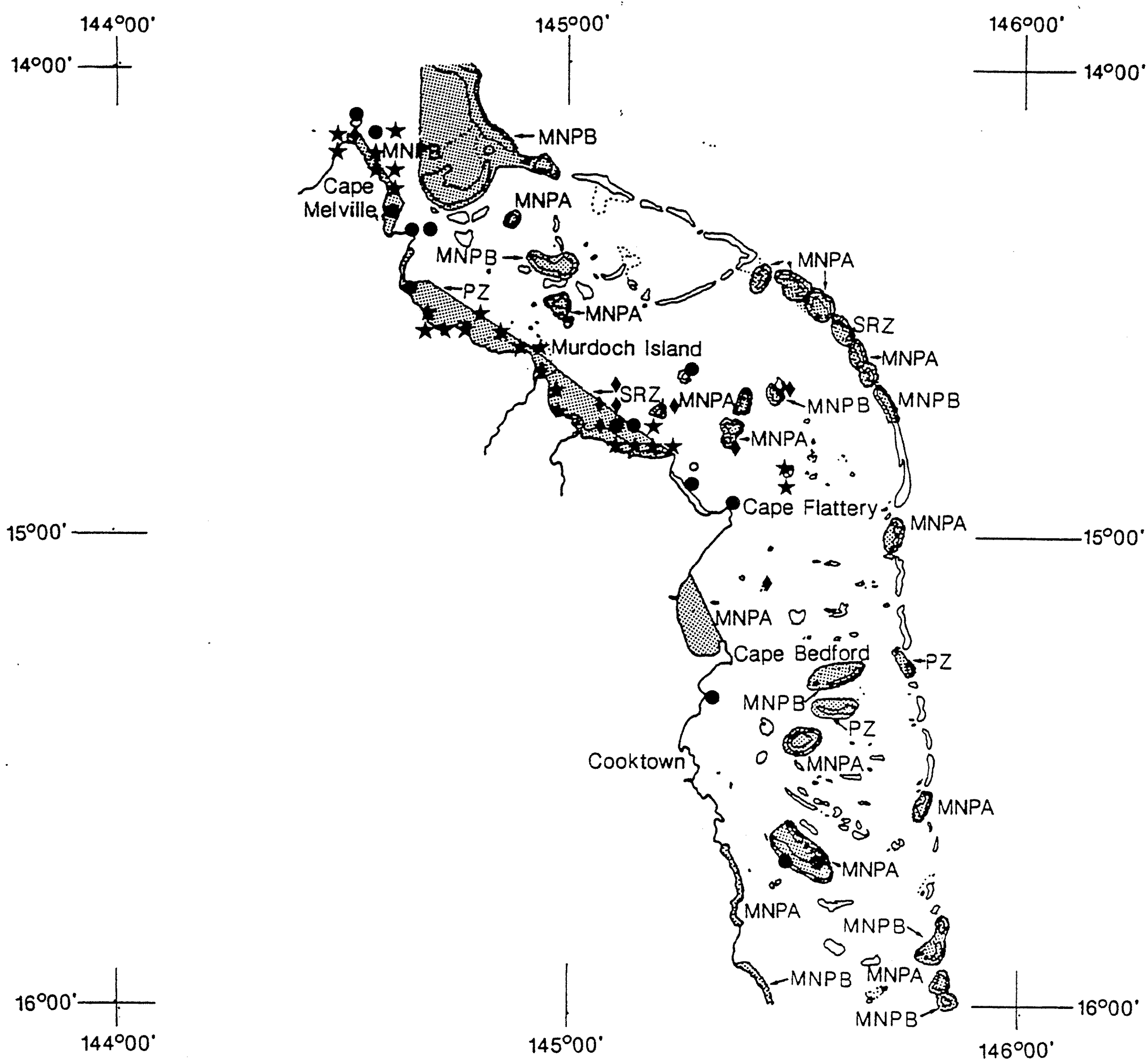

Figure 19: Incidental dugong sightings between Cape Melville and Cape Tribulation in relation to areas protected by MNPA zoning or above.

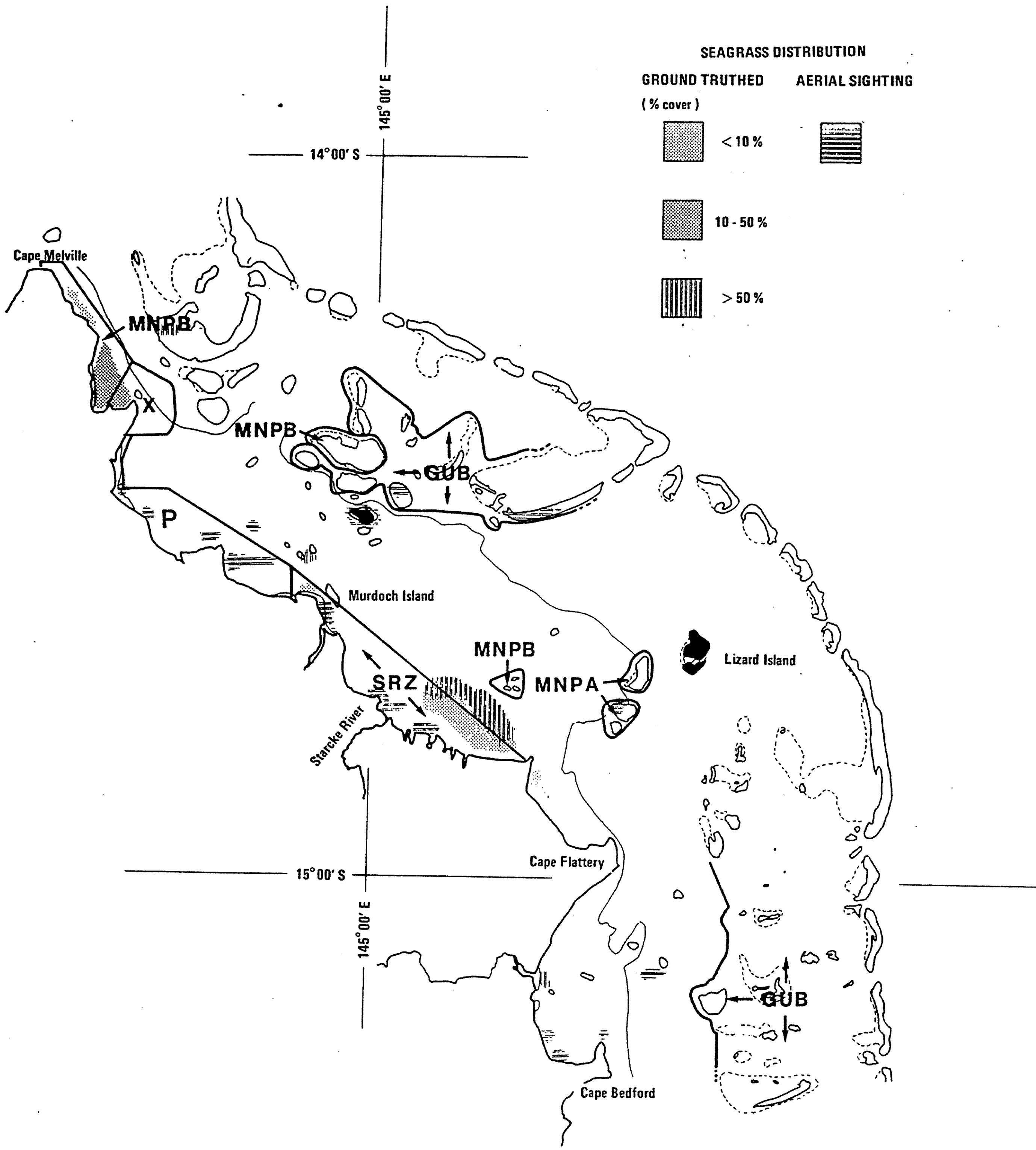

Figure 20: The distribution of known seagrass beds in the survey area from Cape Melville to Cape Bedford with an overlay of the GBRMPA zoning plan for this area. The ground-truthed seagrass data are from Coles *et al*., (1985).

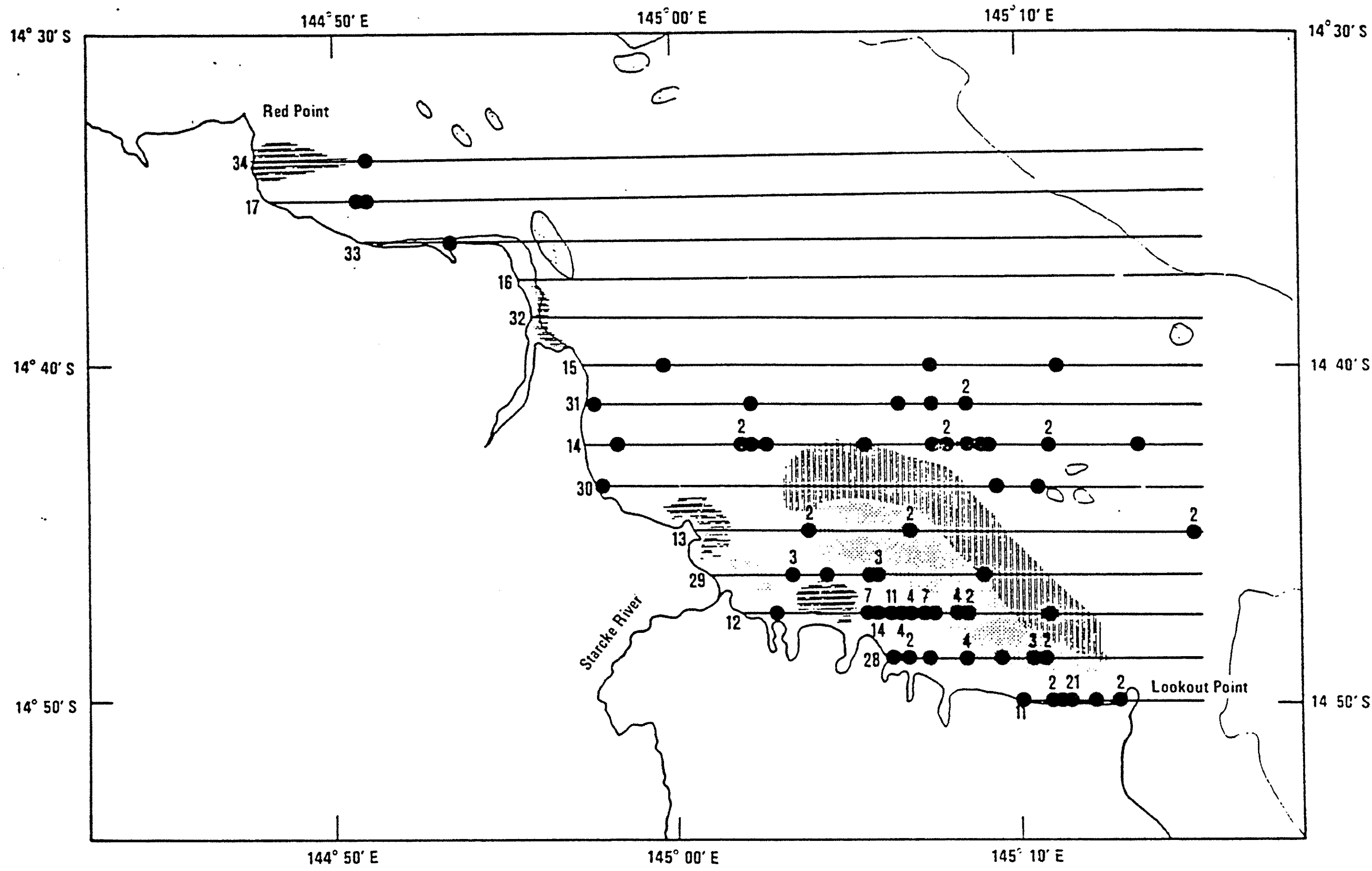

Figure 21: The Starcke River survey area showing the numbers and positions of the intensive transects and dugong sightings in November 1985. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed. The distribution of seagrass beds is also shown. The ground-truthed seagrass data are from Coles *et al.*, (1985).

SECTION 2

Dugong sightings and density distribution maps in the Great Barrier Reef Marine Park south of Cape Bedford

Section 2: Dugong sighting and density distribution maps in the Great Barrier Reef Marine Park south of Cape Bedford.

Figure 1: The survey area from Cape Bedford to Dunk Island showing the numbers and positions of the transects and dugong sightings in October 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 2: Incidental dugong sightings between Cape Tribulation and Dunk Island in relation to areas protected by MNPA zoning or above.

Figure 3: The distribution of known seagrass beds from Cape Bedford to Dunk Island. The ground-truthed seagrass data are from Dr. R. *Coles*, pers. comm. (1988).

Figure 4: The survey area from Dunk Island to Cape Cleveland showing the numbers and positions of the transects and dugong sightings in September 1986. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 5: The survey area from Dunk Island to Cape Cleveland showing the numbers and positions of the transects and dugong sightings in September - October 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

Figure 6: The distribution of dugong density in the survey area from Dunk Island to Cape Cleveland in September 1986 with the GBRMPA zoning plan for the area.

Figure 7: The distribution of dugong density in the survey area from Dunk Island to Cape Cleveland in September - October 1987 with the GBRMPA zoning plan for the area.

Figure 22: Incidental dugong sightings between Townshend Island and Curtis Island in relation to areas protected by MNPA zoning or above.

Figure 23: The distribution of known seagrass beds in the survey area from Repulse Bay to Shoalwater Bay in relation to the Great Barrier Reef Marine Park Authority Zoning Plan. The ground-truthed seagrass data are from Coles *et al.*, (1987).

Figure 24: The distribution of known seagrass beds in the survey area from Shoalwater Bay to Bustard Head in relation to the Great Barrier Reef Marine Park Authority Zoning Plan. The ground-truthed seagrass data are from Coles *et al.*, (1987).

Figure 25: The Shoalwater Bay area showing the numbers and positions of the intensive transects and dugong sightings in November 1986. The numbers associated with the sightings do no necessarily reflect the sizes of the actual groupings observed.

Reference:

Coles, R.G., Mellors, J., Bibby, J., and Squire, B. (1987) Seagrass beds and juvenile prawn nursery grounds between Bowen and Water Park Point. Queensland Department of Primary Industries Information Series Q187021.

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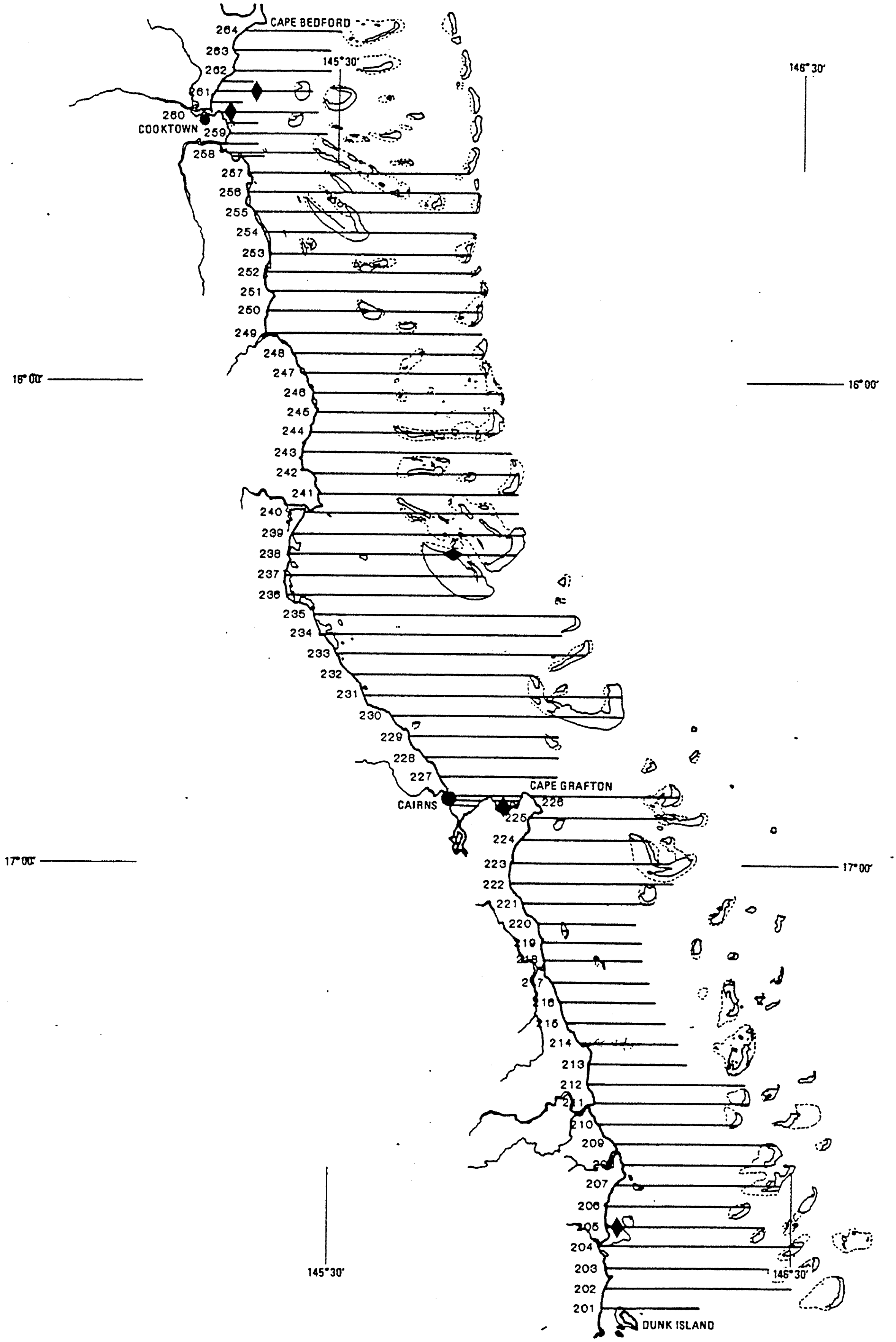

Figure 1: The survey area from Cape Bedford to Dunk Island showing the numbers and positions of the transects and dugong sightings in October 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

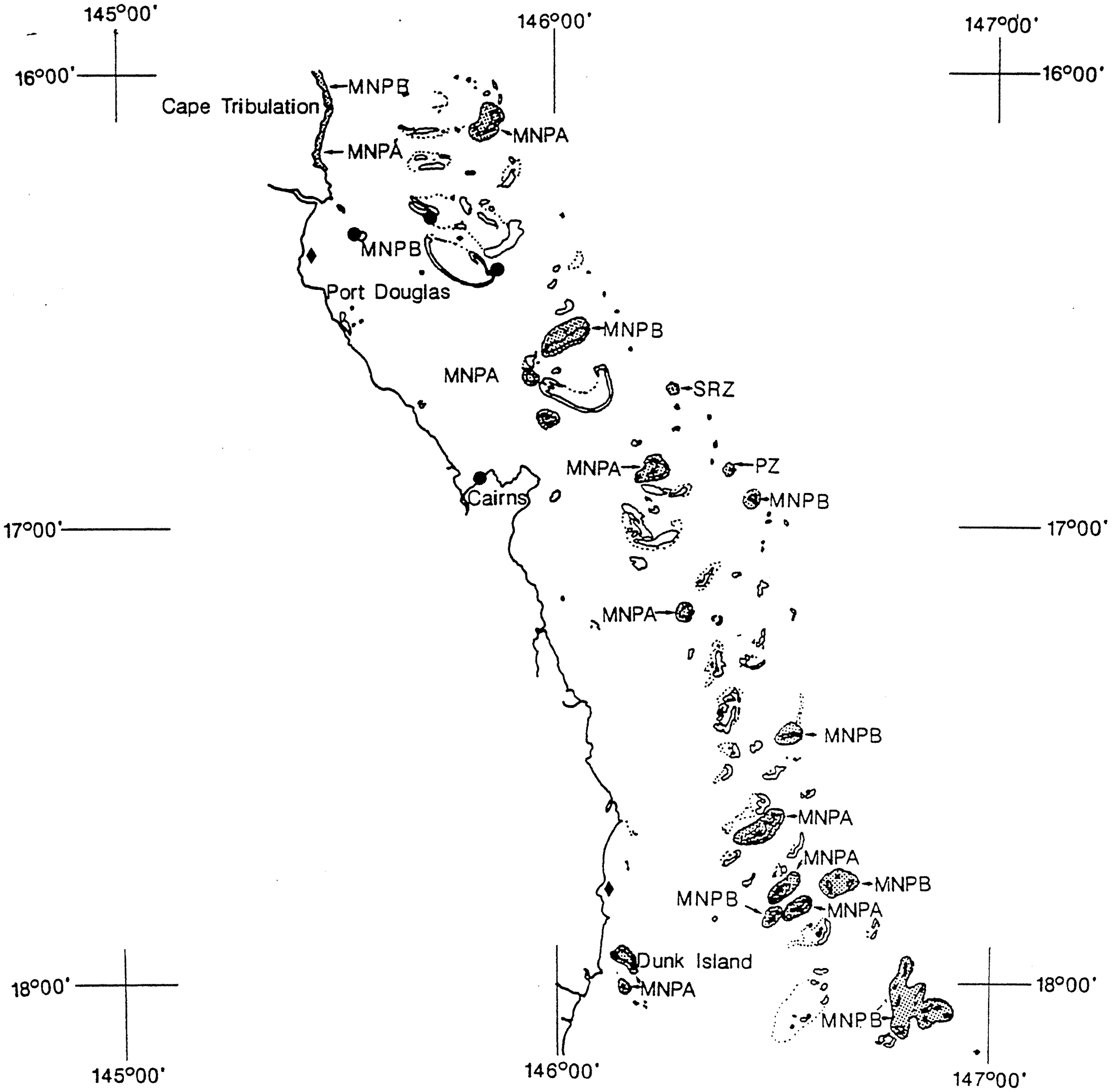

Figure 2: Incidental dugong sightings between Cape Tribulation and Dunk Island in relation to areas protected by MNPA zoning or above.

● One to five dugongs sighted on one date only

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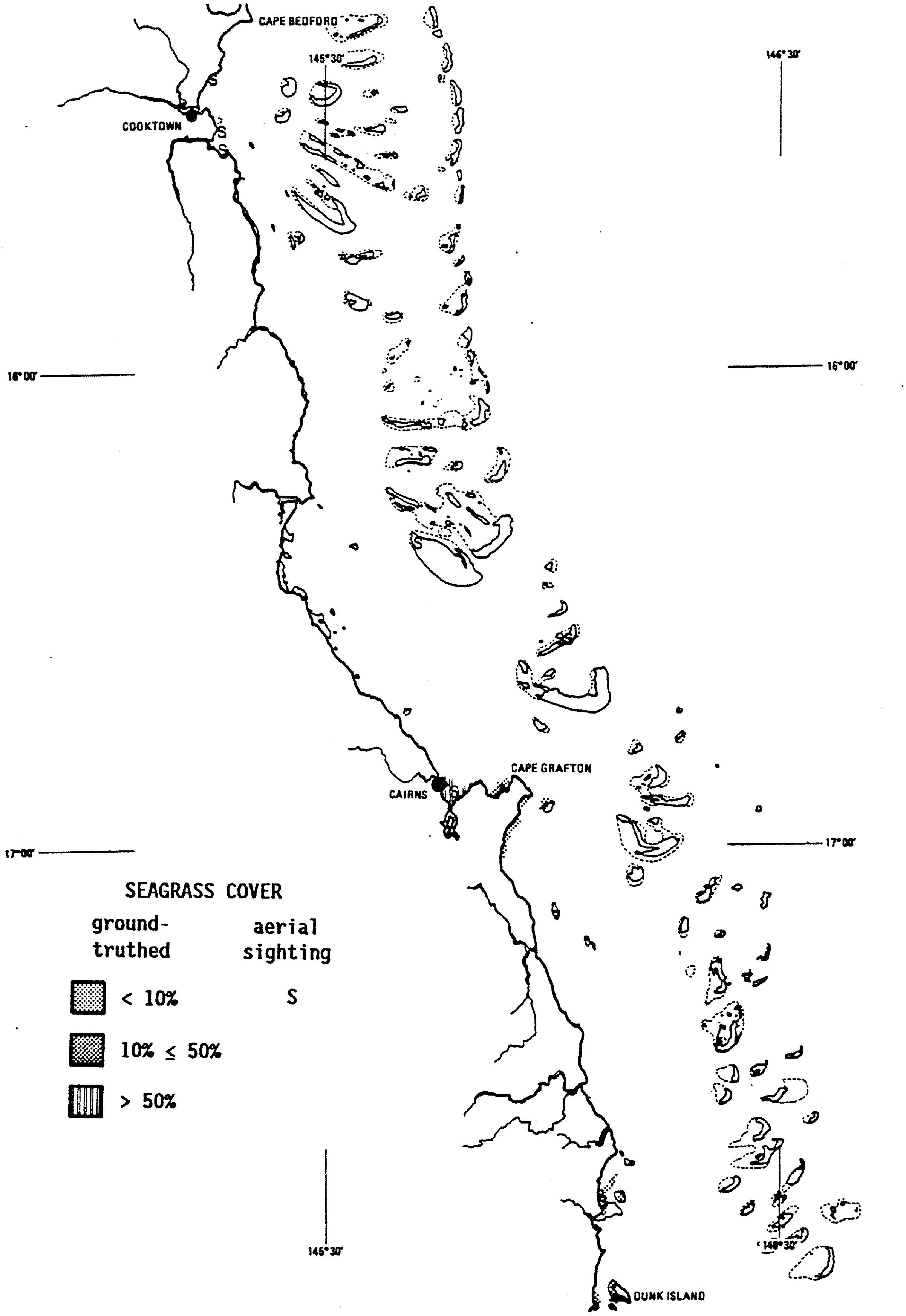

Figure 3: The distribution of known seagrass beds from Cape Bedford to Dunk Island. The ground-truthed seagrass data are from Dr. R. *Coles*, pers. comm. (1988).

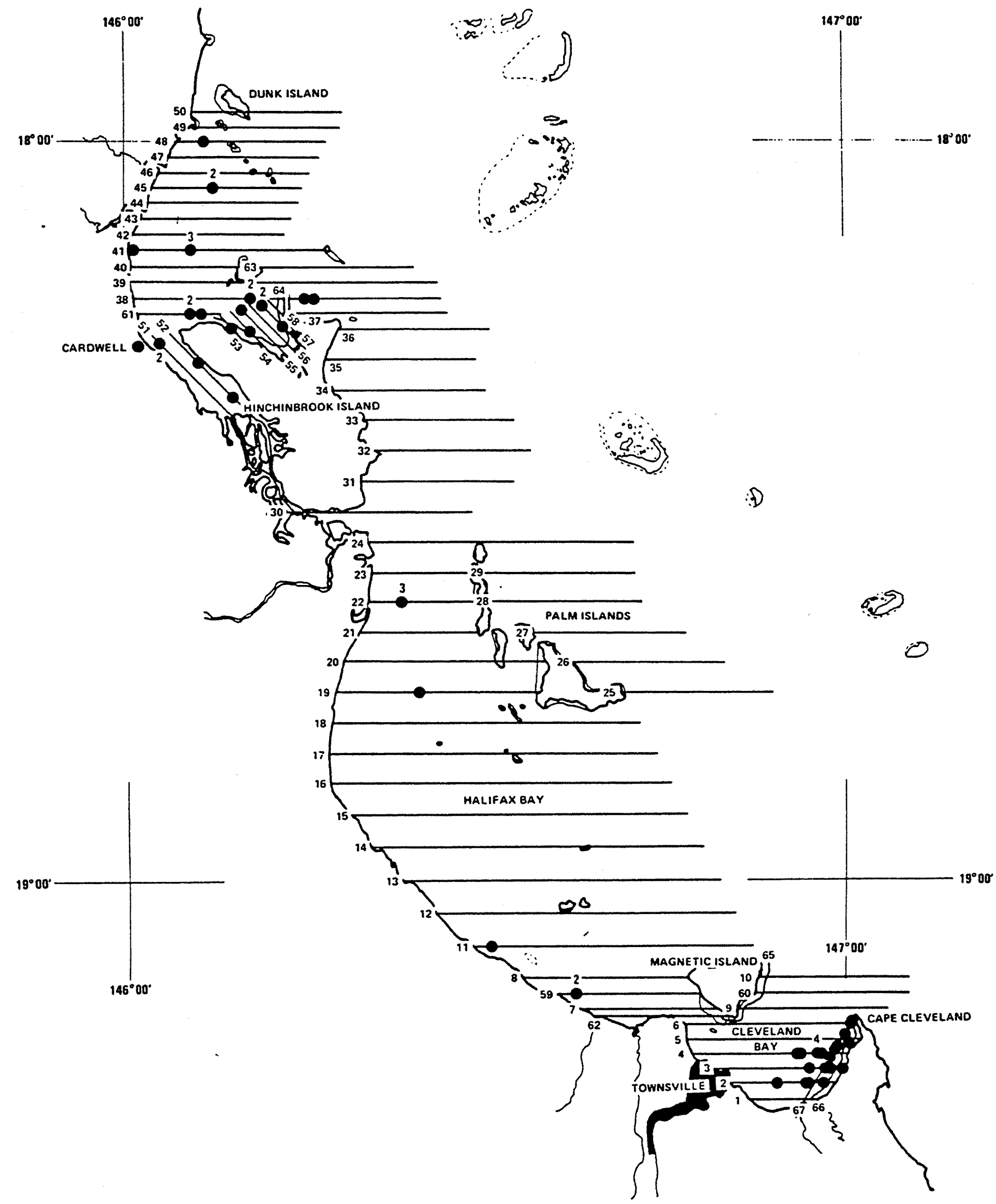

Figure 4: The survey area from Dunk Island to Cape Cleveland showing the numbers and positions of the transects and dugong sightings in September 1986. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

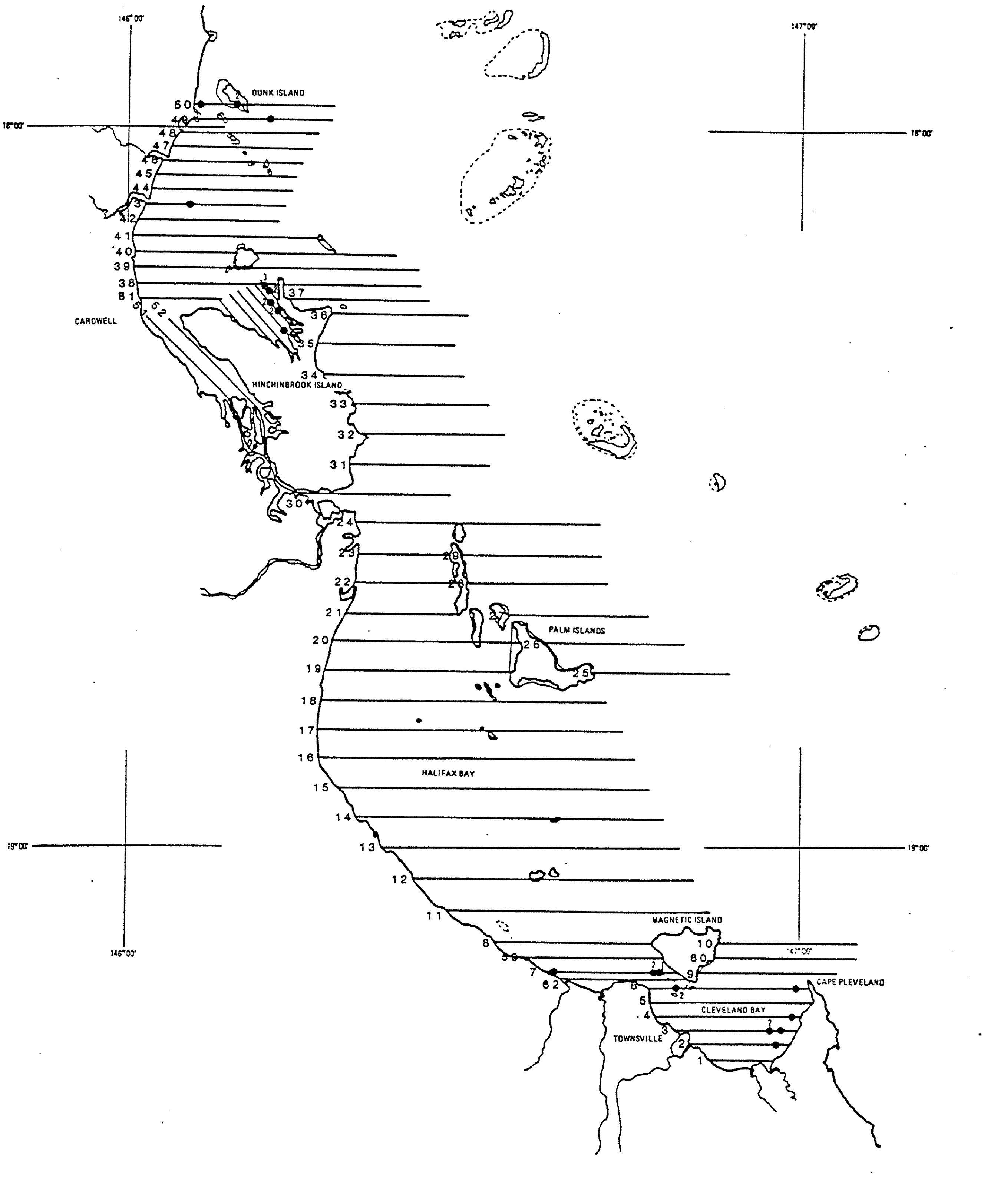

Figure 5: The survey area from Dunk Island to Cape Cleveland showing the numbers and positions of the transects and dugong sightings in September - October 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

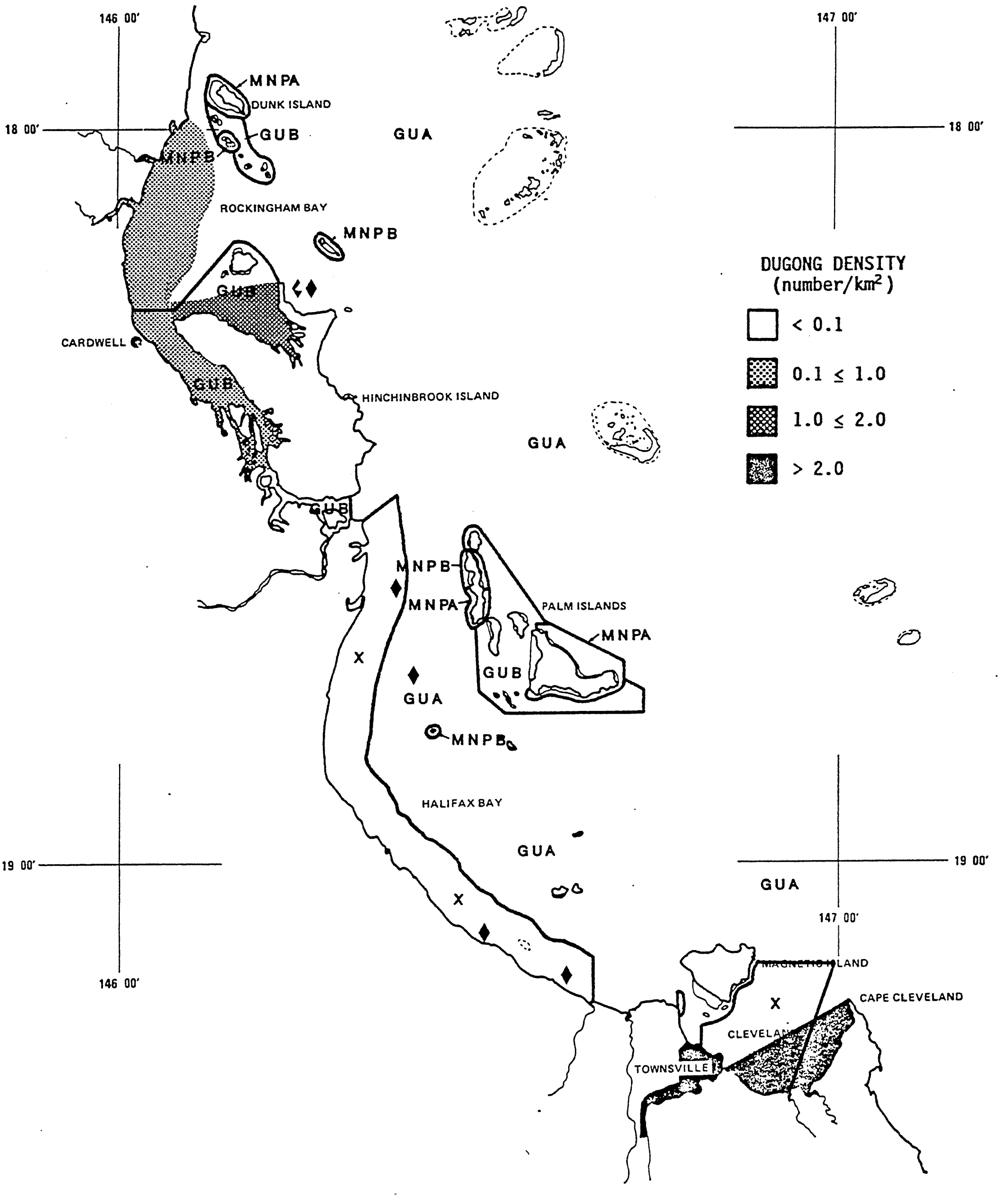

Figure 6: The distribution of dugong density in the survey area from Dunk Island to Cape Cleveland in September 1986 with the GBRMPA zoning plan for the area.

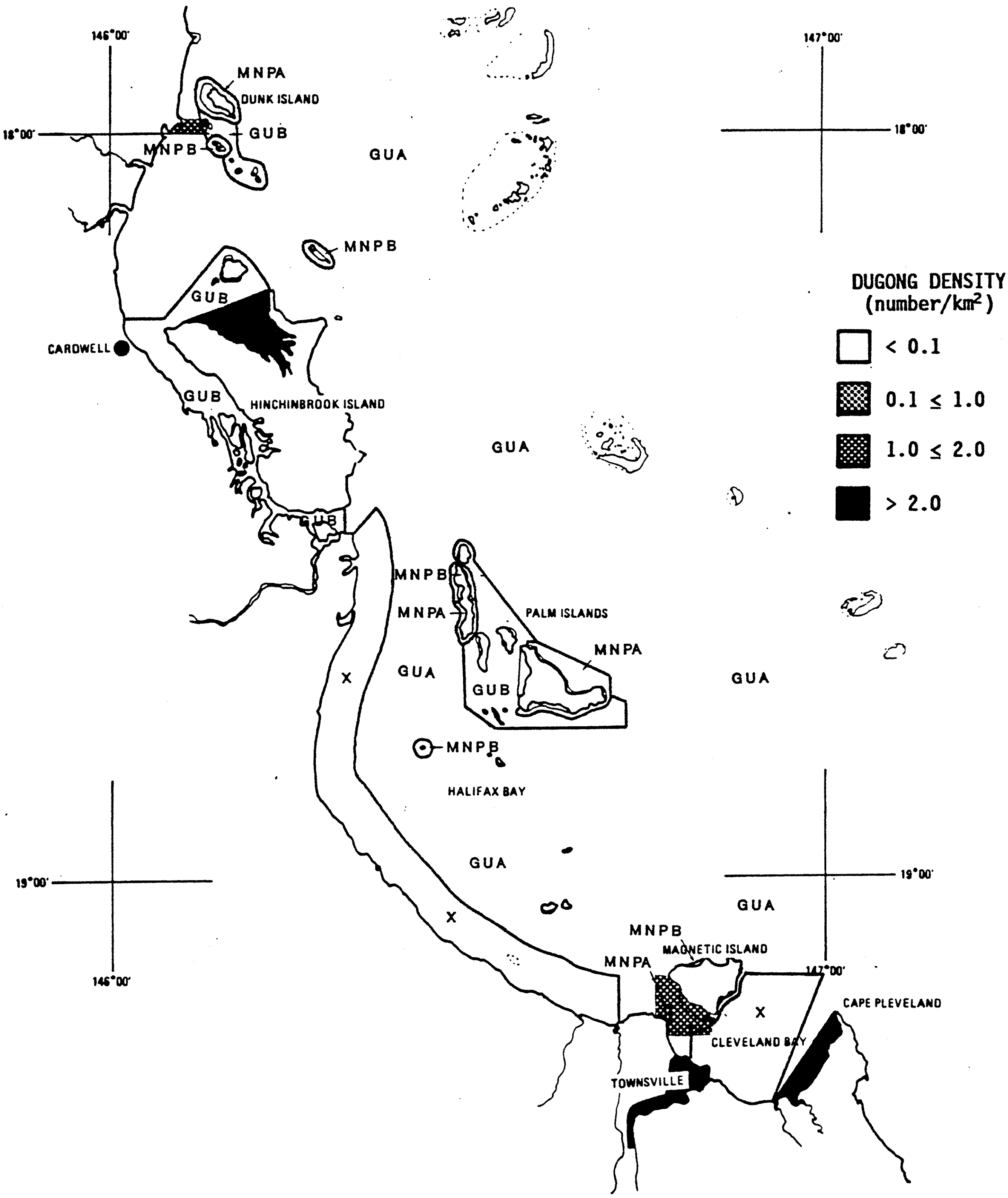

Figure 7: The distribution of dugong density in the survey area from Dunk Island to Cape Cleveland in September - October 1987 with the GBRMPA zoning plan for the area.

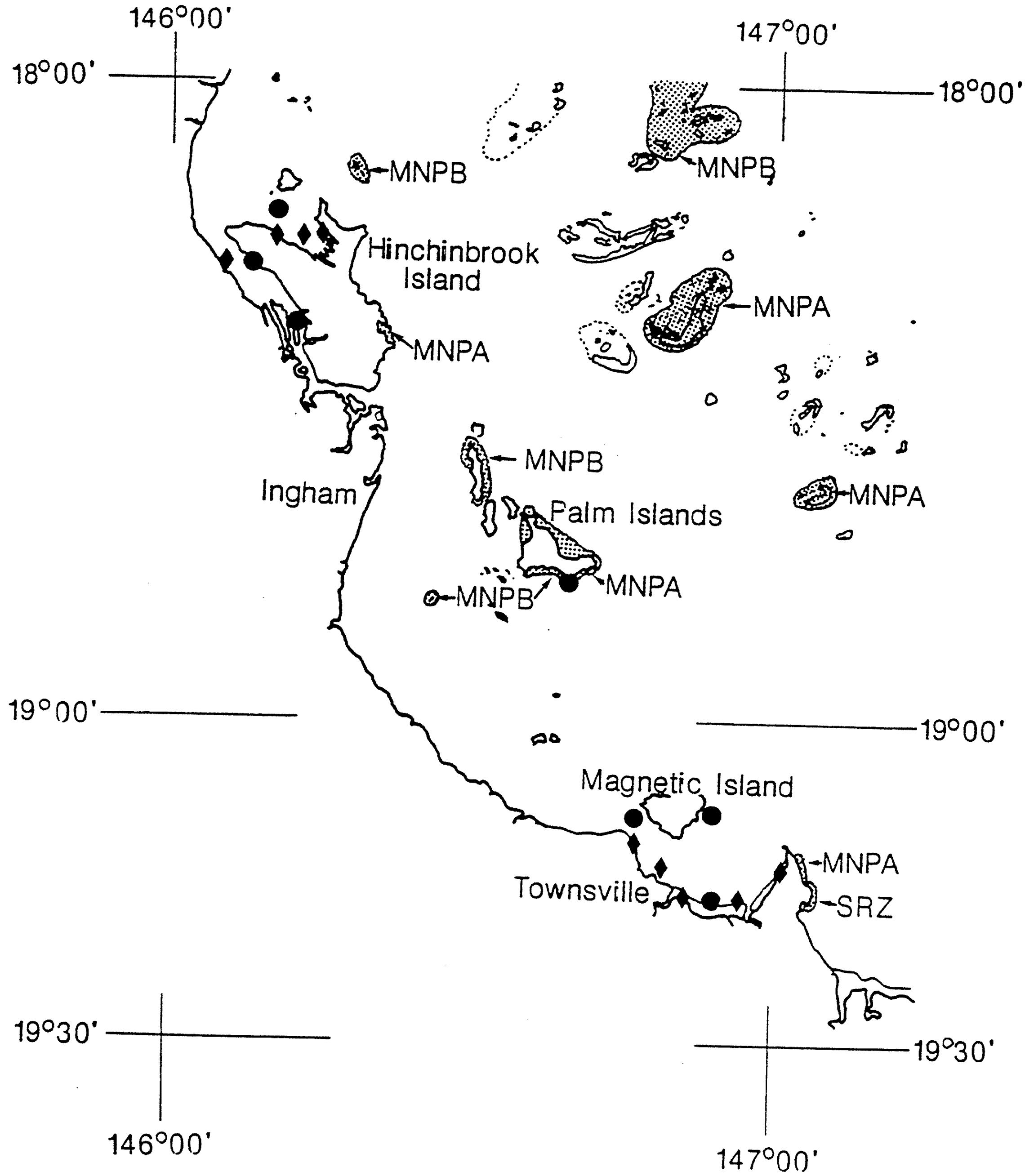

Figure 8: Incidental dugong sightings between Dunk Island and Cape Cleveland in relation to areas protected by MNPA zoning or above.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

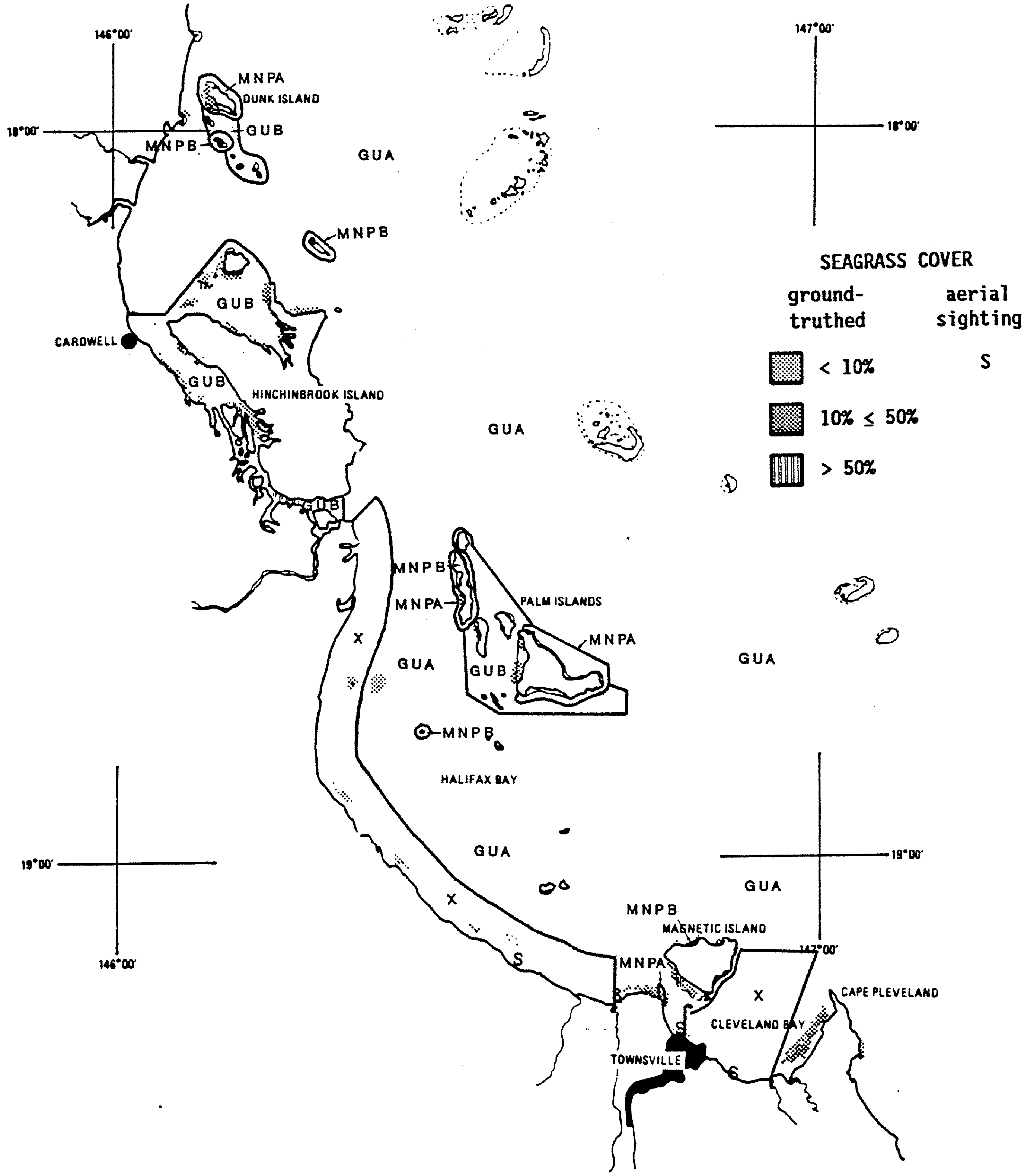

Figure 9: The distribution of known seagrass beds in the survey area from Dunk Island to Cape Cleveland with the GBRMPA zoning plan for the area. The ground-truthed seagrass data are from Dr. R. *Coles*, pers. comm. (1988).

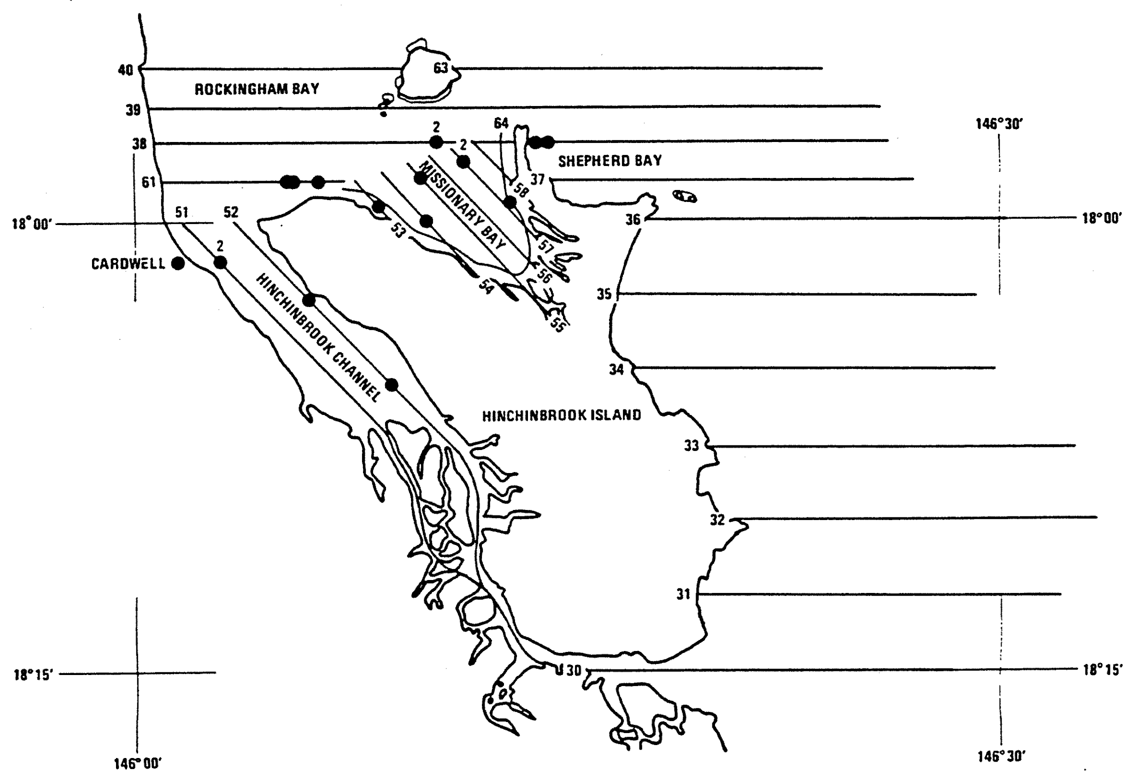

Figure 10: The Hinchinbrook Island area showing the numbers and positions of the intensive transects and dugong sightings in September 1986. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

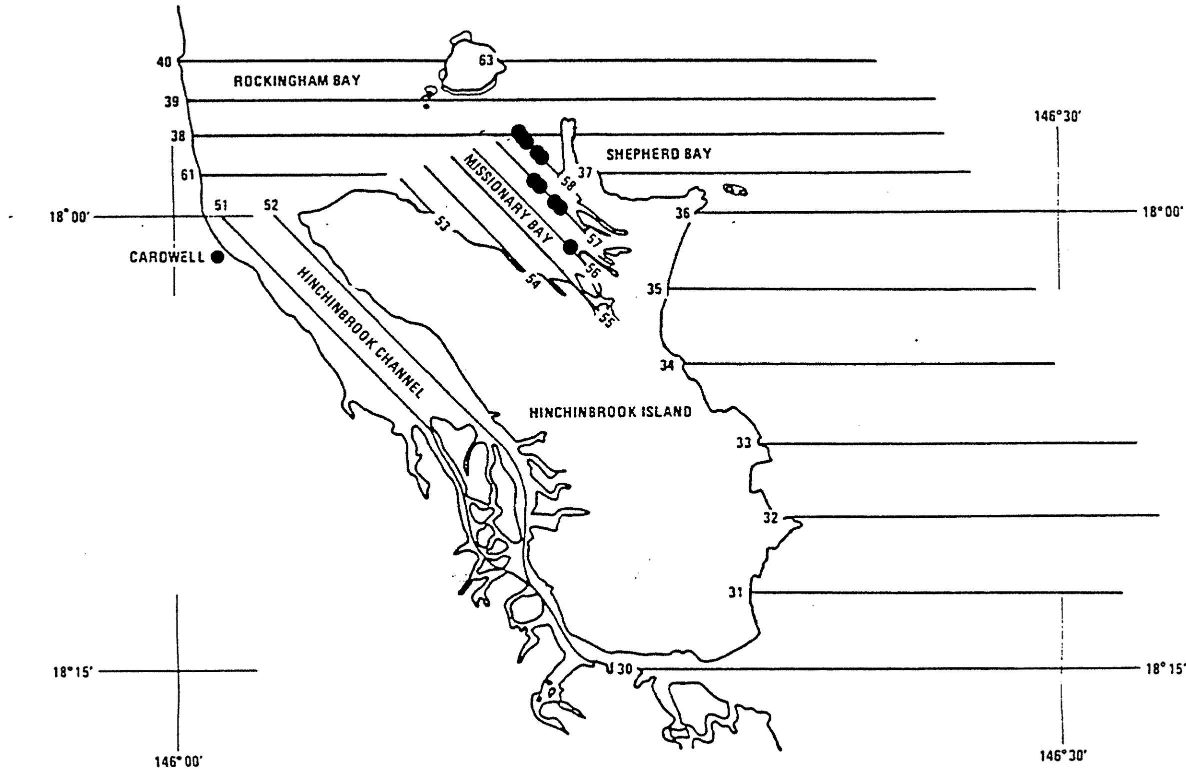

Figure 11: The Hinchinbrook Island area showing the numbers and positions of the intensive transects and dugong sightings in September - October 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

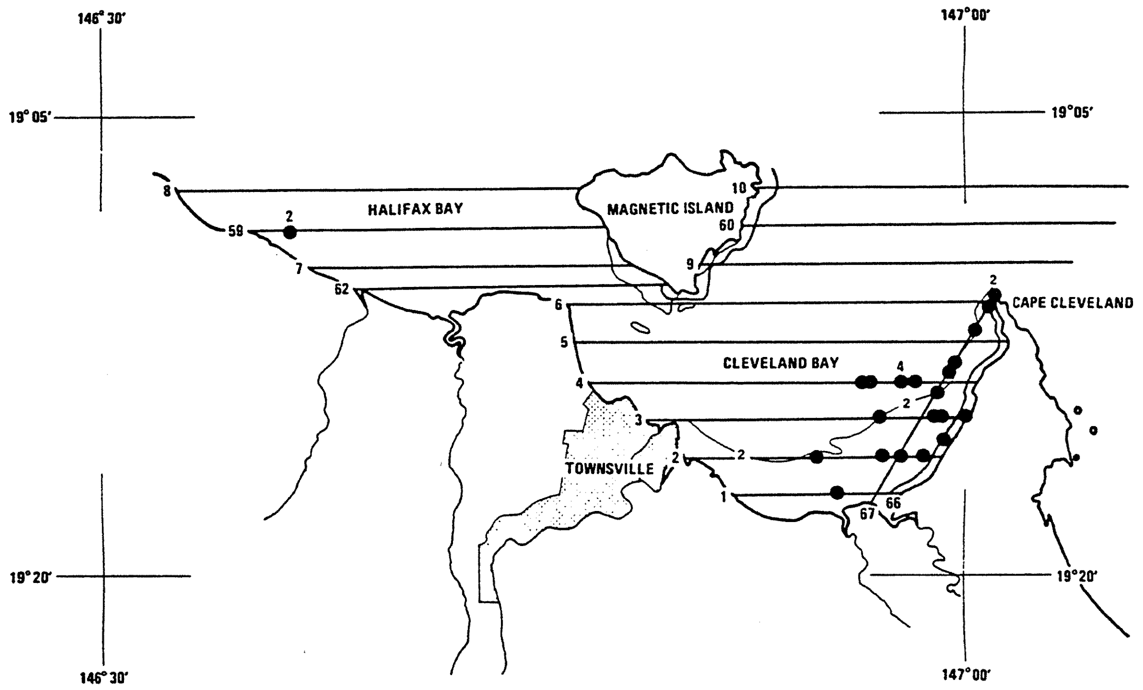

Figure 12: The Cleveland Bay area showing the numbers and positions of the intensive transects and dugong sightings in September 1986. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

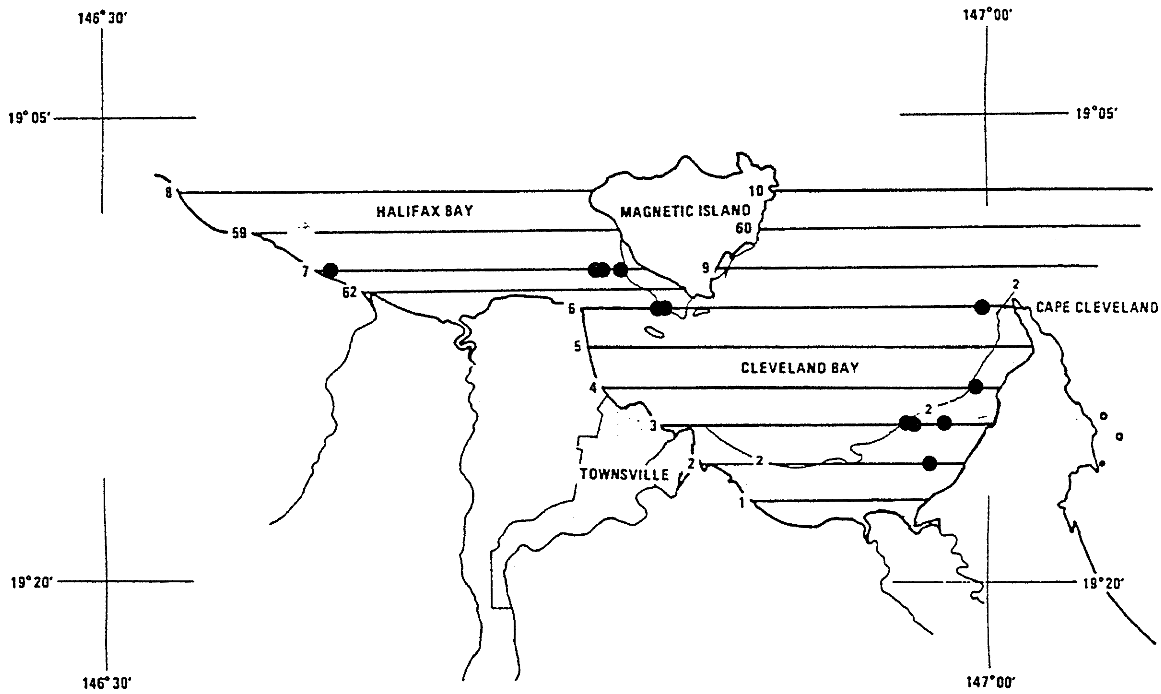

Figure 13: The Cleveland Bay area showing the numbers and positions of the intensive transects and dugong sightings in September-October 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

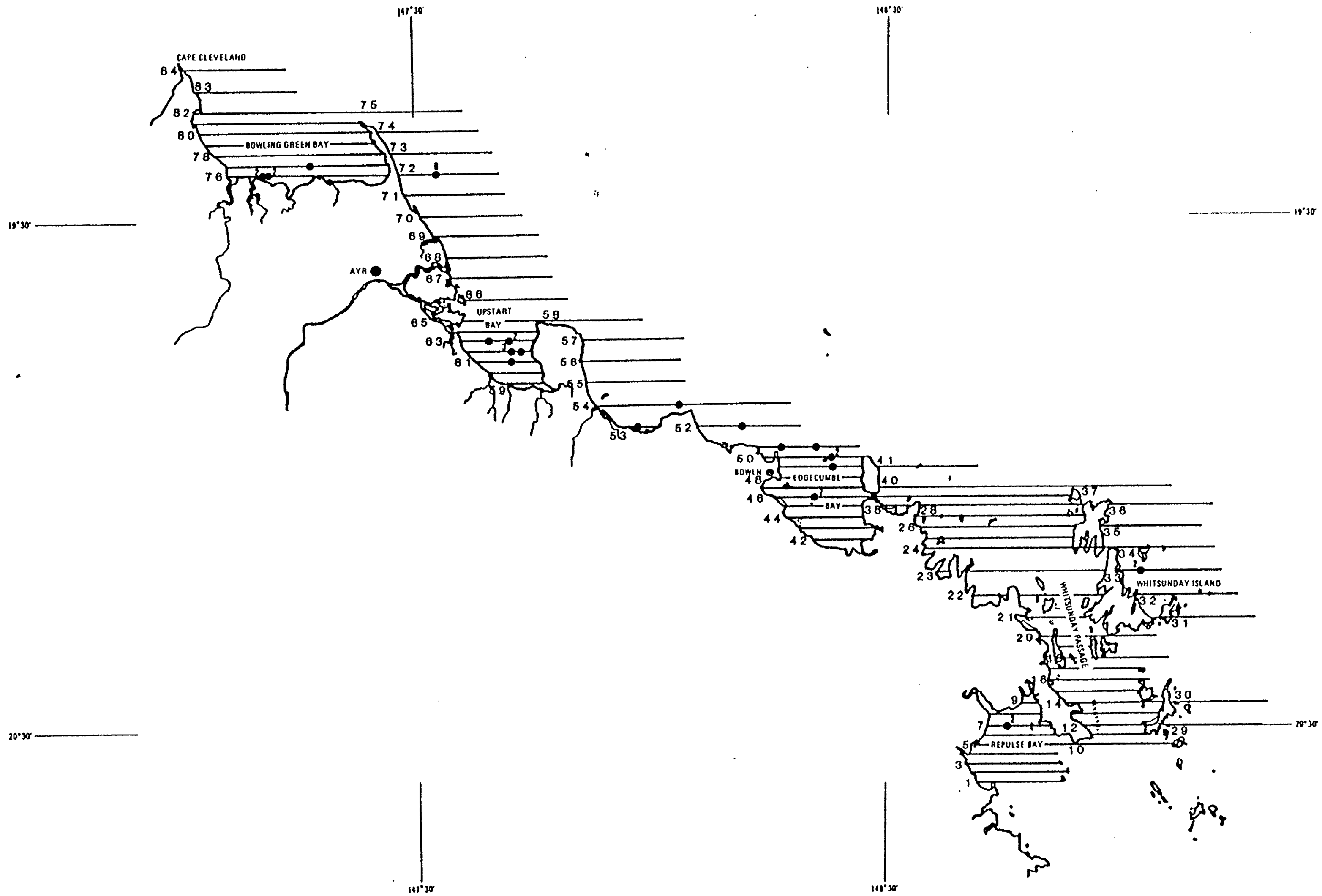

Figure 14: The survey area from Cape Cleveland to Repulse Bay showing the numbers and positions of the transects and dugong sightings in September - October 1987. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

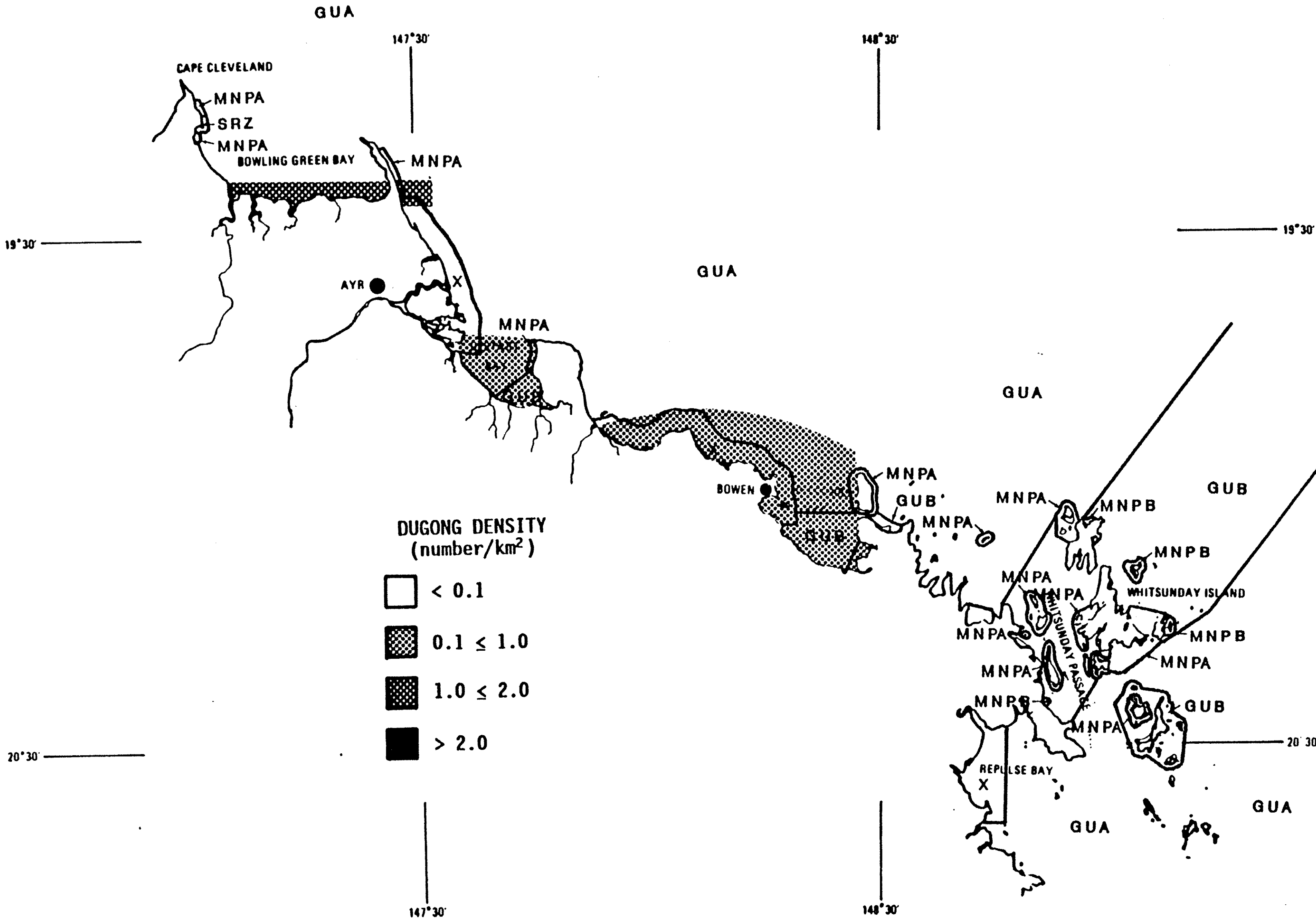

Figure 15: The distribution of dugong density in the survey area from Cape Cleveland to Repulse Bay in September - October 1987 with the GBRMPA zoning plan for the area.

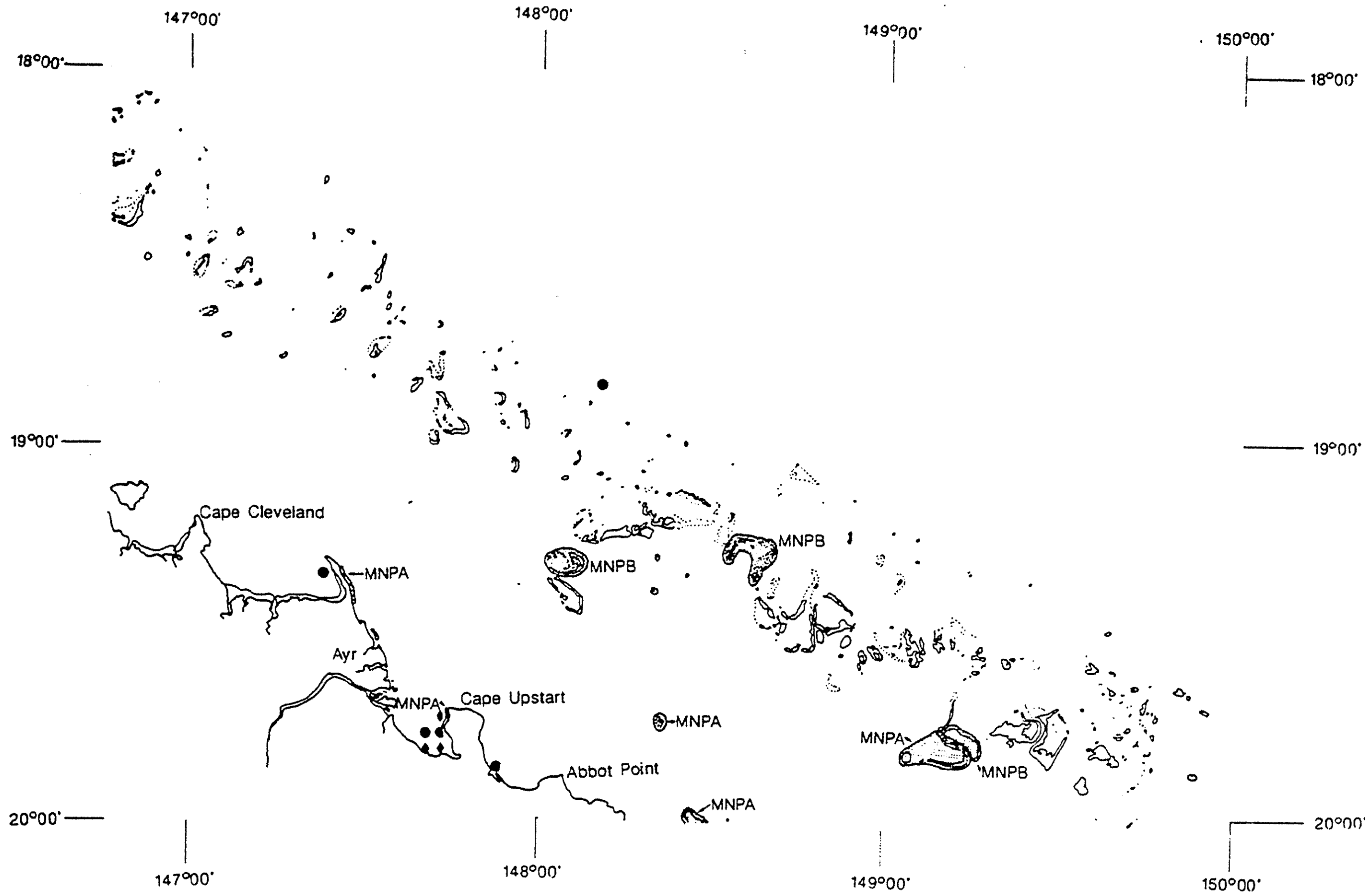

Figure 16: Incidental dugong sightings between Cape Cleveland and Bowen in relation to areas protected by MNPA zoning or above.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

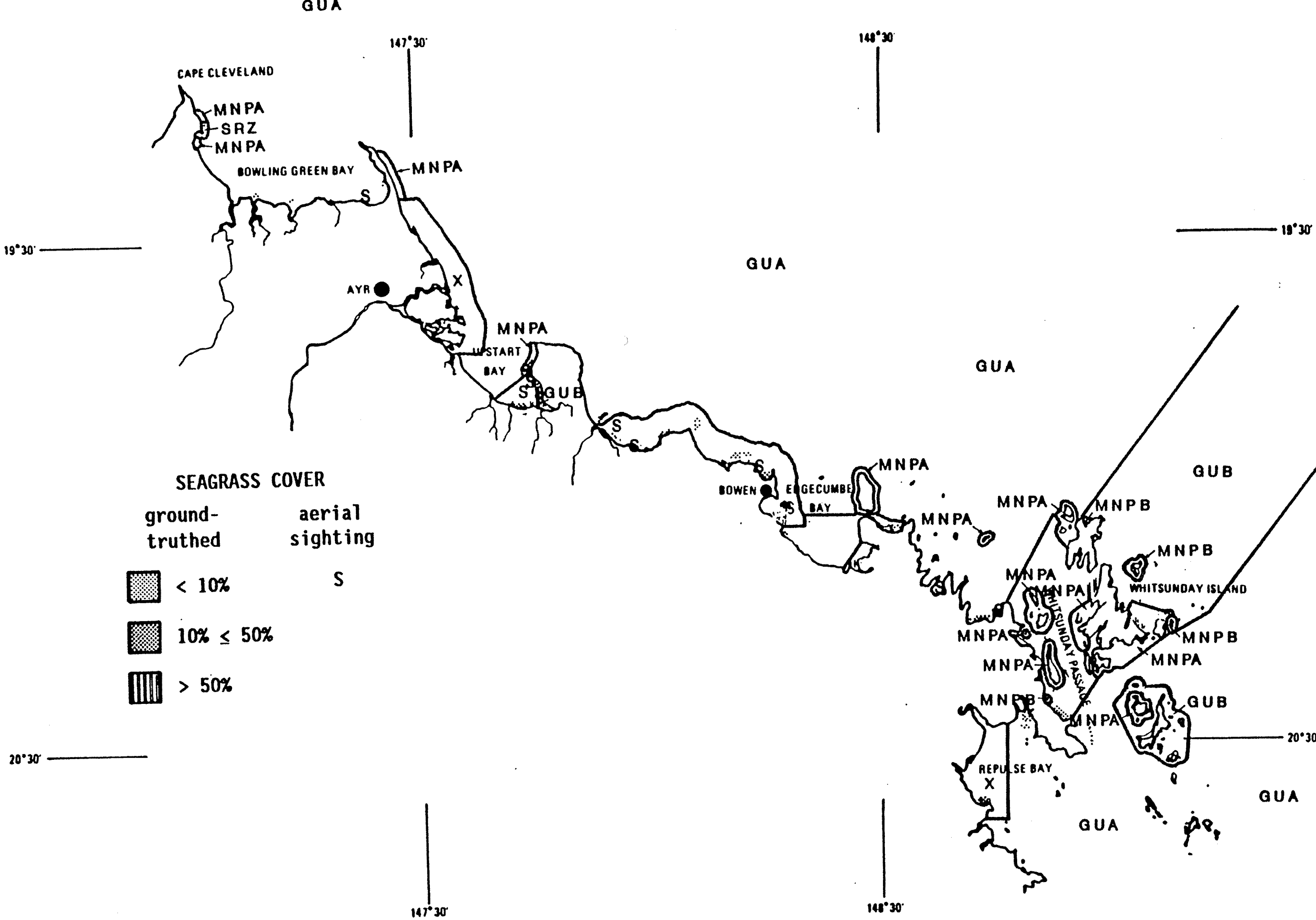

Figure 17: The distribution of known seagrass beds in the survey area from Cape Cleveland to Repulse Bay with the GBRMPA zoning plan for the area. The ground-truthed seagrass data are from Dr. R. *Coles*, pers. comm. (1988).

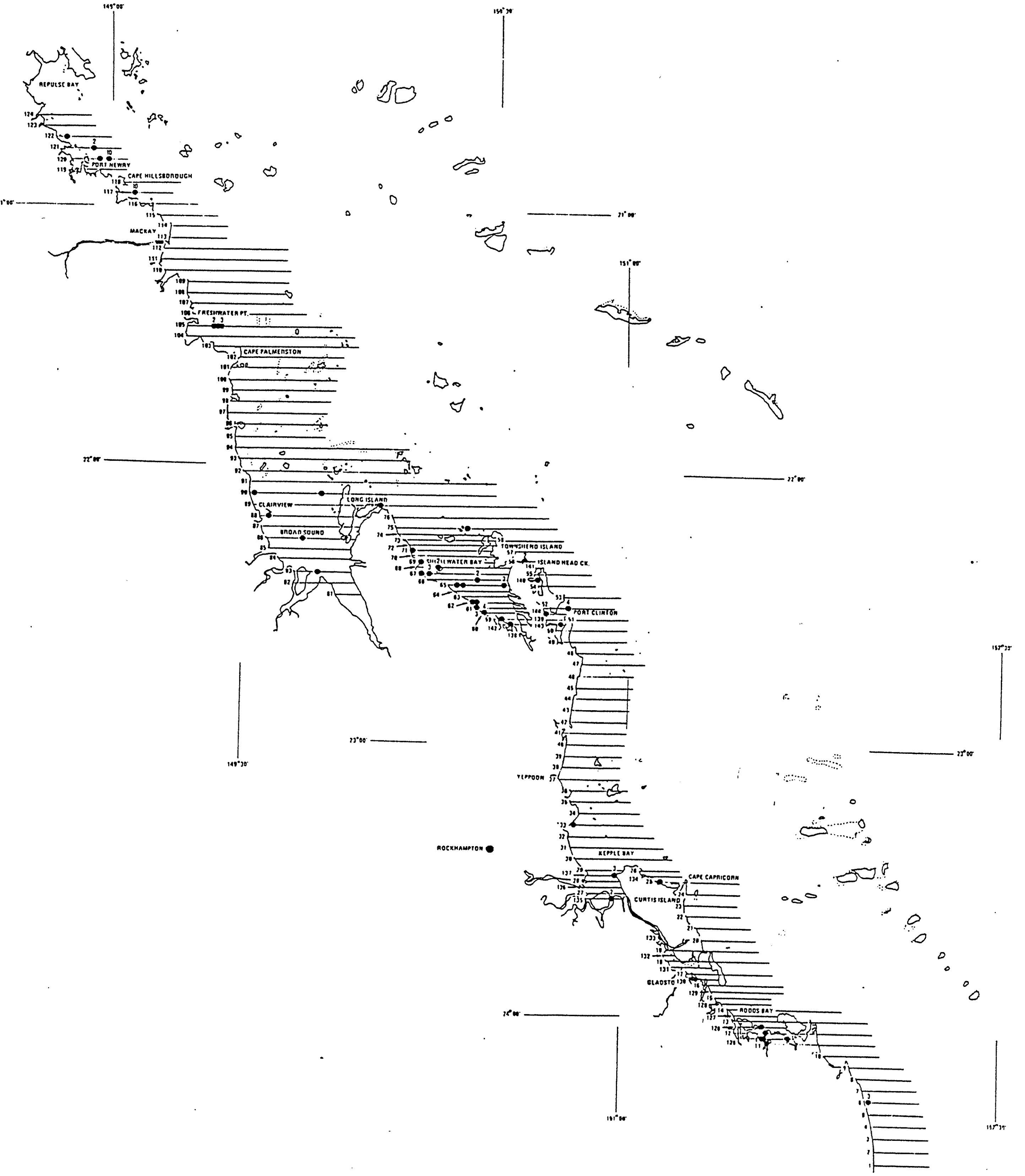

Figure 18: The survey area from Repulse Bay to Bustard Head showing the numbers and positions of the transects and dugong sightings in November 1986. The numbers associated with the sightings do not necessarily reflect the sizes of the actual groupings observed.

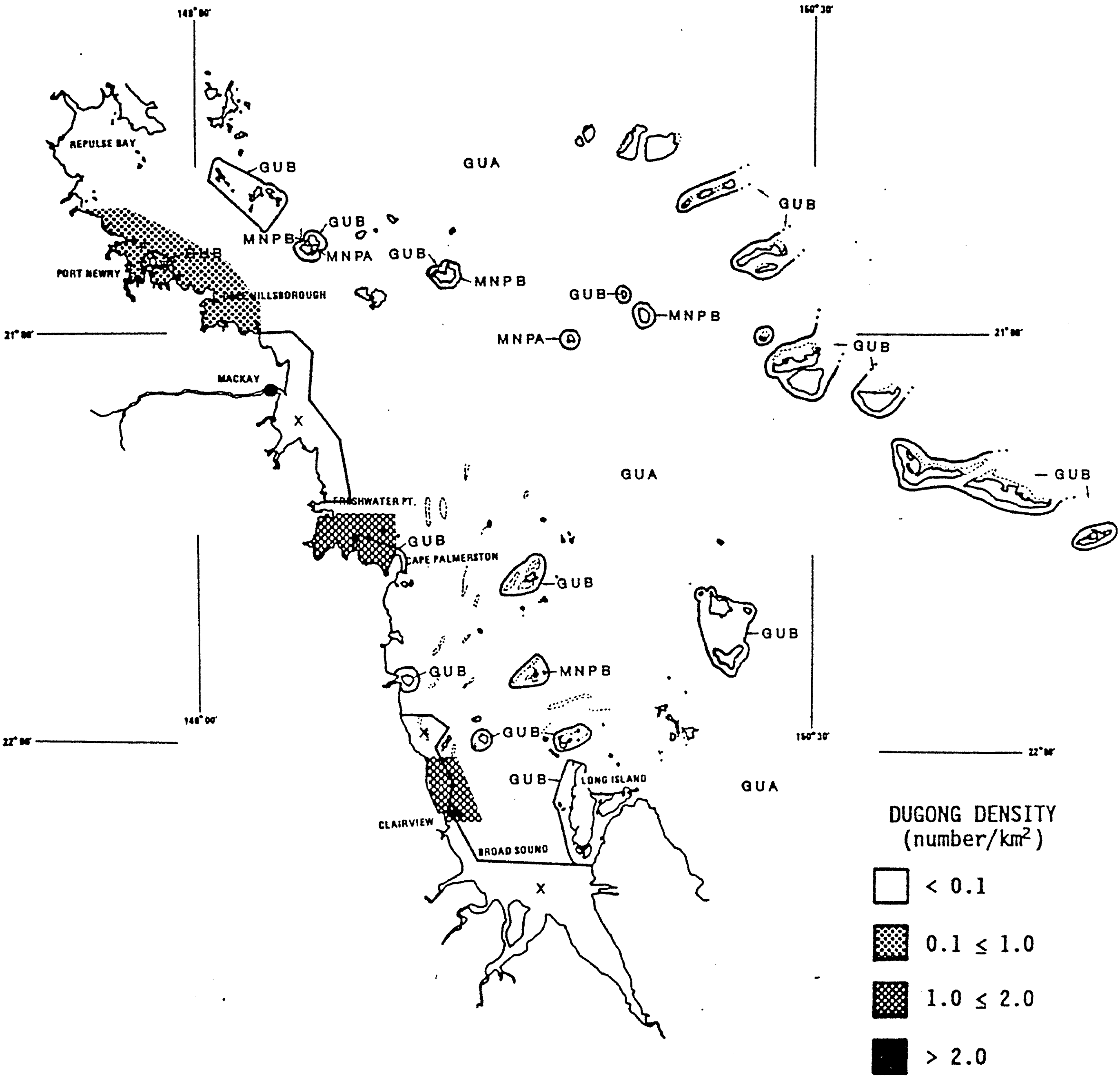

Figure 19: The distribution of dugong density in the survey area from Repulse Bay to Shoalwater Bay in November 1986 .

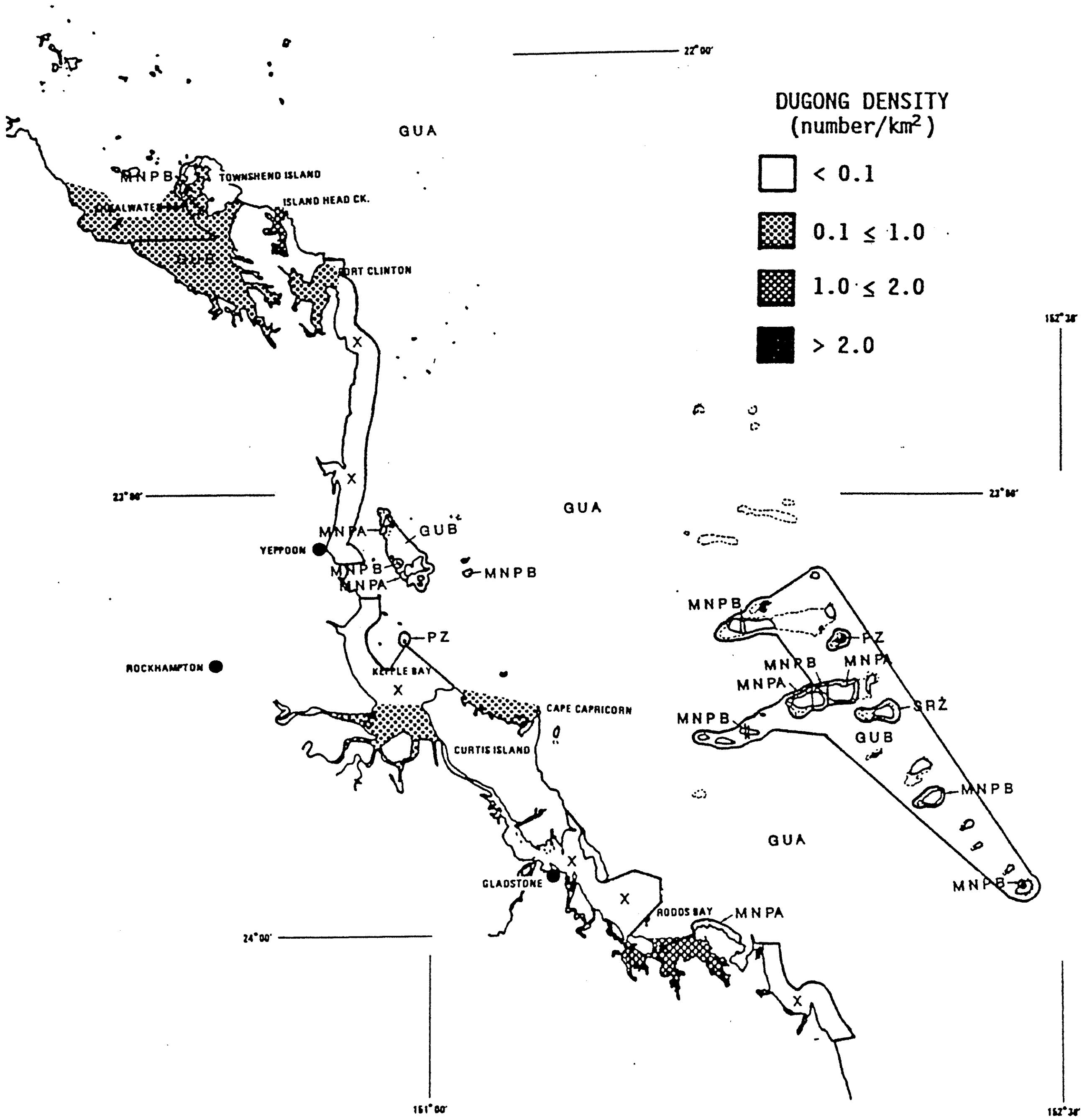

Figure 20: The distribution of dugong density in the survey area from Shoalwater Bay to Bustard Head in November 1986 .

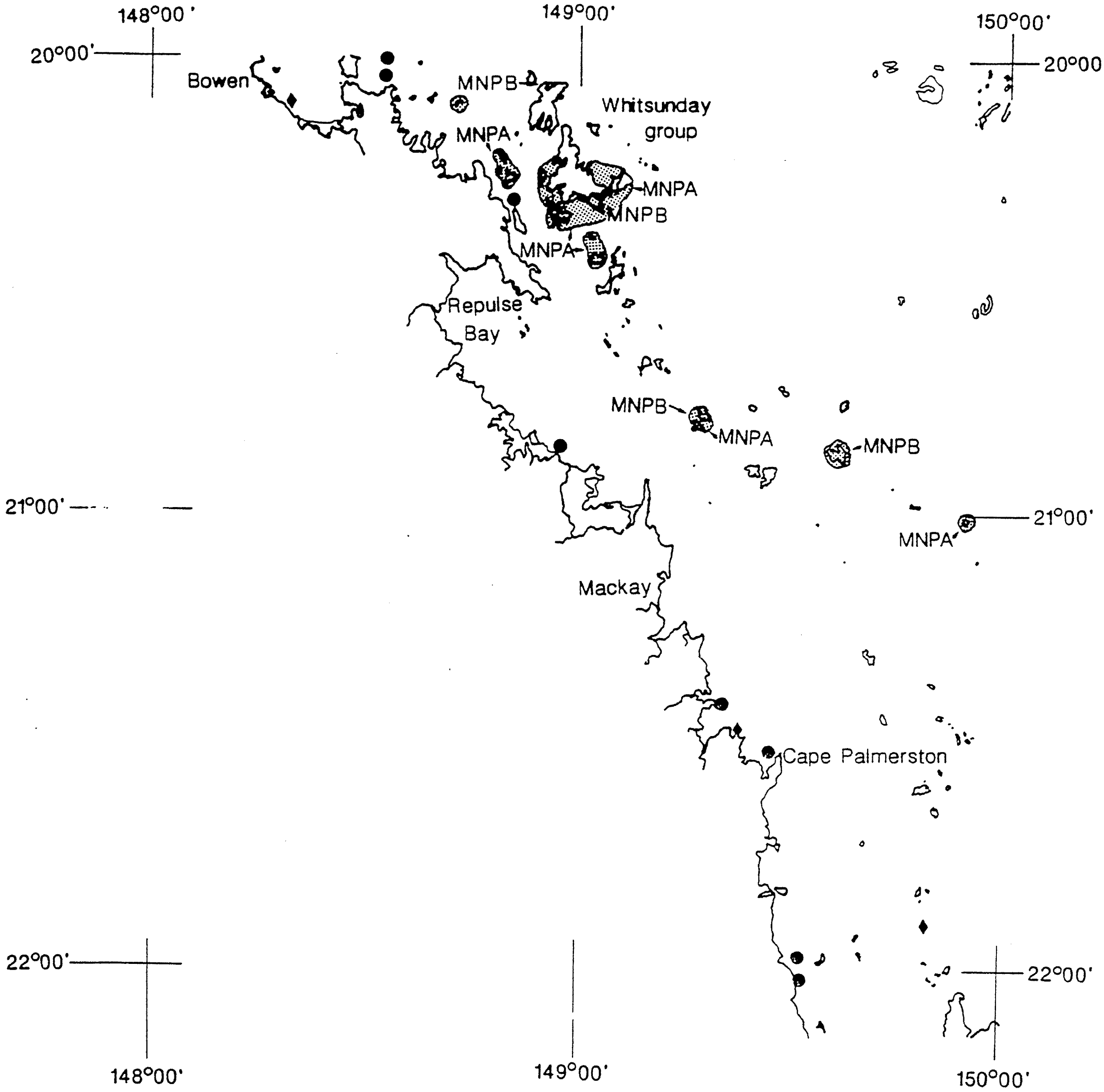

Figure 21: Incidental dugong sightings between Bowen and Townshend Island in relation to areas protected by MNPA zoning or above.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

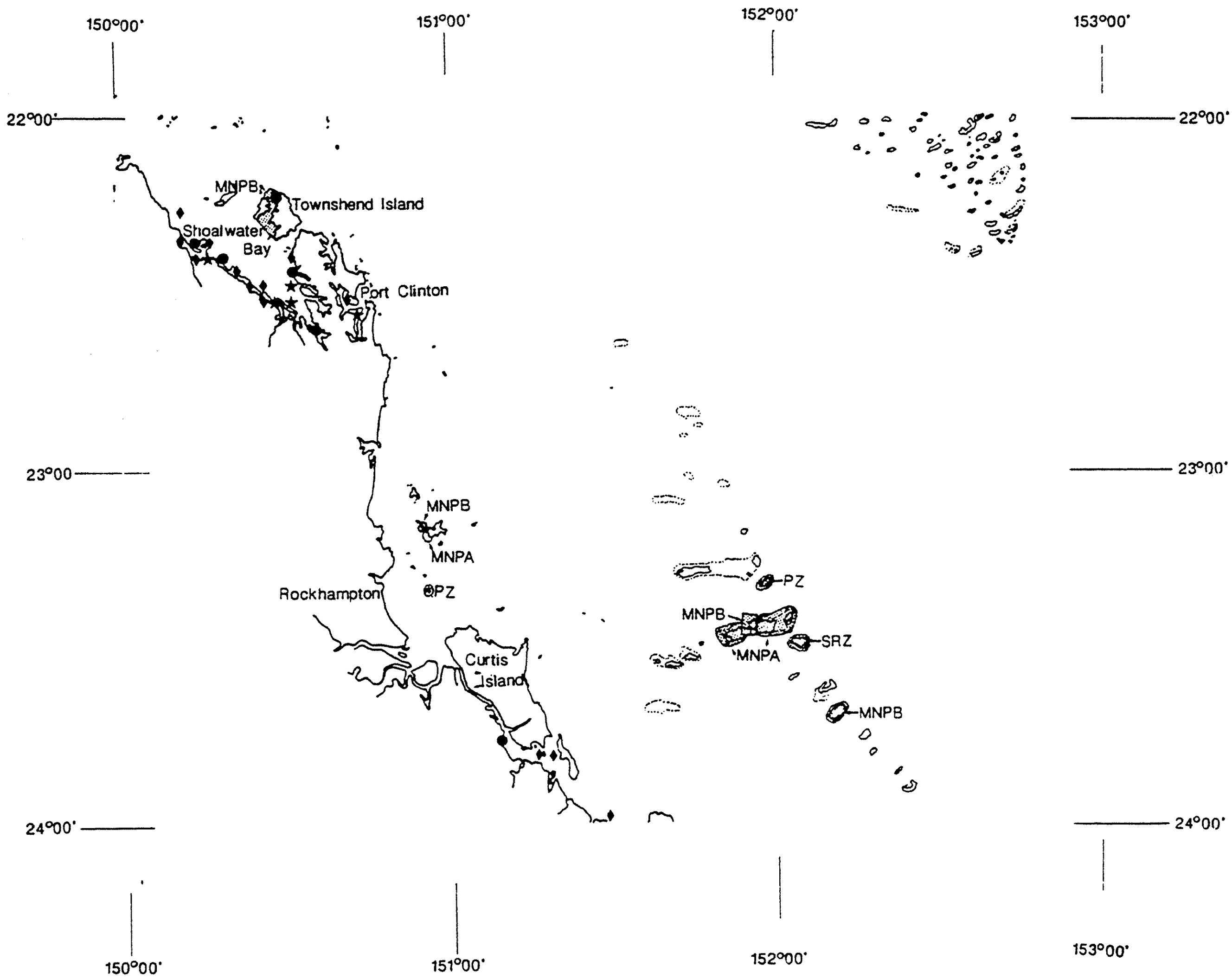

Figure 22: Incidental dugong sightings between Townshend Island and Curtis Island in relation to areas protected by MNPA zoning or above.

● One to five dugongs sighted on one date only

♦ One to five dugongs seen on more than one occasion or between six and twenty dugongs seen on at least one occasion

★ More than twenty dugongs sighted at least once

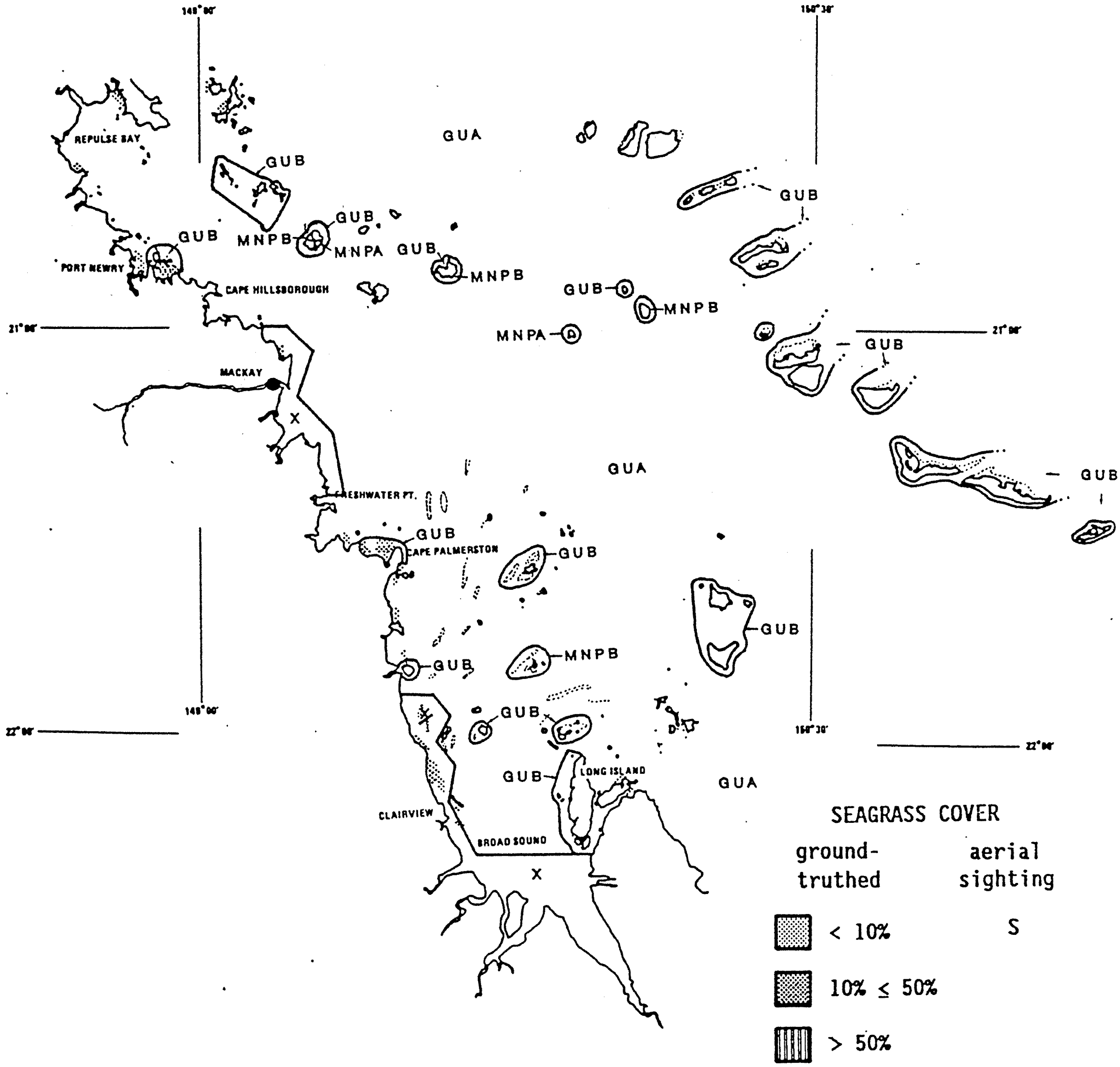

Figure 23: The distribution of known seagrass beds in the survey area from Repulse Bay to Shoalwater Bay in relation to the Great Barrier Reef Marine Park Authority Zoning Plan. The ground-truthed seagrass data are from Coles *et al.*, (1987).

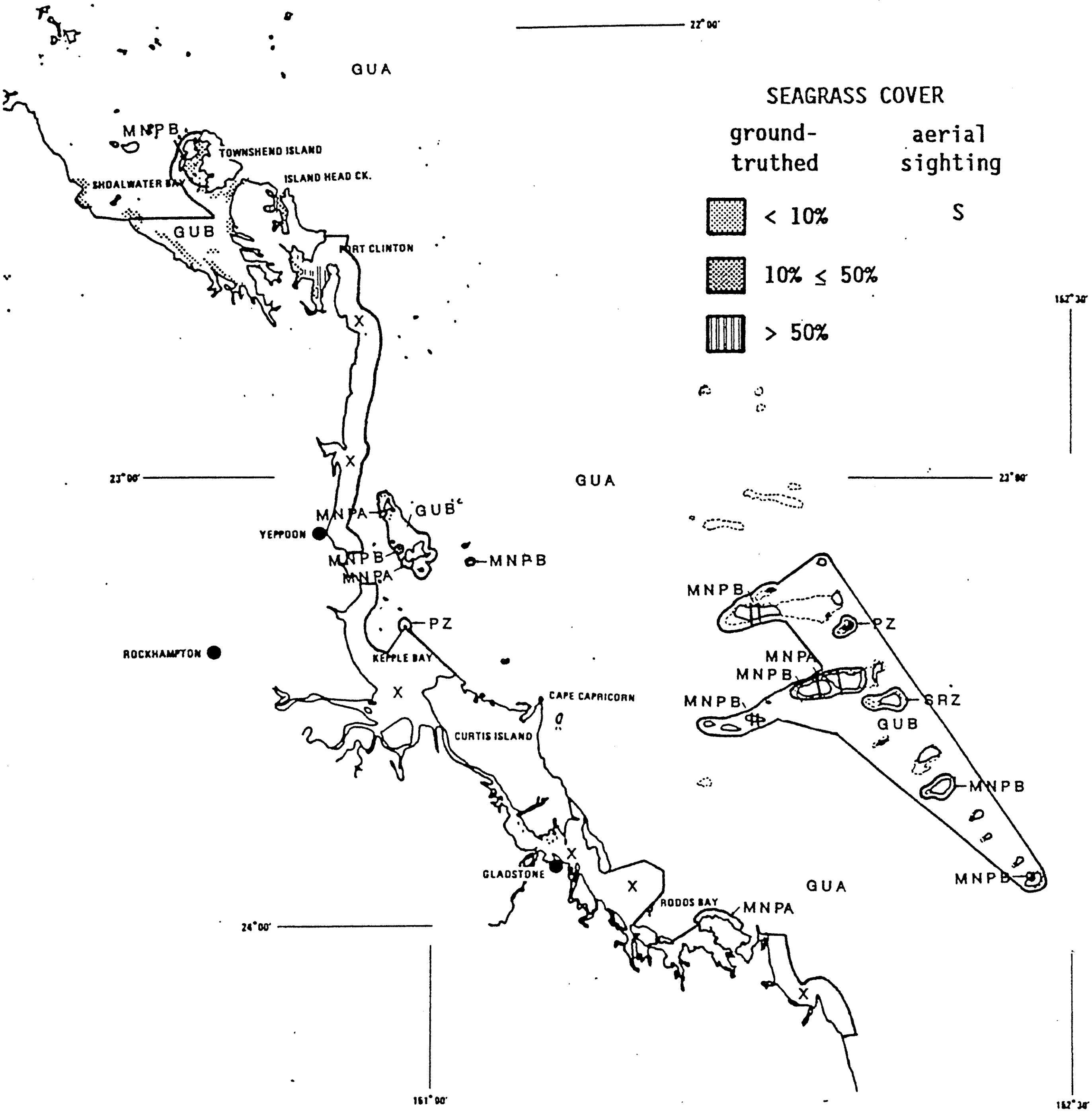

Figure 24: The distribution of known seagrass beds in the survey area from Shoalwater Bay to Bustard Head in relation to the Great Barrier Reef Marine Park Authority Zoning Plan. The ground-truthed seagrass data are from Coles *et al.*, (1987).

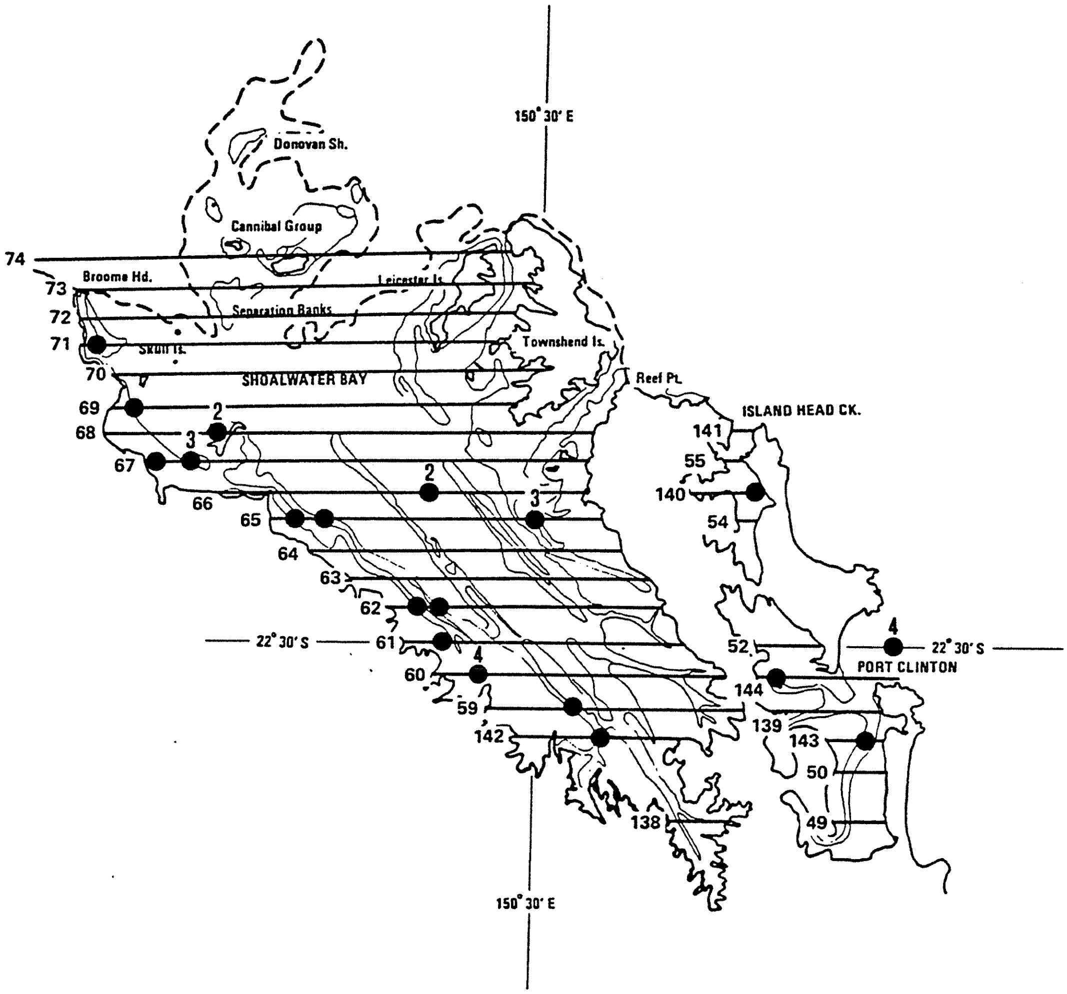

Figure 25: The Shoalwater Bay area showing the numbers and positions of the intensive transects and dugong sightings in November 1986. The numbers associated with the sightings do no necessarily reflect the sizes of the actual groupings observed.

SECTION 3

Turtle sightings and density distribution maps in the Great Barrier Reef Marine Park from the tip of Cape York south to Cape Bedford

Figure 9: The survey area from Cape Melville to Cape Bedford showing the numbers and positions of transects and turtle sightings in November 1984.

Figure 10: The survey area from Cape Melville to Cape Bedford showing the numbers and positions of transects and turtle sightings in November 1985.

Figure 11: The distribution of turtle density in the survey area from Cape Melville to Cape Bedford in November 1985 with the GBRMPA zoning plan for this area.

Figure 12: The Starcke River survey area showing the numbers and positions of the intensive transects and the turtle sightings in November 1985, in relation to the distribution of seagrass.

Section 3: Turtle sightings and density distribution maps in the Great Barrier Reef Marine Park from the tip of Cape York south to Cape Bedford.

Reference:

Coles, R.G., Lee Long, W.J., and Squire, L.C. (1985) Areas of seagrass beds and prawn nursery grounds on the Queensland coast between Cape York and Cairns. Queensland Department of Primary Industries Information Series Q185017.

Key to Great Barrier Reef Marine Park Zones:

GUA - General Use 'A' Zone

GUB - General Use 'B' Zone

MNPA - Marine National Park 'A' Zone

MNPB - Marine National Park 'B' Zone

SRZ - Scientific Research Zone

PZ - Preservation Zone

X - excluded from the GBRMP

Note: the zones drawn on the overlays and maps following are based on the Great Barrier Reef Marine Park Authority's Zoning Information releases and are approximate only.

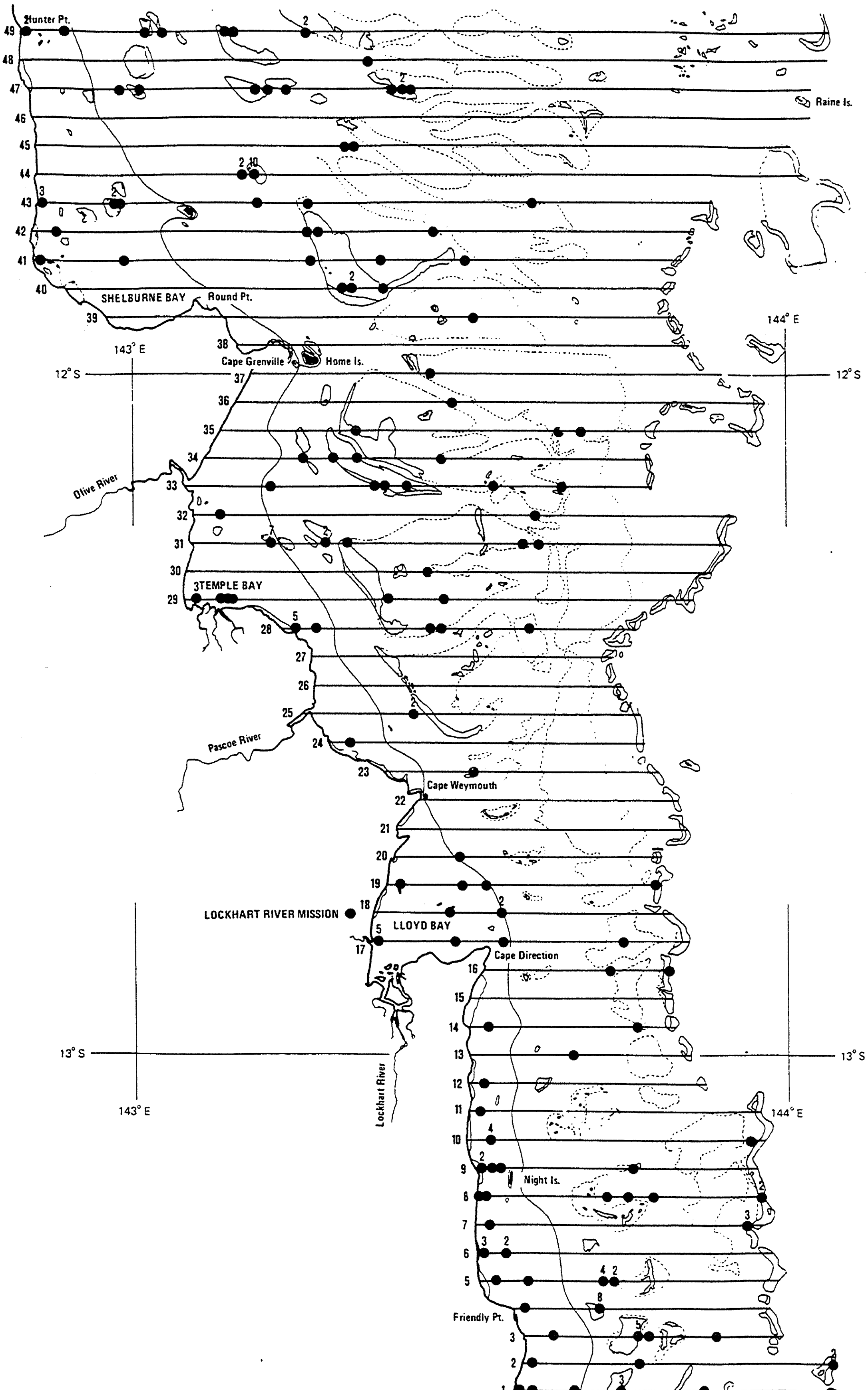

Figure 1: The survey area from Hunter Point to Campbell Point showing the numbers and positions of the transects and turtle sightings in April 1985.

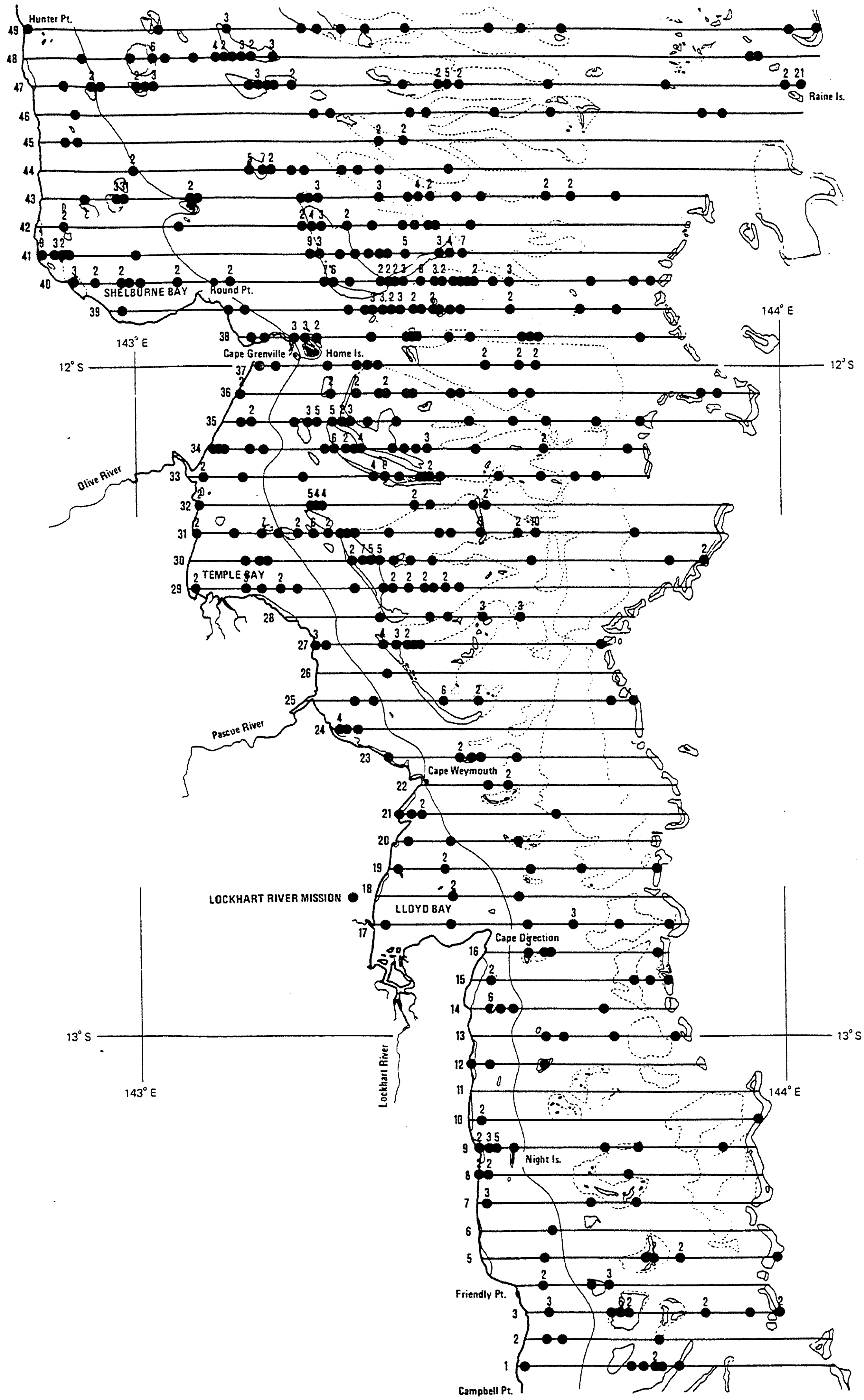

Figure 2: The survey area from Hunter Point to Campbell Point showing the numbers and positions of the transects and turtle sightings in November 1985.

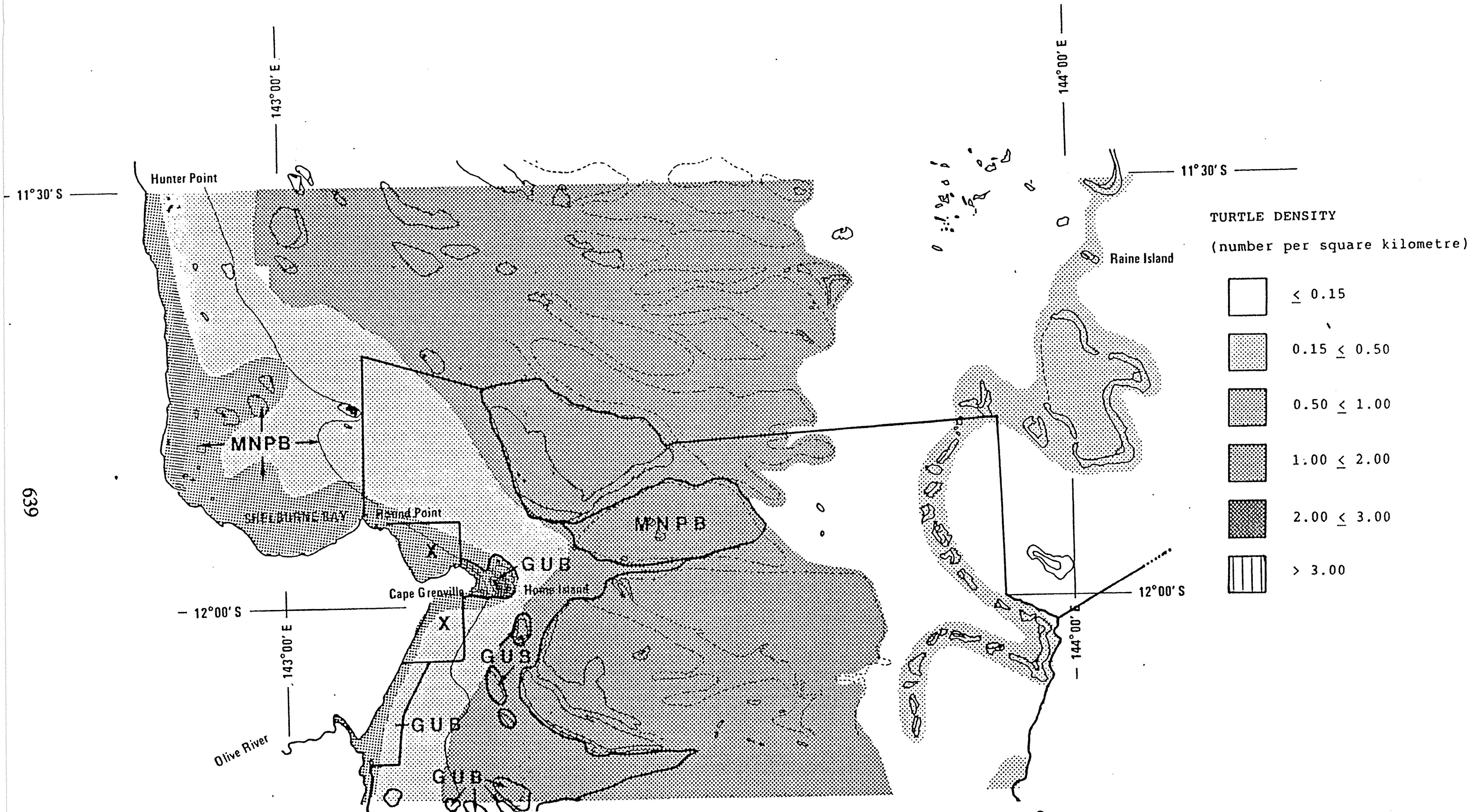

Figure 3: The distribution of turtle density in the survey area from Hunter Point to the mouth of the Olive River in November 1985 with the GBRMPA zoning plan for this area.

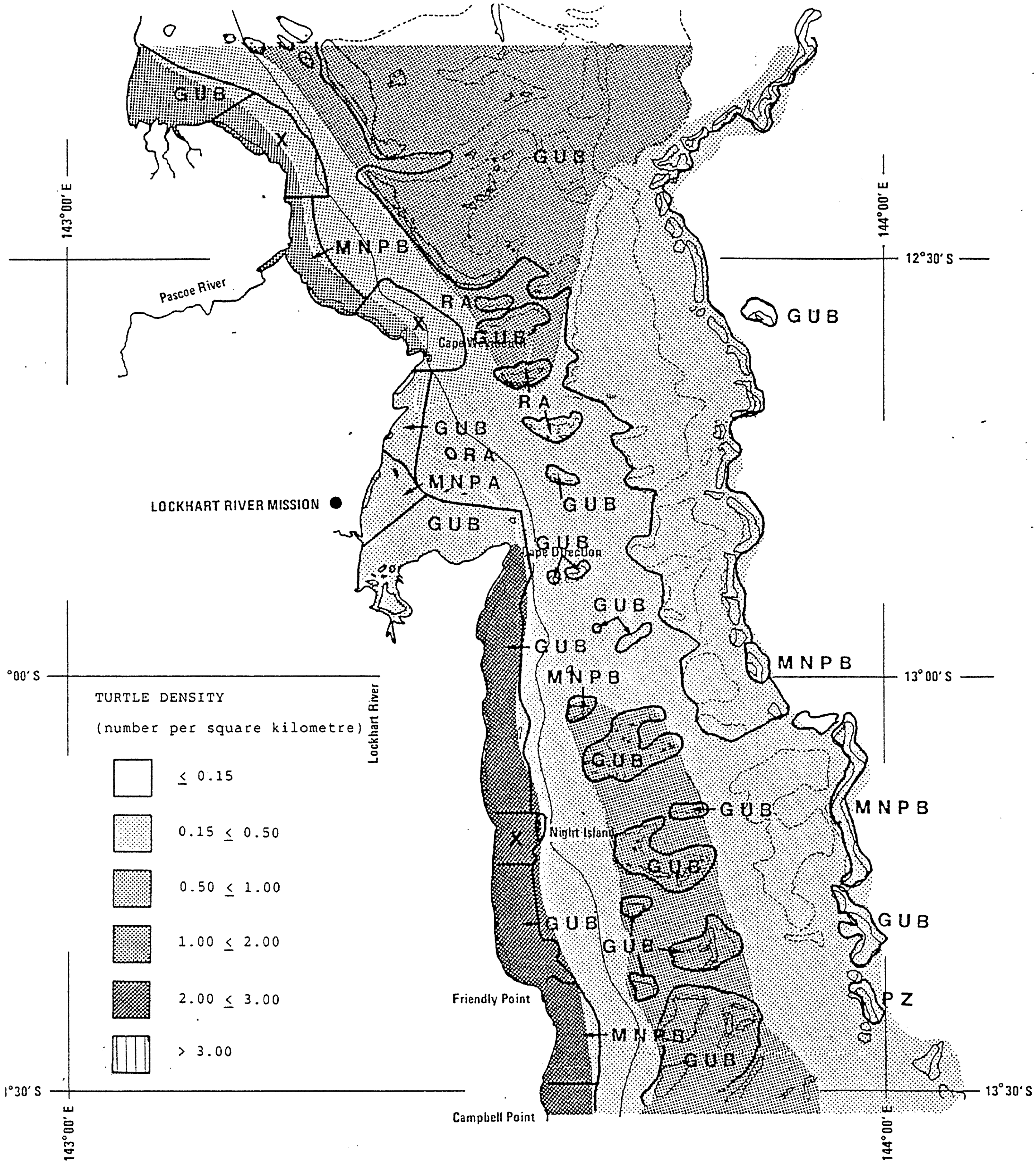

Figure 4: The distribution of turtle density in the survey area from the mouth of the Olive River to Campbell Point in November 1985 with the GBRMPA zoning plan for this area.

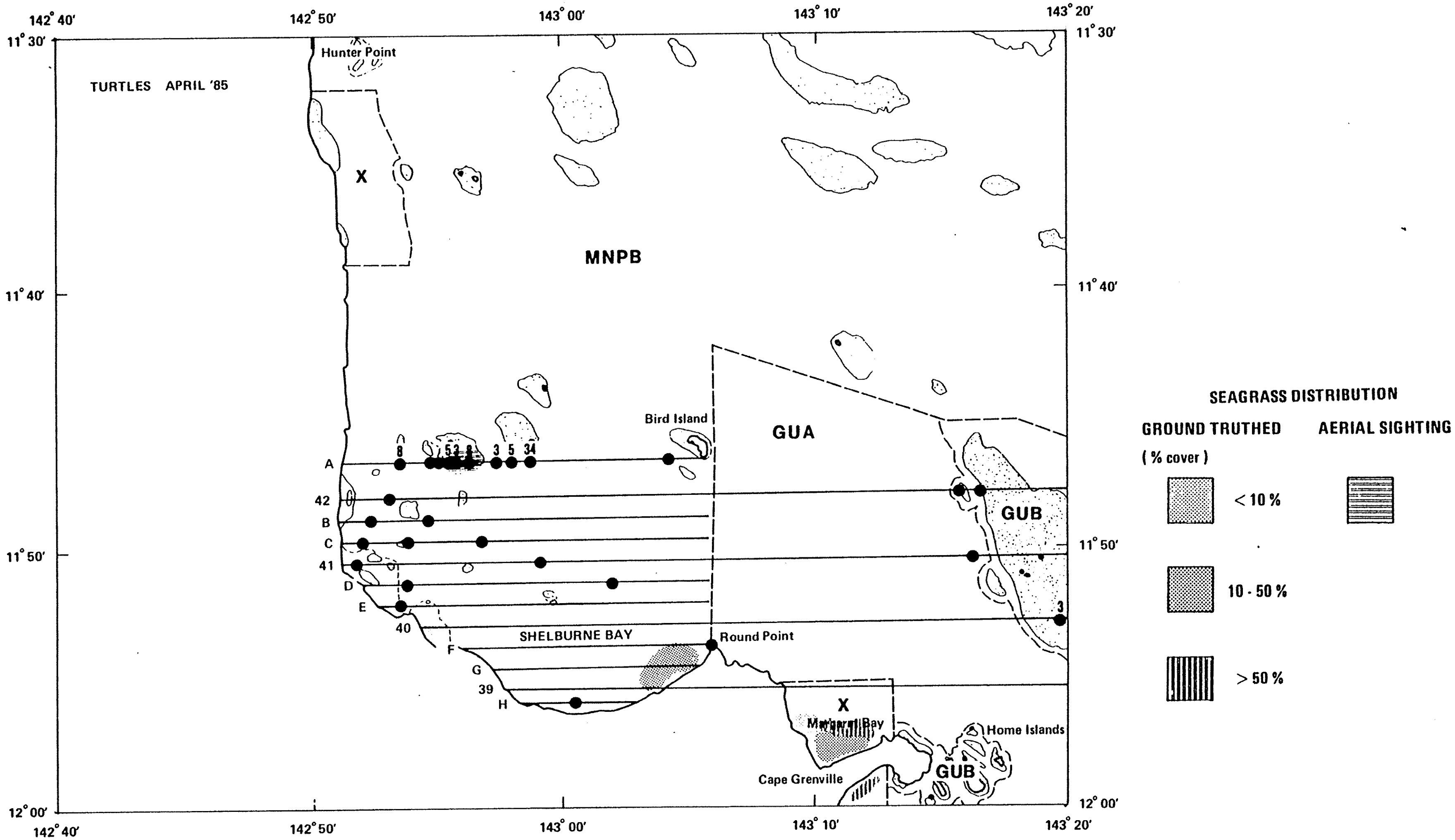

Figure 5: The Shelburne Bay survey area showing the numbers and positions of the intensive transects and turtle sightings in April 1985, in relation to the distribution of seagrass.

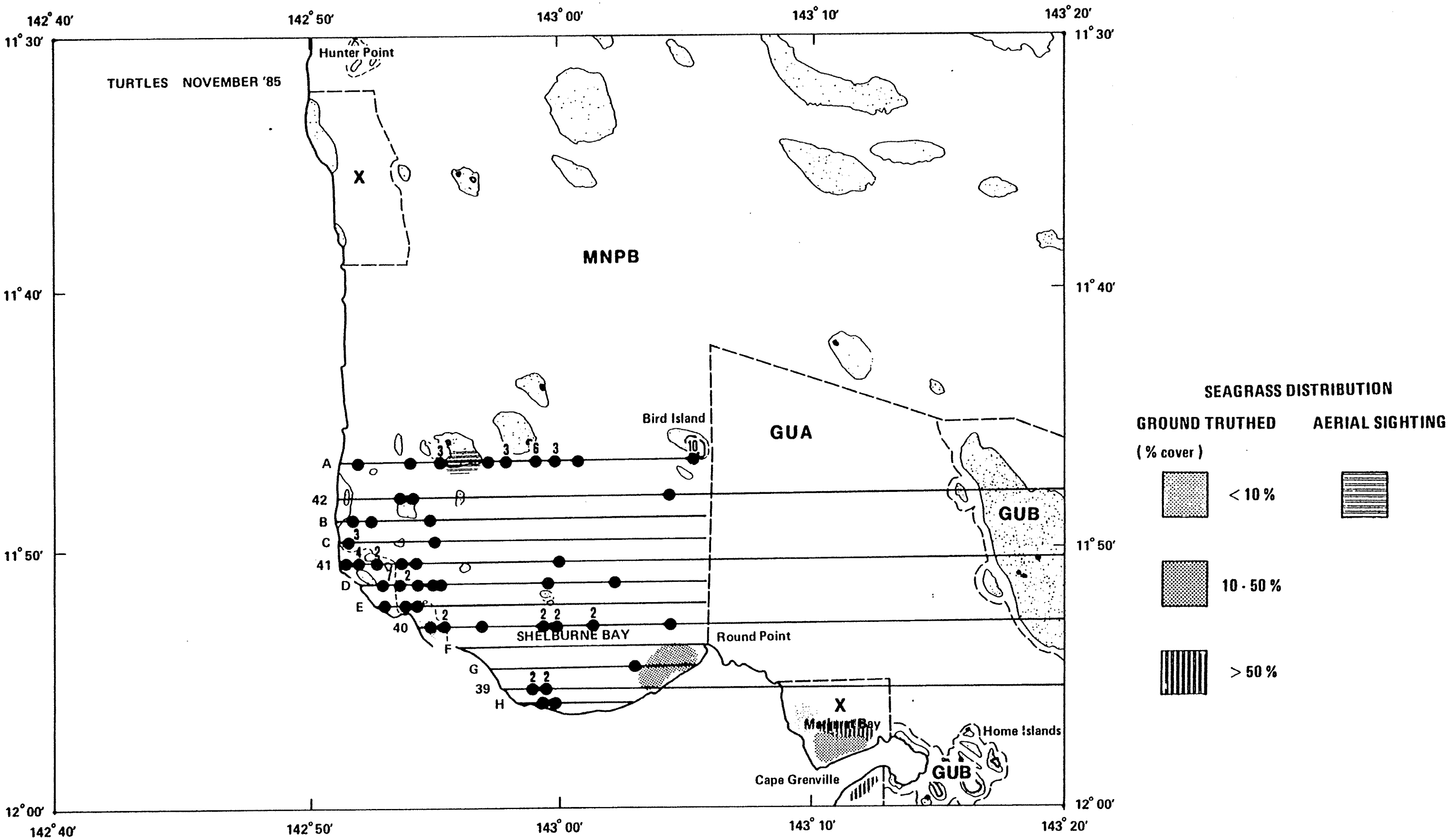

Figure 6: The Shelburne Bay survey area showing the numbers and positions of the intensive transects and turtle sightings in November 1985, in relation to the distribution of seagrass.

Figure 7: The survey area from Campbell Point to Cape Melville (Princess Charlotte Bay) showing the numbers and positions of transects and turtle sightings in November 1985.

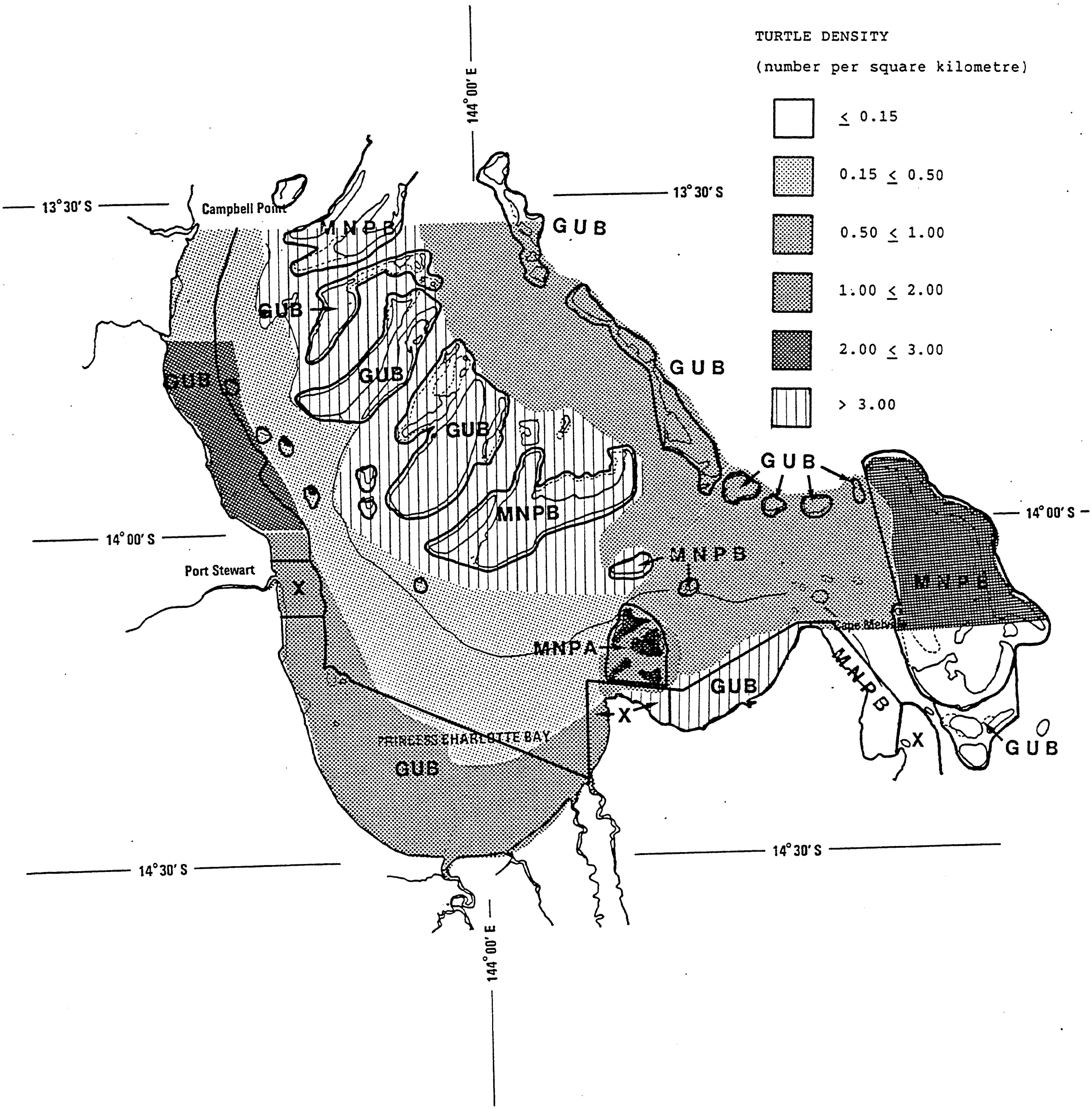

Figure 8: The distribution of turtle density in the survey area from Campbell Point to Cape Melville (Princess Charlotte Bay) in November 1985 with the GBRMPA zoning plan for this area.

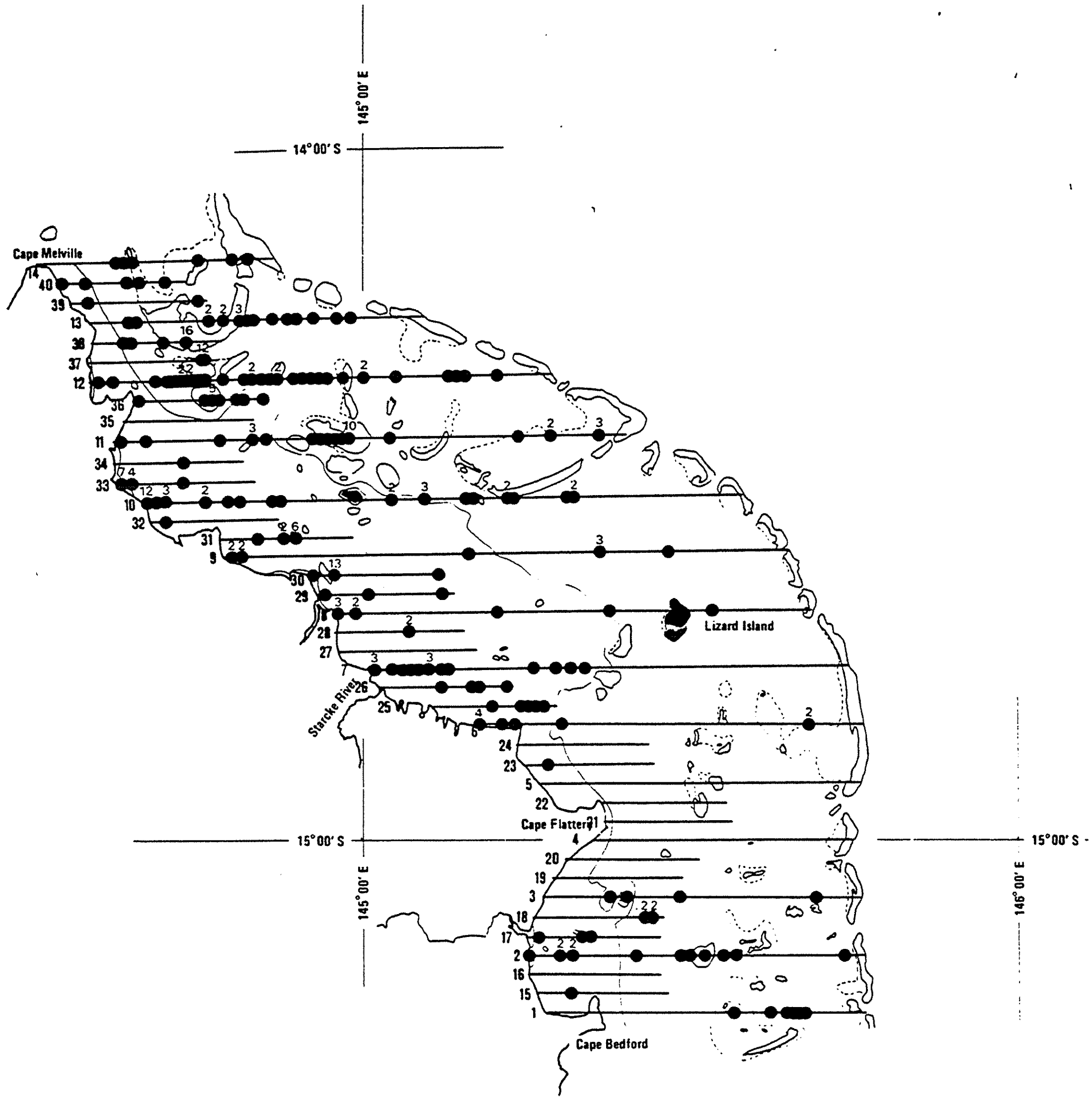

Figure 9: The survey area from Cape Melville to Cape Bedford showing the numbers and positions of transects and turtle sightings in November 1984.

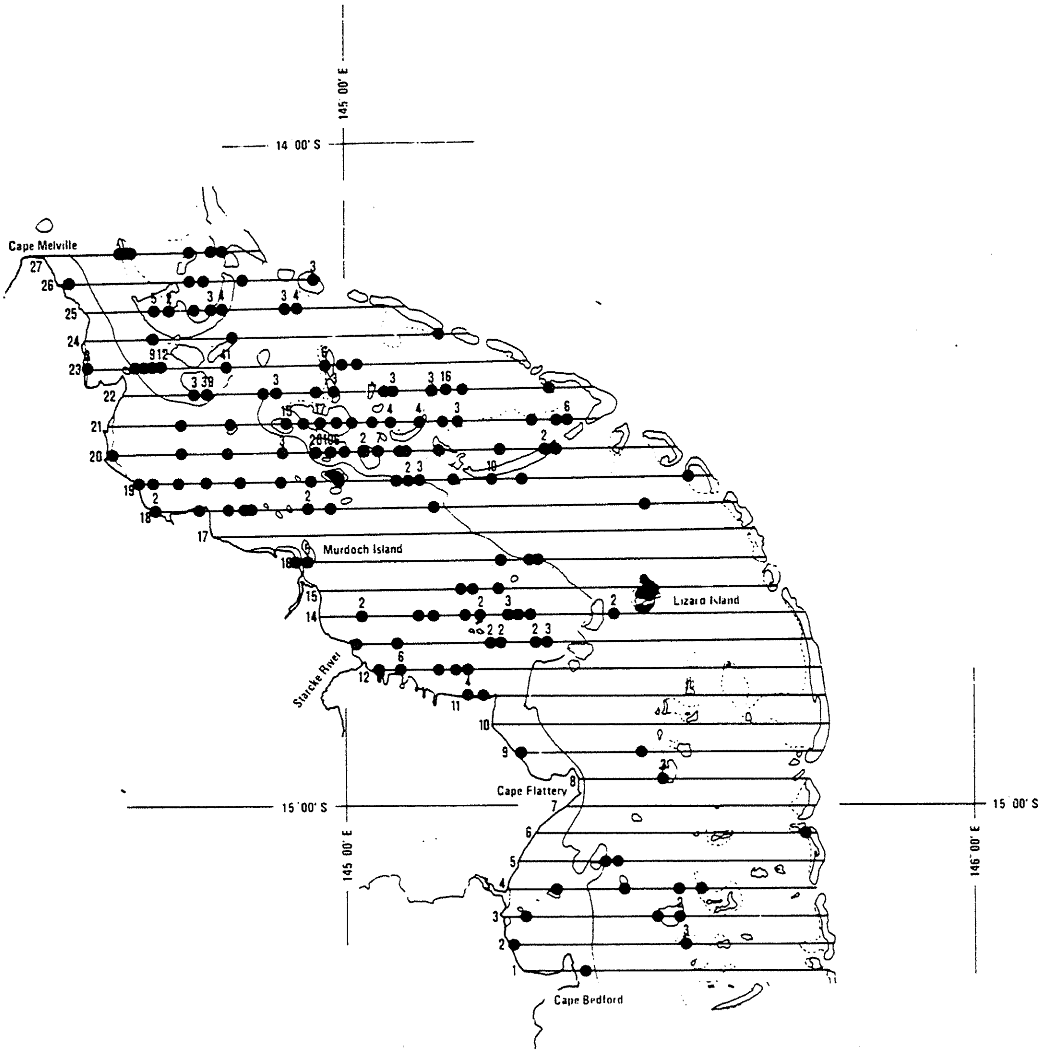

Figure 10: The survey area from Cape Melville to Cape Bedford showing the numbers and positions of transects and turtle sightings in November 1985.

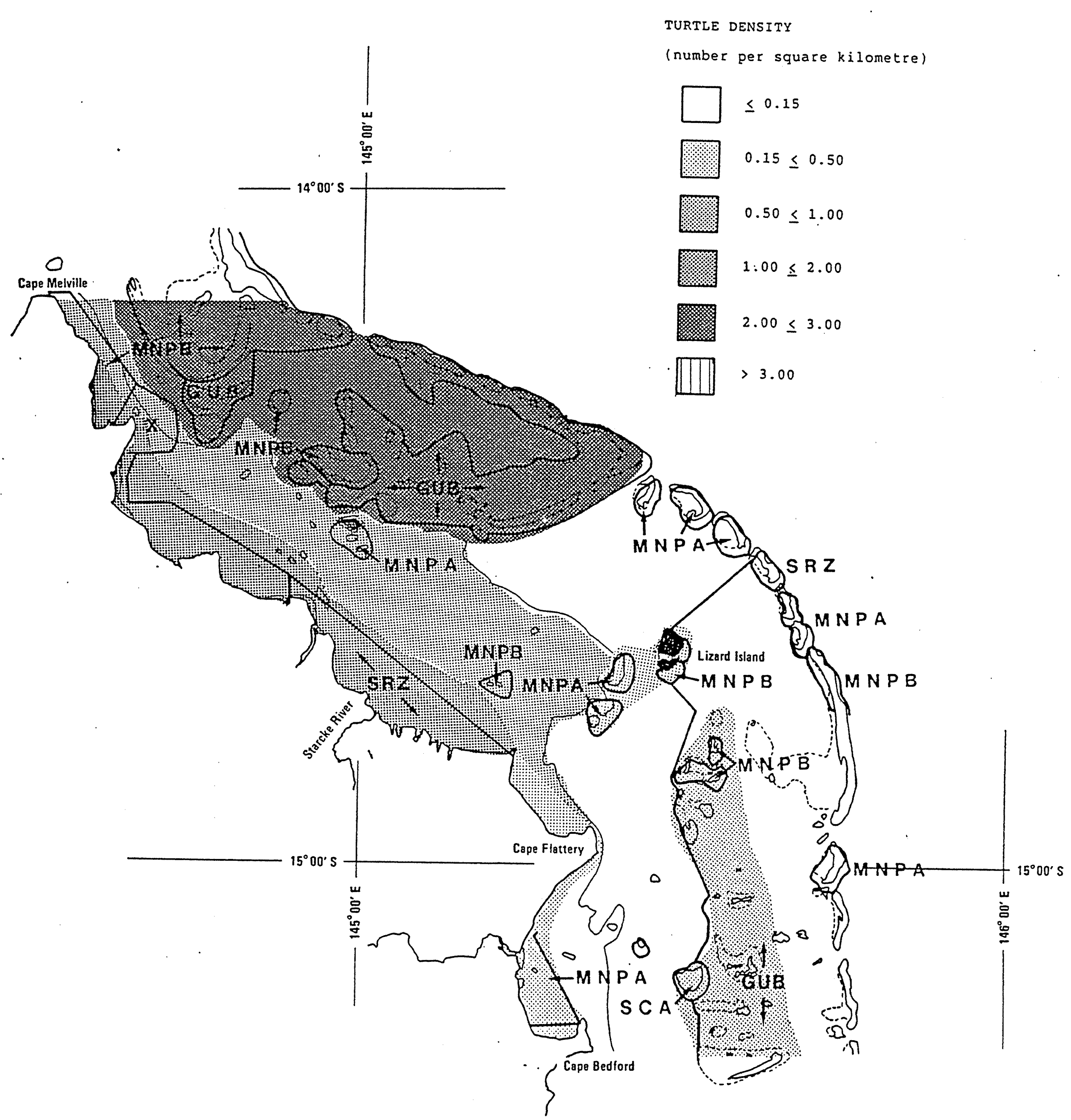

Figure 11: The distribution of turtle density in the survey area from Cape Melville to Cape Bedford in November 1985 with the GBRMPA zoning plan for this area.

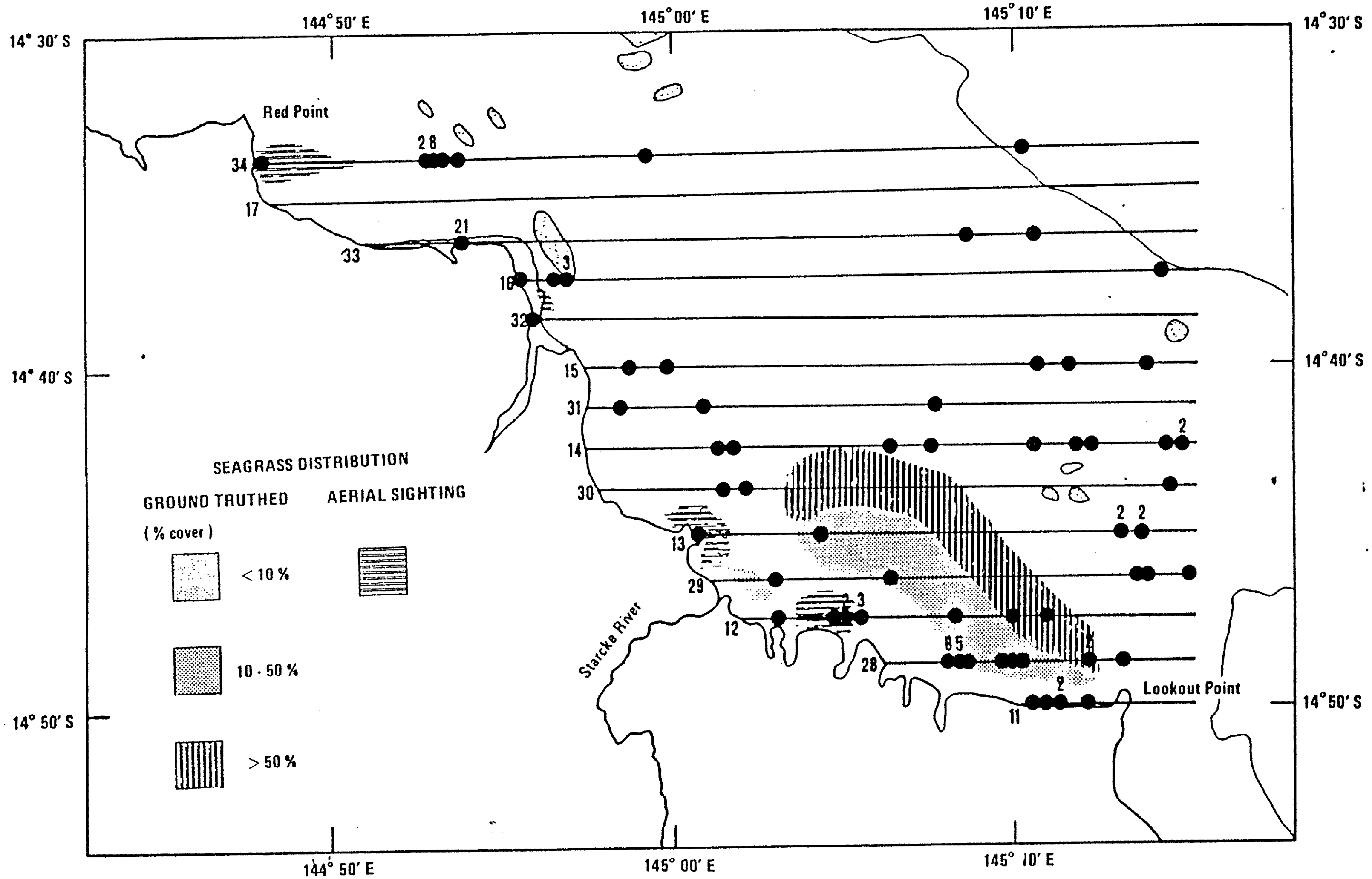

Figure 12: The Starcke River survey area showing the numbers and positions of the intensive transects and the turtle sightings in November 1985, in relation to the distribution of seagrass.