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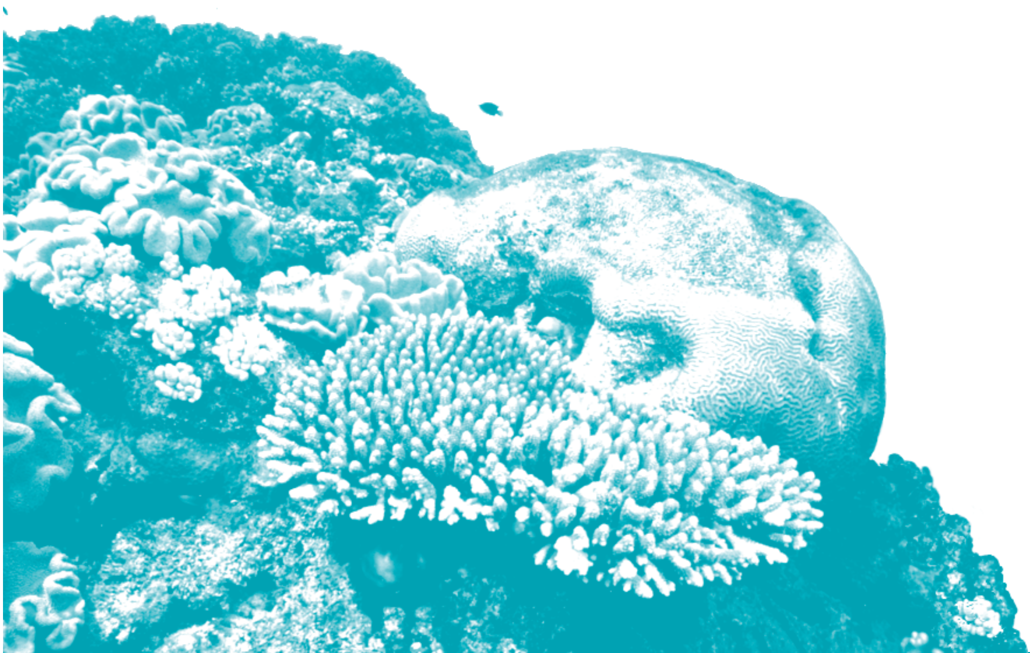

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SUMMARY

The waters of northern Australia are internationally recognised as the stronghold of the dugong (*Dugong dugon*) which is listed as vulnerable to extinction by the IUCN (2000). Significant populations persist in Australian waters, and dugongs are specifically cited as one of the World Heritage values of the Great Barrier Reef World Heritage Area. Much of the information used to manage dugong populations in this region has been provided by aerial surveys using standardised techniques. We report here on aerial surveys conducted in the following regions in November 2000 to assess the status of the dugong:

(1) the Northern Great Barrier Reef Region between Hunter Point (11°15'S — south of Cape York) and Cape Bedford (15°30'S — near Cooktown); and,
(2) the region between Cape Bedford and 17°25'S (near Innisfail).

Northern Great Barrier Reef Region

The estimated size of the dugong population for this region in 2000 was 9081 dugongs (± s.e. 917). Statistical comparison of this result with those from previous surveys indicates that overall dugong numbers in the region are stable at the scale of the region as a whole. The survey technique is designed to detect regional scale trends and cannot accurately detect changes at a local scale even if they are occurring.

The dugongs were distributed differently from previous surveys. The surveys in 1985, 1990 and 1995 indicated that Princess Charlotte Bay supported between 37% and 56% of dugongs in the northern GBR region. The corresponding proportion for 2000 was 24.5%. At the same time, the area south of Cape Melville supported 59% of the dugongs in the region, a proportion about twice as high as the percentages of between 25% and 32% in 1985, 1990 and 1995.

The results of the 2000 survey add to a growing body of evidence from aerial surveys and satellite tracking that dugongs undertake large-scale movements. The reasons for such large-scale movements are not generally known, but at least sometimes appear to be associated with disturbance to their seagrass habitat. In some instances, large-scale movements are associated with large-scale episodic disturbance to habitat caused by cyclones and floods.

The distribution and abundance of dugongs has influenced the placement of highly protected areas within this region. Great Barrier Reef Marine Park (GBRMP) zoning protects dugongs in the coastal waters of Shelburne Bay, the Friendly Point region, Corbett Reef and much of the region between Cape Melville and Lookout Point from extractive activities, especially fishing impacts including incidental capture in commercial gill nets and habitat damage from trawling. Such protection has been enhanced by the rezoned Far Northern Section of the Great Barrier Reef Marine Park, which provides increased protection for dugong and their habitats in Temple Bay, the Cape Direction region, parts of Princess Charlotte Bay and Bathurst Bay.

Nonetheless, dugongs and dugong habitats are not specifically protected in intertidal areas in the Northern Great Barrier Reef Region that are outside the Great Barrier Reef Marine Park. The planned introduction of zoning which complements that introduced as

a result of the rezoning of the Far Northern Section of the Great Barrier Reef Marine Park and the review of fisheries' management arrangements by the Queensland Government, will help ensure threats to dugong in this region are minimised.

The potential biological removal method was used to estimate sustainable anthropogenic mortality from all causes for a range of estimates of dugong life history parameters based on empirical data from various wild populations using values of both 0.5 and 1 for the recovery factor. The justification for using a recovery factor of 1 was that the temporal series of aerial surveys suggests that population numbers are stable at a regional scale. We also used a recovery factor of 0.5 because the dugong is listed as a threatened species in Queensland and the default value is 0.5 for such stocks. The middle value for the maximum rate of increase R max (=0.03) suggests that the following total annual anthropogenic mortalities should be sustainable:

- for the whole NGBR region: 63 dugongs (RF= 0.5); 125 dugongs (RF=1) for Blocks 1-4;
- the region south to Cape Bedford based on the population's distribution in 2000: 36 dugongs (RF= 0.5); 72 dugongs (RF=1) for Blocks 1-4; and
- the region south to Cape Bedford based on the population distribution in 1995 (worst case scenario): 13 dugongs (RF= 0.5); 26 dugongs (RF=1).

Given that the population estimates in this report are relative estimates, these estimates of sustainable anthropogenic mortality should be revised when absolute population estimates become available.

Cape Bedford to 17°25'S

The survey was extended south from Cape Bedford to 17°25'S, between Cairns and Innisfail. Poor weather had prevented us from surveying this region as scheduled in 1999 as part of a survey of the Southern Great Barrier Reef (southern GBR). Unsuitable weather once again prevented us extending this survey to be contiguous with the northern boundary of the 1999 survey of the southern Great Barrier Reef region. However, the gap between the two surveys (17°25'S to 17°45'S) was only 35km so that we surveyed 87% of the planned survey area between Cooktown and the northern boundary of the 1999 survey.

The number of dugongs sighted south of Cooktown was too low to calculate a population estimate for this region, a result similar to those obtained in 1987 and 1992.

This inability to calculate a population estimate for this region made it impossible to estimate a sustainable level of human-induced mortality. Marine Park zoning currently provides little protection of dugong habitats in the region between Cape Bedford and Innisfail.

Options For Management

Northern Great Barrier Reef Region

Optimisation and Recognition of Measures to Protect Dugongs

We suggest that consideration be given to extending the seaward boundary of the highly protected zones between Cape Melville and Lookout Point and the northern boundary of the National Park Zone around Friendly Point when this region is rezoned again as part of the Representative Area Program.

We suggest that the Queensland Government should introduce zoning above mean low water mark (for which it has jurisdication) which compliments the zones in the Far Northern Section of the Great Barrier Reef Marine Park. The introduction of such zoning is essential to adequately protect of dugong and dugong habitats in the Northern Great Barrier Reef Region.

We suggest that Great Barrier Reef Marine Park Authority (GBRMPA) and the Queensland Parks and Wildlife Service (QPWS) negotiate with the Queensland Fisheries Service and local Aboriginal communities with a view to improving the protection of dugongs from drowning in mesh nets set in the intertidal reaches of rivers and creeks and in coastal intertidal areas.

We suggest that, in view of the generally high level of protection given to dugongs in the northern GBRMP, especially under the Far North Section Zoning Plan, GBRMPA consider producing public education material outlining the protection given to dugongs throughout the GBR World Heritage Area. To date such material has featured the southern GBR region.

Cape Bedford to 17°25’S

Protected Areas for Dugong Conservation

We suggest that GBRMPA should consider the following through the Representative Areas Program:

(1) improving the protection of seagrass habitats in this region;
(2) establishing a highly protected area in the Port Douglas region.

Management of Dugong Mortality

In view of the low numbers of dugongs sighted in this region, all sources of dugong mortality should be minimised. In particular, we suggest that GBRMPA and QPWS negotiate with Yarrabah community with a view to developing protocols for minimising the risk of capturing dugongs in the mesh net fishery operated by the community in adjacent Mission Bay.

INTRODUCTION

The waters of northern Australia are internationally recognised as the stronghold of the dugong (*Dugong dugon*). As the only surviving member of the family Dugongidae (Marsh et al. 1999), the dugong is a species of high biodiversity value. The dugong is listed as vulnerable to extinction by the IUCN (2000), along with the other three species in the order Sirenia, the manatees (family Trichechidae). Anecdotal evidence suggests that dugong numbers have decreased dramatically throughout most of their range (Marsh et al. 2002), but significant populations persist in Australian waters, which are now believed to support most of the world's dugongs. In Australia, dugongs occur along much of the coast from Shark Bay in Western Australia to Moreton Bay in Queensland. Consequently, Australia has an international obligation to ensure their conservation (Bertram 1981). In addition, dugongs are specifically cited as one of the World Heritage values of the Great Barrier Reef World Heritage Area (GBRMPA 1981).

Much of the information used to manage dugong populations in Australia has been provided by aerial surveys using the standard techniques developed by Marsh and Sinclair (1989a; 1989b). The northern Great Barrier Reef (GBR) region between Hunter Point (11°15’S — south of Cape York) and Cape Bedford (15°30’S — near Cooktown) was surveyed using this technique in 1985, 1990 and 1995. The aim of these surveys was to provide a temporal series of information on the distribution and relative abundance of dugongs in a region where Indigenous hunting and incidental capture in commercial fishing nets are considered to be the major impacts (Marsh et al. 2002).

In this report, we present the results of the aerial surveys conducted in 2000, five years after the last survey, to again assess the status of the dugong in the northern GBR region. The results indicate that overall, dugong numbers in the region are stable. However, the dugongs were distributed differently from previous surveys with more animals in the inshore region south of Cape Melville and fewer animals in the Princess Charlotte Bay region, providing further evidence that dugongs undertake large-scale movements.

The survey was also extended south from Cape Bedford to 17°25’S, between Cairns and Innisfail. Poor weather had prevented us from surveying this region as scheduled in 1999 as part of a survey of the southern Great Barrier Reef. Unsuitable weather once again prevented us extending this survey to be continuous with the 1999 survey of the southern Great Barrier Reef region. However, the gap between the two surveys was only 35km. The number of dugongs seen south of Cooktown was too low to calculate a population estimate for this region, a result similar to that obtained in 1987 and 1992.

METHODS

Initially we had intended to survey the entire northern Great Barrier Reef Region (referred to hereafter as the northern GBR) and to extend the survey coverage southwards to at least 17°45'S to overlap with the northern part of the southern GBR survey, conducted in 1999. We were able to complete the northern GBR survey to as far north as transect 506 (11°35'S), rather than the planned transect 508 (11°30'S). The survey coverage extended as far south as the Innisfail region (17°25'S), which was 35km north of the limit of the 1999 survey. Poor weather prevented us completing the intended survey coverage, therefore we ended up surveying approximately 96.8% of the intended survey area in the northern GBR; 87% of the planned survey area south of Cooktown.

Survey Methodology

The surveys were conducted in November 2000. The aerial survey method used was the strip transect technique detailed in Marsh and Sinclair (1989a; 1989b), which involved flying twin-engine Partenavia B aircraft fitted with a GPS at a speed of 100 knots, and a height of 137 m Above Sea Level. We did not use line transect methodology for two reasons:

(1) we wished to retain the same methodology as had been used in the other surveys in the temporal series;
(2) we had been advised to retain the strip transect methodology in a review of dugong survey methodology conducted by Professor Ken Pollock and other experts in 1997.

Transects were flown in an east-west direction as this reduces the interference of glare with the observations. The transect positions and lengths were modelled on previous surveys of the region (northern GBR in 1995 Marsh & Corkeron 1996; southern GBR in 1992 Marsh et al. 1996) (see Figure 1 for details of transect and block positions).

Transects 200 m wide on the water surface were demarcated for the observers using fibreglass rods attached to artificial wing struts on each side of the aircraft. Each transect was divided into four longitudinal sub-transects of equal width. Tandem teams comprising two observers on each side of the aircraft recorded their sightings independently onto separate tracks of an audio-tape. These independent sightings were then used to develop survey specific correction factors (see later section). Each sighting was designated as being made in one of the longitudinal sub-transects within its transect to enable us to decide if simultaneous sightings by the members of the same group of tandem observers were of the same group of animals. Other large marine vertebrates (especially sea turtles and cetaceans) were also recorded during the survey and will form the subject of a second report.

As the window of opportunity of suitable weather for aerial survey is small, we used two aircraft flying concurrently with separate teams of observers. One team (in an aircraft equipped with a pressure altimeter) surveyed the region from Princess Charlotte Bay northwards, while the other surveyed southwards from Cape Melville to Cape Bedford (in an aircraft equipped with a radar altimeter). The region north of Princess Charlotte Bay was surveyed under generally good conditions and in accordance with previous surveys between November 12th to 20th. There were occasional periods of poor weather at the commencement of the survey that caused transects 507 and 508 at the extreme north of the survey region to be omitted. As Shelburne Bay and Temple Bay were initially surveyed under less than optimum conditions, transects in these bays were repeated when conditions improved. The results from the repeat surveys were used in the analyses.

The Cape Melville to Cape Bedford section was surveyed under very good conditions between the 19th and 22nd of November.

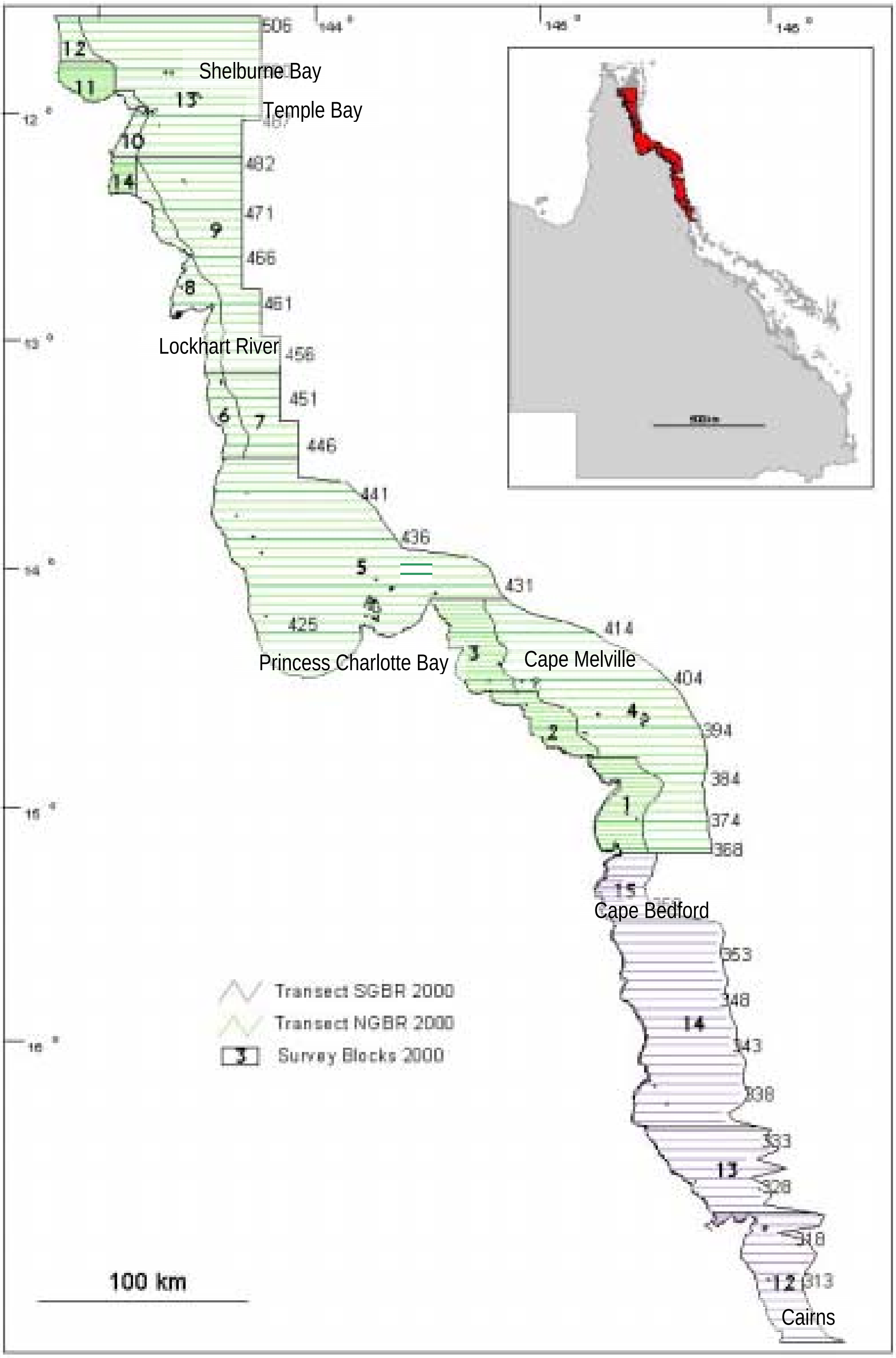

Figure 1. Map of the survey region showing the positions of the survey blocks and transects.The areas of the survey blocks and sampling intensities are presented in Table 1.

Table 1. Areas of survey blocks 1 and sampling intensities. The survey blocks are illustrated in Figure 1.

Block	Area (km²)	Sampling intensity (%)
Central GBR		
C12	1598	9.4
C13	1908	7.9
C14	4865	8.2
C15	794	9.6
Northern GBR		
N1	1040	17.2
N2	673	17.5
N3	1055	16.8
N4	5526	8.7
N5	7991	8.7
N6	463	8.6
N7	389	22.0
N8	977	8.4
N9	3075	8.6
N10	277	8.9
N11	428	24.9
N12	314	9.2
N13	4564	8.7
N14	224	22.3
Total	36163	9.7

Both aircraft were used to survey the region south of Cape Bedford between the 20th and 24th of November. Conditions began to deteriorate on the 23rd and the remainder of the survey was cancelled on November 24th. We continued to seek an opportunity to extend the survey further southwards for the next three weeks, but there was no convenient window of opportunity during which the weather was suitable.

Correction factors

Estimates of dugong abundance were obtained by correcting sightings for perception bias and availability bias (Marsh & Sinclair 1989a). Perception bias occurs when animals are visible in the survey transect but missed by observers. A correction factor used to account for this bias was calculated using a modified Mark-Recapture model that was based on the proportions of animals seen by one or other, or both, observers (Marsh & Sinclair 1989a). Perception correction factors were calculated for each team of observers in each aircraft.

Availability bias was corrected for by standardising the proportion of animals classified as being 'at the surface' against the corresponding proportion in an earlier survey with water conditions enabling all animals in the survey area to be seen (Marsh and Sinclair 1989a). This approach made the untested assumption that a constant proportion of animals are at the surface across all survey conditions. Availability correction factors were also estimated separately for the two aircraft as detailed in Table 2. Appendix 1 lists the raw data used to calculate the correction factors.

Table 2. Details of mean group size estimates and correction factors used in the population estimates for dugongs in the 2000 survey of the northern Great Barrier Reef region. See Figure 1 for block and transect positions.

Blocks: Transects	Group size (C.V.)*	Perception correction factor estimate (C.V.)		Availability correction factor estimate (C.V.)
		Port	***Starboard***	
N5-N14 all lines, C14-C15 all lines	1.39 (0.597)	1.23 (0.046)	1.30 (0.051)	1.32 (0.154)
N1-N4 all lines C12-C13 all lines	1.57 (0.540)	1.17 (0.031)	1.11 (0.021)	2.19 (0.125)

* *Coeficient of variation*

Population estimation

Dugong abundance was estimated separately for each block in the survey area. As transects vary in length, and hence area, the Ratio Method was used to estimate density, population size and associated standard errors (Jolly 1969; Caughley & Grigg 1981). Any statistical bias resulting from this method is considered inconsequential because of the relatively high sampling intensity (Table 1; see also Caughley & Grigg 1981). Input data included the estimated number of dugongs (in groups of <10 animals) for each tandem team per transect calculated from the raw data using the corrections for perception and availability biases and the estimates of mean group size (Table 2). The estimated standard errors incorporate the errors associated with the correction factors described above (Marsh & Sinclair 1989a). The numbers of dugong in groups of >10 were added to the estimates of population size and density as outlined in Norton-Griffiths (1978).

Statistical analysis

As we did for the analysis of the 1999 southern GBR survey (Marsh & Lawler 2001), differences in dugong density among this survey and the previous surveys of the northern GBR were tested using a split-plot Analysis of Variance. The parameters of the ANOVA were estimated by Restricted Minimum Likelihood (REML). The (fixed) year effect was tested against the (random) block*year interaction using density in each block averaged over transects as the response. This approach was taken because the transect term does not contribute to the test for year effects and the distribution of density estimates across transects within blocks is highly variable because of the clumped nature of dugong distribution. The input data were square root transformed to ensure a constant mean-variance relationship. There was some evidence for a slightly stronger transformation (i.e., cube root) but this did not alter the interpretation. Mixed-effects models were employed to estimate the random components of variance and provide appropriate tests for differences between years. The test for the year effect assumed sphericity (i.e. constant correlation between blocks across years).

Estimating the size of a sustainable dugong catch in the northern GBR

We used the Potential Biological Removal (PBR) method (Wade 1998) to estimate the size of a sustainable dugong catch in the northern GBR as a whole and for the region between Cape Melville and Cape Bedford. The PBR is defined as the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population.

The PBR is the product of the following factors:

- The minimum population estimate of the stock N_{min} (defined as the 20th percentile of a log-normal distribution based on an absolute estimate of the number of animals in that stock);
- the maximum rate of increase R_{max}; and,
- Recovery Factor (RF) of between 0.1 and 1. (The use of a RF less than one allocates a proportion of expected net production towards population growth and compensates for uncertainties that might prevent population recovery, such as biases in the estimation of N_{min}, and R_{max} or errors in the determination of stock structure. Population simulations (Wade 1998) suggest that the default value for endangered species should be 0.1 and that the default for depleted or threatened stocks, or stocks of unknown status should be 0.5. Stocks taken primarily by Indigenous subsistence hunters that are not known to be decreasing could have higher values for RF up to and including 1. We used values of 0.5 and 1 as explained in future sections).

RESULTS

Survey conditions

Despite our difficulties with the weather, the survey was conducted under good conditions that were generally within the range of those encountered on other surveys in the temporal series (Table 3). The details of Beaufort sea state and glare for each transect are given in Appendix 2.

Table 3. Weather conditions encountered during the survey compared with those encountered on previous surveys of the northern GBR.

	1985	1990	1995	2000
Wind speed (km.h^{-1})*	<28	<15	<15	<18
Cloud cover (oktas)*	0-5	0-7	2-7	2-8
Minimum cloud height (m)*	305-1525	1500-35000	305-1220	300-10000
Beaufort sea state#	1.5 (0-4)	1.5 (0-2.5)	3 (1-4)	1.65
Glare# • – North				1.44 (0-3)
South				1.69 (0-3)
Overall~	1 (0-2.5)	2.2 (1-3)	1.5 (0-3)	1.9 (0-3)
Visibility (km)*	8->50	N / A	10-30	>10

* *Range*
\# *Means of modes for each transect*
• *0-none, 1<25% of field of view affected, 2<25-50%, 3>50%*
~ *taken from the side of the aircraft with the highest glare*

Group size and composition

A total of 947 dugongs was seen during the survey. Most were small groups of one to three animals (Figure 2). Eight groups of more than ten dugongs were sighted as follows:

- three groups of 10 (none with calves), one of 20 (no calves), one of 35 (no calves), and one of 200 (few calves which were not counted); all in Block 2 (Figures 2 and 3b);
- one group of 16 (no calves) in Block 3 (Figures 2 and 3b); and,
- one of 76 dugongs (3 calves) north of Friendly Point in Block 6 (Figures 2 and 3a).

Of the 348 dugongs sighted north of Cape Melville, 41 were classified as calves, an overall percentage of 11.8%. We found it difficult to count calves in large groups of dugongs. The only group of more than 10 dugongs sighted in this region was the group of 76 (3 calves). Excluding this group, 14 % of dugongs sighted north of Cape Melville were calves. South of Cape Melville, 33 calves (8.1%) were seen out of 409 dugongs (excluding the herd of 200 for which a formal calf count was not possible). If we exclude all groups of greater than 10 dugongs seen south of Cape Melville, the proportion of calves was 33 / 308 or 10.7%. Overall, 12.2% of the dugongs sighted in groups <10 in the northern GBR were calves. This percentage is similar to that seen in 1996 (12%), and is not significantly different from the percentage sighted in the region in 1990 (Marsh & Corkeron 1996). In making these comparisons, we made the assumption that the proportion of calves in a group is independent of group size.

Only six groups of dugongs (seven animals, 0 calves) were seen south of Cape Bedford near Cooktown. Two of these were close to Yarrabah Community.

The raw data detailing the sightings of dugong groups for each transect in each block are in Appendix 3.

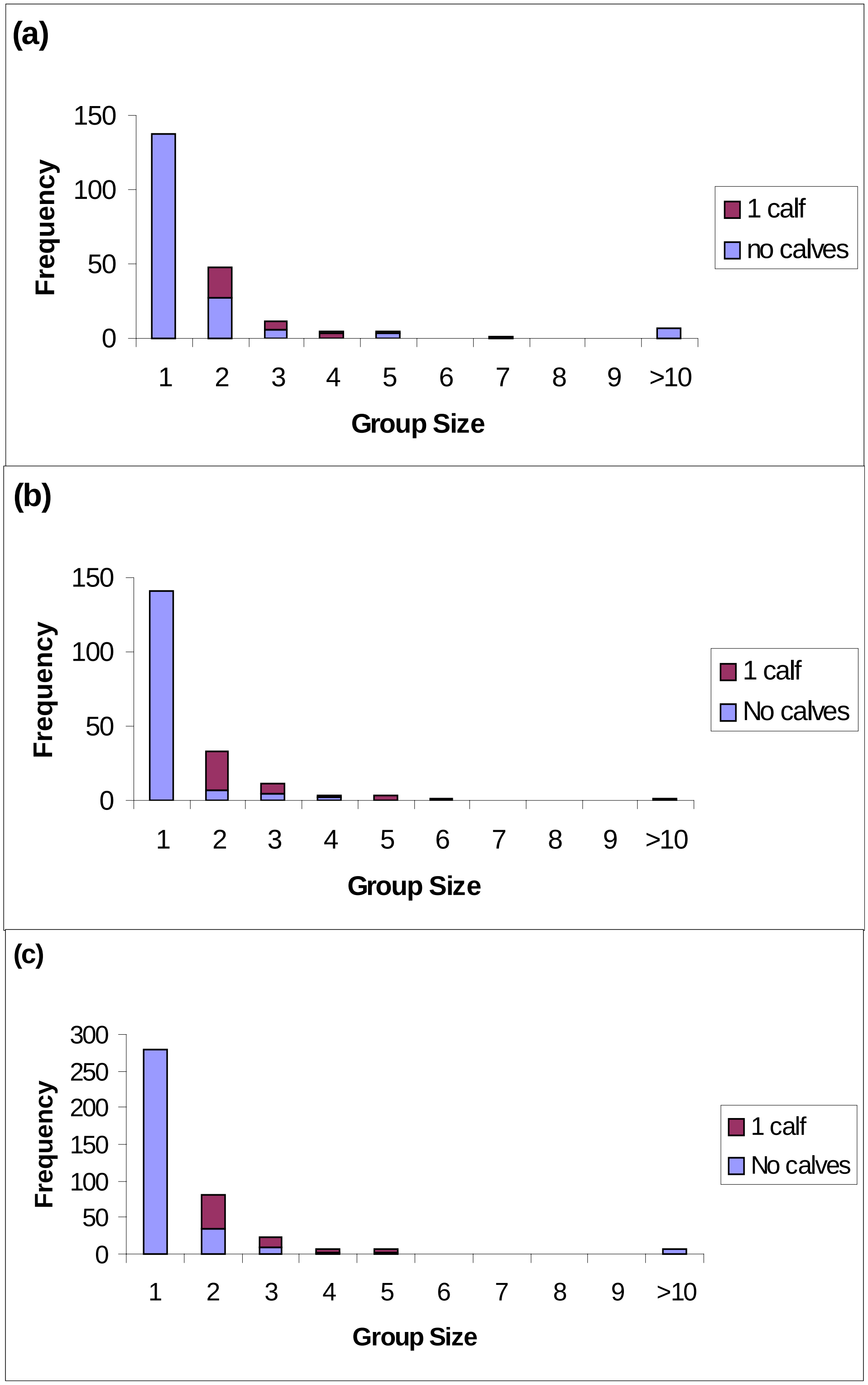

Figure 2. Histograms showing the frequencies of groups of dugongs of various sizes and and with varying number of calves sighted in November 2000: (a) south of Cape Melville; (b) north of Cape Melville; and (c) entire Northern GBR survey region. Note that only groups with one calf are evident on the graph because of the very low frequency of groups with more than one calf. There were two groups, (one of four and one of five animals respectively) each with two calves south of Cape Melville and one group of 76 with three calves north of Cape Melville.

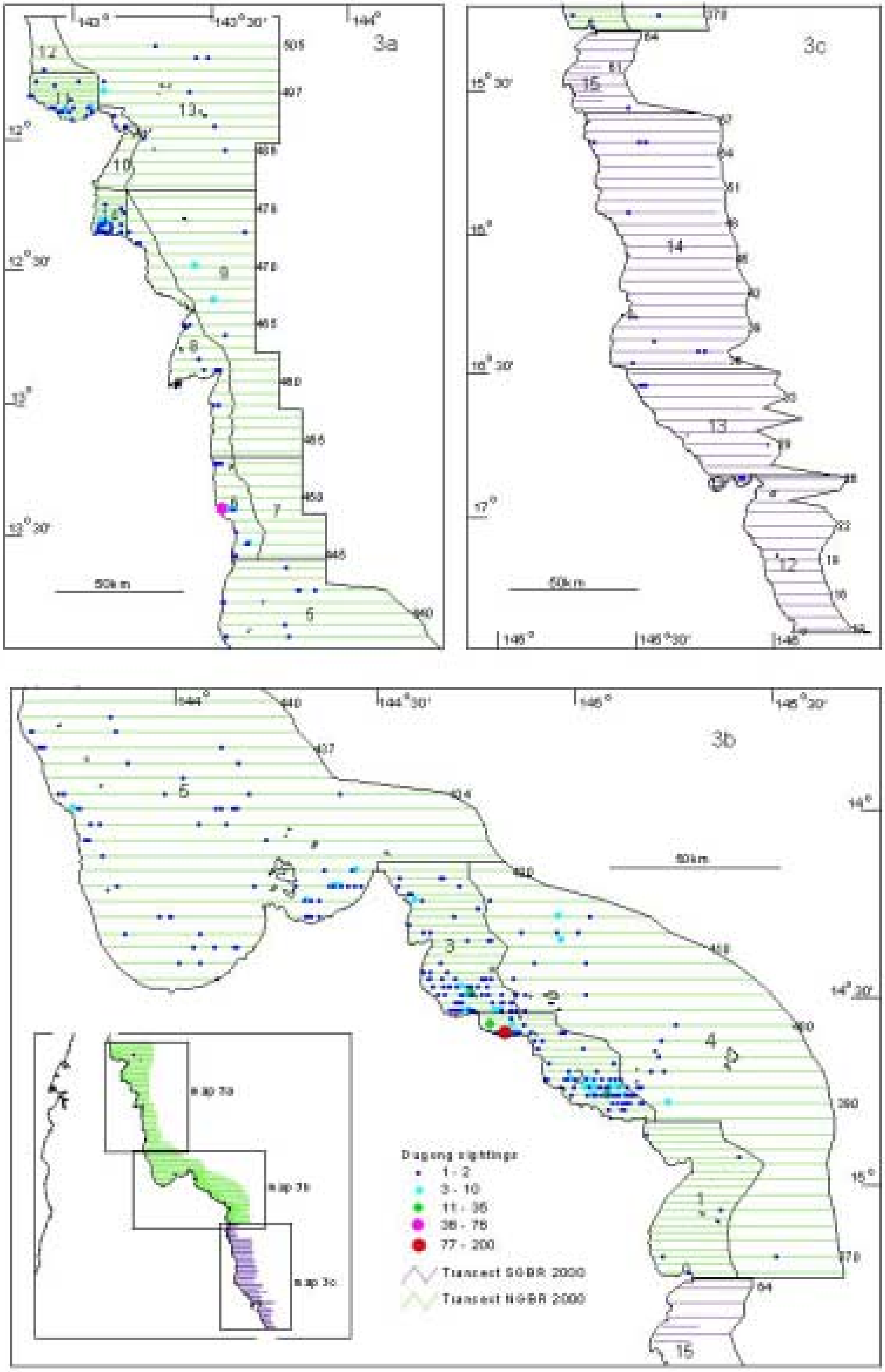

Figure 3. Locations where dugongs were sighted in the Northern GBR on the November 2000 survey. Note the differences in survey intensity between survey blocks as evidenced by the density of transects (see also Table 1).

Dugong distribution and abundance

Northern Great Barrier Reef Region

The estimated size of the dugong population for this region in 2000 was 9081 dugongs (±s.e. 917) (Table 4). Correcting for any minor differences in survey design, the dugong density seen on this survey was not significantly different ($p=0.099$, Table 5) from the previous surveys in 1985, 1990 and 1995.

Table 4. Estimates of dugong abundance in each of the survey blocks in the Northern GBR survey in 2000 in comparison with the corresponding data for 1985, 1990, and 1995. The minor differences in design among surveys (see Marsh & Corkeron 1996) should make no substantive difference to the population estimates. The data for the survey blocks south of Cape Bedford have been omitted from this table because too few animals (<5 sightings per to block) were sighted to reliably estimate the population size.

Northern GBR	**Year**							
Block	***1985 est. abund.***	***1985* ± s.e.**	***1990 est. abund.***	**1990 ± s.e.**	***1995 est. abund.***	**1995 ± s.e.**	***2000 est. abund.***	**2000 ± s.e.**
1	0#		*		*		112	47
2	1644	570	1564	488	910	157	2265§	562
3	272	110	903	650	832	213	1985§	488
4	626	256	768	202	235	101	1074	242
5	3630	714	3782	767	4396	1052	2233	407
6	792	423	1673	1037	676	312	540~	164
7	0		182	97	0		0	
8	611	192	829	305	305	181	389	132
9	*		*		*		*	
10	*		*		*		*	
11	222	81	268	66	309	109	214	79
12	*		*		*		*	
13	128	83	207	99	82	69	242	83
14~	-#	-	-	-	98	26	139	56
Overall Total	7925	1068	10176	1575	7843	1155	9081	917

* *Too few animals (<5 sightings per to block) to reliably estimate population size. The estimates for 1985, 1990, and 1995 have also been adjusted to conform with this rule and are slightly different to the values presented in Marsh & Corkeron 1996.*

\# *0 indicates no dugongs sighted;*

\- *indicates not flown*

§ *Groups of >10 stratified out of calculation and added in to estimate at the end*

~ *Block 14 is part of Block 8 sensu Marsh & Saalfeld (1989). Additional transects were flown in this area from 1990, but were not presented in the 1990 survey report.*

Table 5. Summary of Split-plot Analysis of Variance comparing dugong densities among surveys. The minor differences in design among surveys conducted in 1985, 1990, 1995 and 2000 (see Marsh & Corkeron 1996) have been accounted for in the analyses. The density data for blocks in which too few animals were sighted (<5 sightings per to block) to reliably estimate population size (see Table 4) have been included in these comparisons.

Term	Df	SS	MS	Est. Var	F	P
Year*#~	3	0.241	0.080		2.265	0.099
Block§	11	9.916	0.901	0.2165		
Year*Block	33	1.169	0.035	0.0354		

* *Tested against year by block interaction*
\# *Fixed factor*
§ *Random factor*
~ *Conservative lower bound test for year effects which does not assume sphericity - F = 2.265, d.f. = 1 & 11, p = 0.161.*

The variance between blocks (~83% of the total variation), relative to the year*block variance (~15%) and the variance accounted for by fixed year effects (~2%), provided evidence of the patchy distribution of dugongs at the spatial scale of blocks. This can be used to design highly protected areas to protect dugongs as discussed below. The variance accounted for by the block*year interaction was more than seven times the variance between years suggesting that dugongs were distributed differently in different years. For example, the surveys in 1985, 1990 and 1995 indicated that Princess Charlotte Bay supported between 37% and 56% of dugongs in the northern NGBR region. The corresponding proportion for 2000 was 24.5%. At the same time, the area south of Cape Melville supported 59% of the dugongs in the region, a proportion about twice as high as the percentages of between 25% and 32 % in 1985, 1990 and 1995 (Table 4 and Figure 4).

Cape Bedford to 17°25'S

The number of dugongs sighted was too low to calculate a population estimate for this region, a result similar to those obtained in 1987 and 1992.

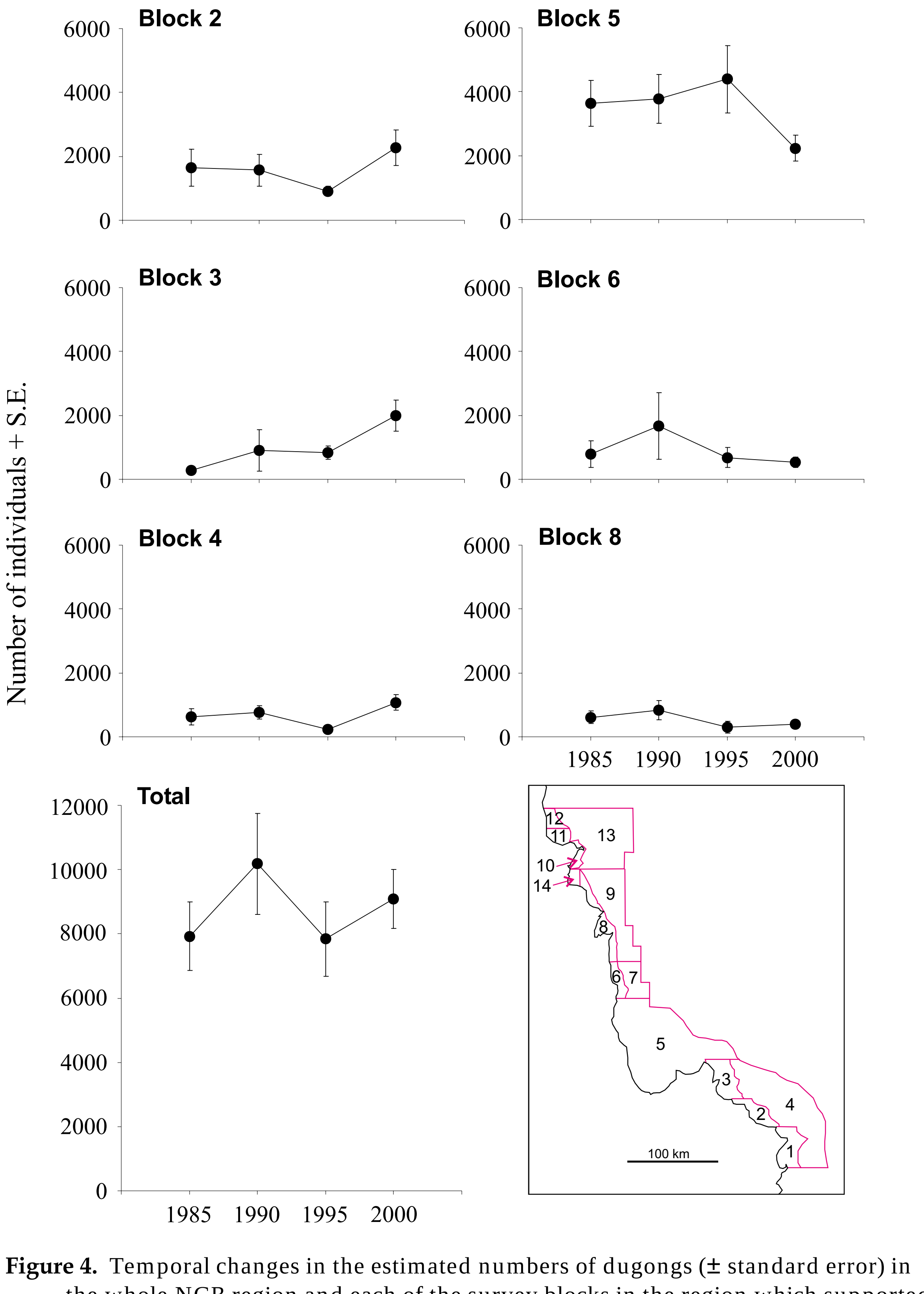

Figure 4. Temporal changes in the estimated numbers of dugongs (± standard error) in the whole NGB region and each of the survey blocks in the region which supported an estimated 500 dugongs or more on at least one of the aerial surveys.

Estimating a sustainable level of human-induced mortality for dugongs in the survey regions

Northern GBR

In applying the PBR method to estimate a sustainable harvest rate for the dugong in the northern GBR region, we considered the following factors.

Minimum population estimate N_{min}

The population estimates obtained from the aerial surveys are standardised indices designed to monitor population trends. They are not absolute estimates as assumed by the PBR. The greatest uncertainty is in the correction for availability bias (the proportion of dugongs that are unavailable to observers because of water turbidity). As explained in Marsh (2000), we are in the process of developing methodology to estimate the absolute abundance of dugongs by:

- estimating the visibility of dugongs under a range of aerial survey conditions (water clarity, water depth, cloud cover and Beaufort sea state) using a series of experiments with fibreglass models of dugongs viewed from a helicopter at aerial survey altitude;
- recording the dive profiles of wild dugongs using time depth recorders to obtain information on the time spent at various depths; and
- modifying the aerial survey procedures to record the survey conditions associated with all dugong sightings.

However, as this methodology has not been finalised we have taken the conservative approach and used the relative estimates of dugong abundance provided by the aerial surveys (Table 4) as estimates of absolute abundance. We used these estimates at two scales:

(1) the whole NGBR survey region; and
(2) the region between Cape Melville and Cape Bedford (blocks 1-4), which includes the hunting grounds of the people of Hope Vale community (Smith & Marsh 1990).

Maximum rate of increase R_{max}.

The application of population models to dugongs has been hampered by uncertainty about the estimates of the population parameters as discussed by Marsh (1995;1999). Age determination has been validated only by the marginal increment method (Marsh 1980). This is unlikely to be a significant error as the mammalian literature indicates that the rate of deposition of growth layer groups is remarkably similar across taxa. The rate for dugongs is also in accord with that for Florida manatees, a rate that has been verified using tetracycline marking (Marmontel 1995).

We have no estimates of R_{max} for the northern GBR region and must apply data from other regions with caution. Dugong life history parameters are spatially and temporally variable as discussed by Marsh (1999) and Kwan (2002). In addition, estimates of the calving intervals of these populations may be biased by hunters targeting pregnant females (Johannes & MacFarlane 1991; Roberts et al. 1996). The sample sizes are not large enough to calculate the age at which 50% of females mature, rather they are suitable only to define the range of ages at which maturity has been observed to occur. The minimum ages of first reproduction observed are 6 years (Mabuaig in 1997; Kwan (2002)); 10 years (Townsville) and 13 years (Daru) (Marsh 1995).

There are no estimates of natural mortality. The early models assumed a pattern of natural mortality based on that of the dugong's nearest living terrestrial relative, the African elephant. More recent modelling (Marsh 1999; Table 6) uses a pattern of natural mortality based on that obtained from longitudinal studies of manatees (Eberhardt & O'Shea 1995; Langtimm et al.1998) which is likely to be more realistic for dugongs than the pattern based on that for elephants.

Accordingly, we have used a range of estimates of R_{max} from 0.01 to 0.05 (1-5%). The basis for these estimates is summarised in Table 6.

Table 6. Estimates of the maximum rate of population increase R_{max} for dugong populations for combinations of life history parameters (age of first calving and mean calving intervals spanning the known range of these parameters in various wild populations.

	Age at first reproduction (years)*	**R_{max} # § for each of the following mean calving intervals**		
		2.5 years*	***3.0 years****	***5.0 years****
Mabuig, Torres Strait 1997-98	6	5.08%	3.9%	1.15%
Townsville 1970-early 1980s	10	3.35%	2.45%	0.3%
Daru, Torres Strait 1976-83	13	2.46%	1.65%	-0.22%
Mornington Island 1970-early 1980s	15	1.92%	1.2%	-0.53%

* *These data are based on recorded age of first reproduction (calf birth) rather than mean age of first reproduction and are from Marsh (1999) and Kwan (2002).*

\# *The population models use survivorship schedules based on empirical data for the Florida manatee as follows: dependent calves- 0.822 p.a., independent young – 0.965, reproductive adult – 0.965 (see Marsh 1999 for details)*

§ *The age distribution has been truncated at 45 years. Extending it to the maximum age recorded for dugongs of 70 years makes only a trivial difference.*

The Recovery Factor (RF)

We used values of 0.5 and 1 for the Recovery Factor (RF) in the calculation of PBRs for dugongs in the northern GBR. The justification for using a RF of 1 is that the temporal series of aerial surveys suggests that population numbers are stable at a regional scale (Table 5). We also used a RF of 0.5 because the dugong is listed as a threatened species in Queensland and the default value is 0.5 for such stocks.

The above ranges and uncertainties produce the scenarios for the PBR in Table 7. In the absence of reliable data on natural mortality in dugongs, empirical data for the annual survival in Florida manatee (Eberhardt & O'Shea 1995; Langtimm et al. 1998) were used to construct mortality schedules used in the population models of dugongs on the basis of their close taxonomic relationship and similar shallow inshore distribution. We cannot assign formal weightings or probabilities to these scenarios. Nonetheless, we consider that both the most pessimistic and most optimistic scenarios are unlikely as the overall percentage of calves (12.2%, excluding the large groups for which it was impossible to obtain reliable calf counts) was average for dugongs. Calf counts are an index of fecundity. The middle value for R_{max} suggests that the following total annual anthropogenic mortality from all sources should be sustainable. The decision on where to use a Recovery Factor of 0.5 or 1 is a matter for discussion between the managing agencies and the traditional owners of the region under discussion.

- For the whole region: 63 dugongs (RF= 0.5); 125 dugongs (RF=1);
- for Blocks 1-4, the region between Cape Melville and Cape Bedford based on the population's distribution in 2000: 36 dugongs (RF= 0.5); 72 dugongs (RF=1); and,
- for Blocks 1-4, the region south to Cape Bedford based on the population distribution in 1995 (worst case scenario): 13 dugongs (RF= 0.5); 26 dugongs (RF=1).

Given that the population estimates presented in this report are not absolute estimates, these estimates of sustainable anthropogenic mortality should be revised when absolute population estimates become available.

Table 7. Estimates of the total sustainable anthropogenic mortality (Potential Biological Removal sensu Wade 1998) for various estimates of dugong population size in the entire NorthernGBR and the region south of Cape Melville for a range of estimates of R_{max}.

(a) Recovery Factor = 0.5

Region and date of survey	N	s.e.	CV	N_{min}	Potential Biological Removal				
					R_{max} =0.01	R_{max} =0.02	R_{max} =0.03	R_{max} =0.04	R_{max} =0.05
Entire NGBR 2000	9081	917	0.101	8342.6	21	41	62	83	104
Blocks 1-4 2000	5436	783	0.144	4818.1	12	24	36	48.	60
Blocks 1-4 1995	1977	283	0.143	1753.6	4	9	13	17	22

(b) Recovery Factor = 1

Region and date of survey	N	s.e.	CV	N_{min}	Potential Biological Removal				
					R_{max} =0.01	R_{max} =0.02	R_{max} =0.03	R_{max} =0.04	R_{max} =0.05
Entire NGBR 2000	9081	917	0.101	8342.6	42	83	125	167	209
Blocks 1-4 2000	5436	783	0.144	4818.1	24	48	72	96	120
Blocks 1-4 1995	1977	283	0.143	1753.6	9	18	26	35	44

Cape Bedford to 17°25'S

As the number of dugongs sighted was too low to calculate a population estimate for this region, it was impossible to estimate a sustainable level of human-induced mortality for dugongs in this region.

DISCUSSION

Northern Great Barrier Reef Region

Status

The results of the temporal series of surveys conducted in the northern Great Barrier Reef in 1985, 1990, 1995 and 2000 suggest that dugong abundance is stable at the scale of the region as a whole (Tables 4 and 5). However, it must be appreciated that the survey technique is designed to detect regional scale trends and cannot accurately detect changes at a local scale even if they are occurring. Despite the evidence of large-scale movements of dugongs presented below, the potential for local-scale depletion of dugongs has been demonstrated from previous research. For example, Marsh et al. (2001) documented a decline between 1962 and 1999 in the number of dugongs caught per beach in shark nets set for bather protection along the Queensland coast from Cairns south.

Changes in Distribution between Surveys

The results of the 2000 survey add to a growing body of evidence (Table 8) that dugongs undertake large-scale movements. The survey results from several areas in both Queensland and Western Australia (documented in Table 8) suggest both movements into and out of survey regions, and movements within survey regions between surveys. The patterns of changes cannot be explained by natural increase in the absence of immigration. The reasons for such large-scale movements are not generally known, but appear to be associated in part, with large-scale episodic disturbance to habitat by cyclones and floods (Poiner & Peterken 1996; Marsh et al. 2002).

Data for Moreton Bay suggest a similar pattern – dugong numbers in the Bay were lower in December 2000 and April 2001 (Lawler 2001) in comparison to surveys conducted in 1995 (Lanyon & Morrice 1997). However, these differences were confounded by differences in survey technique. If the differences are real, dugongs may have moved from the Bay in response to the outbreak of the toxic algae *Lyngbea majuscula* which extended over favoured dugong habitats in early 2000 (Haines & Limpus 2000).

The results of the temporal series of aerial surveys of the northern GBR region suggest large-scale movements of dugongs within the survey region, especially between Princess Charlotte Bay (Block 5) and the region south of Cape Melville (Blocks 1-4). The reasons for these movements are unknown.

Table 8. Evidence of significant changes in the spatial distribution of dugongs as suggested by standardised aerial surveys in Australia.

Region	**Evidence of significant change in dugong abundance suggested by standardised aerial surveys**		**Likely reason for change**
	Date	Population estimate ± s.e. *	
Torres Strait Qld (Marsh et al 1997a; Marsh et al. 1997b; H. Marsh, pers. comm.)	1987 1991 1996 2001	13319 ± 2,136 a 24225 ± 3,276 a 27,881 ± 3,216 b 14106 ± 2314	Unknown except for seagrass dieback in 2001
Southern GBR Qld (Marsh et al. 1996; Marsh and Lawler 2001)	1986 / 87 1992 1994 1999	3479 ± 459 a 1857 ± 292 b 1682 ± 236 b 3993 ± 641 a	Unknown
Hervey Bay Qld (blocks 1-4) (Preen and Marsh 1995; Marsh et al. 1996; Marsh and Lawler 2001)	1988 1992 1993 1994 1999	2206 ± 420 1109 ± 383 521-571 ± 126 775 ± 150 1473 ± 242	Seagrass loss in 1992 after episodic disturbance
Shark Bay (Marsh et al. 1994; Preen et al.1997; Gales pers comm)	1989 1994 1999	10146 ± 1,665a 10529 ± 1,464a 13929 ± 167	Seagrass loss in Exmouth Gulf after episodic disturbance in 1999
Exmouth Gulf (Preen et al.1997; Gales pers comm. 2001; Prince et al. 2001)	1989 1994 1999 2000	1062 ± 321a 1006 ± 494a 337 ± 108 too small to estimate	Seagrass loss in Exmouth Gulf after episodic disturbance in 1999 Time x Block Interaction significant for 1989-94 comparison; 1999 –2000 comparisons n.a.

* *Populations estimates that have same letters after them within a temporal series have been shown statistically not to be significantly different from each other.*

Satellite-tracking has confirmed that some individual dugongs undertake long-distance movements. An adult female moved 600 km between two sites in the Gulf of Carpentaria over about five days (Preen 1995). Another male travelled a straight-line distance of 140 km, three times in six weeks between two localities in the Central Section of the GBR, (Marsh & Rathbun 1990). Of the ten dugongs fitted with satellite transmitters in Shoalwater Bay in the Southern Section of the GBR by Preen (1999), four made substantial trips out of that bay. Two made return trips: one 100 m north, the other 220 km north. Two other animals journeyed 400 km south to Hervey Bay where their transmitters came off. Thirteen dugongs were tracked between the Townsville and Hinchinbrook Island region in Queensland. Twelve trips were made of more than 30 km beyond the area regularly used by these animals, six trips of more than 100 km and one trip of more than 600 km (Preen 2001). Most of these movements were return trips. For example, the animal that moved more than 600 km north returned to her capture point after five months and almost immediately moved another 165 km south along the coast. The movements of this dugong thus spanned about 800 km of coast and demonstrate that it is possible for individual dugongs to move the distances necessary to effect the change in distribution suggested by the aerial surveys.

Strategies for Protecting the Dugong in the northern GBR

Marsh et al. (2002) reviewed the impacts on dugongs in 37 countries throughout their range. They concluded that dugongs were subjected to multiple impacts in all areas including mortalities associated with fishing (>34 countries), poaching and hunting (>28 countries), boating (>13 countries) and habitat loss (all countries). In view of these multiple impacts, Marsh et al. (2002) concluded that the optimum conservation strategy is to:

- identify areas that still support significant numbers of dugongs;
- consider, with extensive local involvement, how impacts on dugongs can be minimised and the habitat protected in these ‘dugong sanctuary’ areas.

They suggested that this should be done in the context of comprehensive plans for coastal zone management, perhaps using the dugong as a ‘flagship’ species.

The only place in the world where this strategy has been formally adopted is in the southern GBR – Hervey Bay region. In 1997 the Australian and Queensland governments agreed to several measures specifically aimed at arresting the decline of dugongs along the urban coast of Queensland. In the GBR region these measures were introduced within the context of the overall management structure of the GBR Marine Park. The most controversial measure was to establish a two-tiered system of Dugong Protection Areas (DPAs). Gill and mesh netting are greatly restricted or banned in seven Zone A DPAs totalling 2,407 km^2, and subject to lesser modifications in eight Zone B DPAs totalling 2,243 km^2 (Fisheries Amendment Regulation [No. 11] Queensland 1997). An additional Zone A DPA of 1703 km^2 in which gill and mesh netting practices were modified was established in Hervey Bay (Marsh 2000). A conservation plan for dugongs in Queensland was implemented in 1999 by the Queensland Environment Protection Agency. This plan further reinforced the functions of the Dugong Protection Areas.

The establishment of such areas as Dugong Protection Areas should reduce dugong mortality, provided the areas chosen consistently support high numbers of animals, even though individual dugongs move in and out of the areas (Marsh et al. 1999; Marsh 2000). The long-term effectiveness of these areas will depend on whether high-quality dugong habitat can be maintained. This will hinge on the capacity to control land-based inputs.

Although a similar strategy has not been formally applied in the northern GBR region, the distribution and abundance of dugongs has influenced the placement of highly protected areas within the Great Barrier Reef Marine Park in this region. Marine Park zoning has protected dugongs in the coastal waters of Shelburne Bay, the Friendly Point region, Corbett Reef and much of the region between Cape Melville and Lookout Point since the mid 1980s The recent rezoning will improve the protection of dugongs in several areas including Temple Bay, the Cape Direction region, parts of Princess Charlotte Bay and Bathurst Bay. This zoning protects animals from extractive activities, especially fishing impacts including incidental capture in commercial gill nets and habitat damage from trawling. Such protection has been enhanced by the rezoned Far Northern Section, which provided increased protection for several important dugong habitats including Temple Bay, the Cape Direction region, parts of Princess Charlotte Bay and Bathurst Bay (Figures 5; 6; 7). When the area is rezoned again as part of the Representative Areas Project, consideration should be given to extending the seaward boundary of the highly protected zones between Cape Melville and Lookout Point and the northern boundary of the National Park Zone around Friendly Point.

The whole region is remote and impacts from land-use and boating traffic will be much less than in other regions of the GBR World Heritage Area. The major challenges will be to:

(1) work with the local Indigenous communities to ensure that hunting is sustainable; and,

(2) negotiate with the Queensland government (who have jurisdiction in tidal waters which extend generally for three nautical miles from the mainland and around Queensland islands) to achieve ecologically sustainable net-fishing arrangements to operate in the tidal reaches of the rivers and creeks and in the intertidal areas adjacent to those parts of the region with high protection through marine park zoning. This has potential to afford greater protection to dugongs in their inshore shallow water habitats where timed depth recorders attached to 15 dugongs demonstrate that they spend most of their time (L. Chilvers, pers. comm.). Dugongs have also been tracked in creeks and river mouths (Marsh & Rathbun 1990).

We consider that public education material outlining the protection given to dugongs should cover the entire GBR World Heritage Area. To date such material has featured the southern GBR region.

Cape Bedford to 17°25'S

As the number of dugongs sighted was too low to calculate a population estimate for this region, it was impossible to estimate a sustainable level of human-induced mortality. In view of the low numbers of dugongs sighted in this region, all sources of dugong mortality should be miminised. We suggest that negotiations should be conducted with Yarrabah community with a view to developing protocols for minimising the risk of capturing dugongs in the mesh net fishery operated by the community in adjacent Mission Bay. Nine dugongs were reported dead as bycatch in this fishery in 1999 and there were anecdotal reports of multiple dugong captures in this fishery in 2000 (Haines & Limpus 1999; Haines & Limpus 2000).

Marine Park zoning provides little protection of dugong habitats in the region between Cape Bedford and Innisfail (Figure 8). Consideration should be given to improving this through the Representative Areas Program. In particular, consideration should be given to establishing a highly protected area in the Port Douglas region as recommended by Preen and Morissette (1997). They documented extensive dugong habitat use north and south of Port Douglas based on incidental sightings (refer to Figure 5I, Preen & Morissette 1997).

CONCLUSIONS

The number of dugongs in the northern GBR is internationally significant. Although the population appears to be stable at a regional scale, the likelihood of local depletions needs to be investigated. In the region between Cape Bedford and Innisfail, we suggest that negotiations with Yarrabah community should be the highest priority.

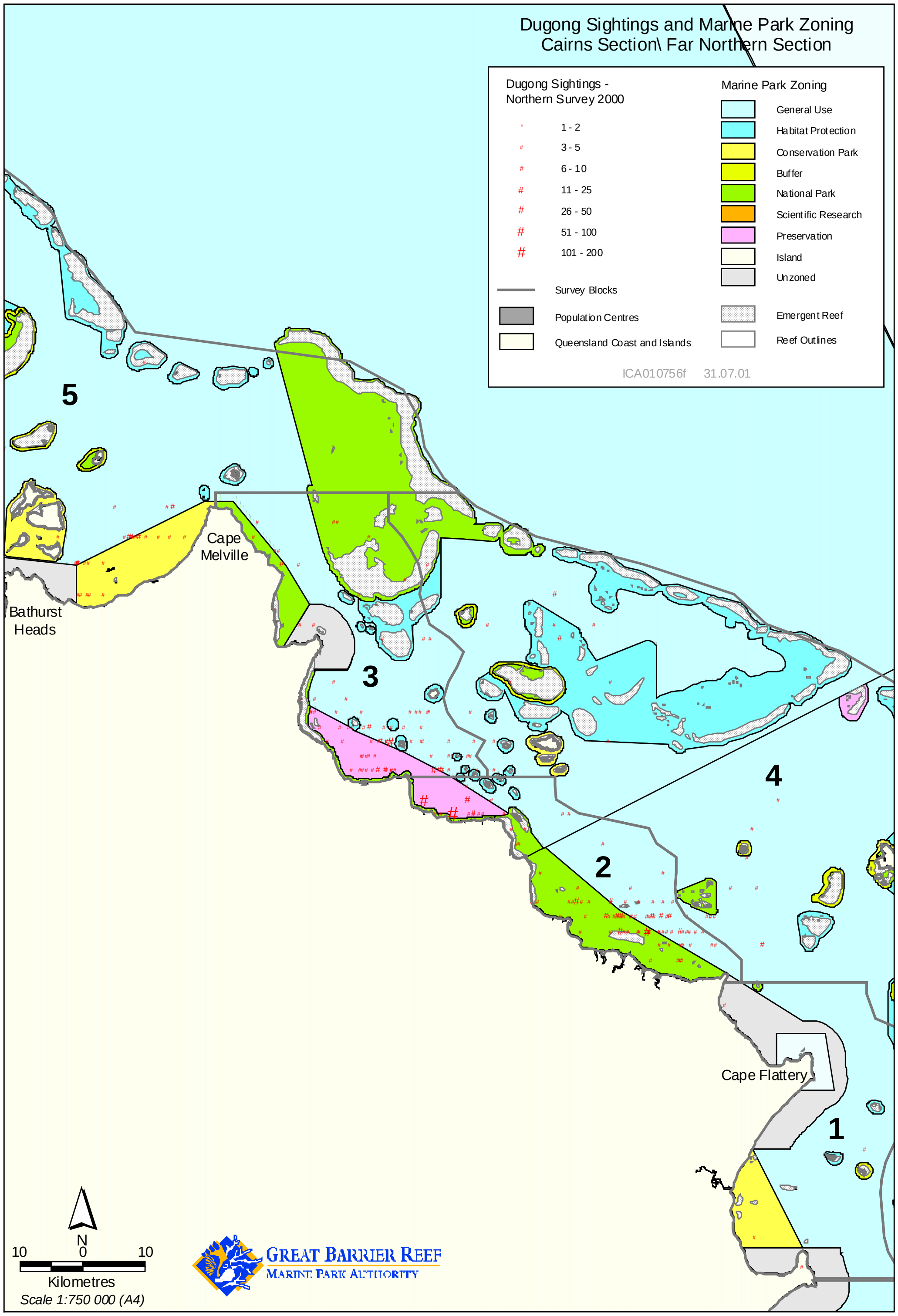

Figure 5. Dugong sightings on the 2000 Aerial survey of the Northern GBR in relation to the Marine Park Zoning in the area between Cape Bedford and Bathurst Bay. Note the differences in survey intensity between survey blocks.

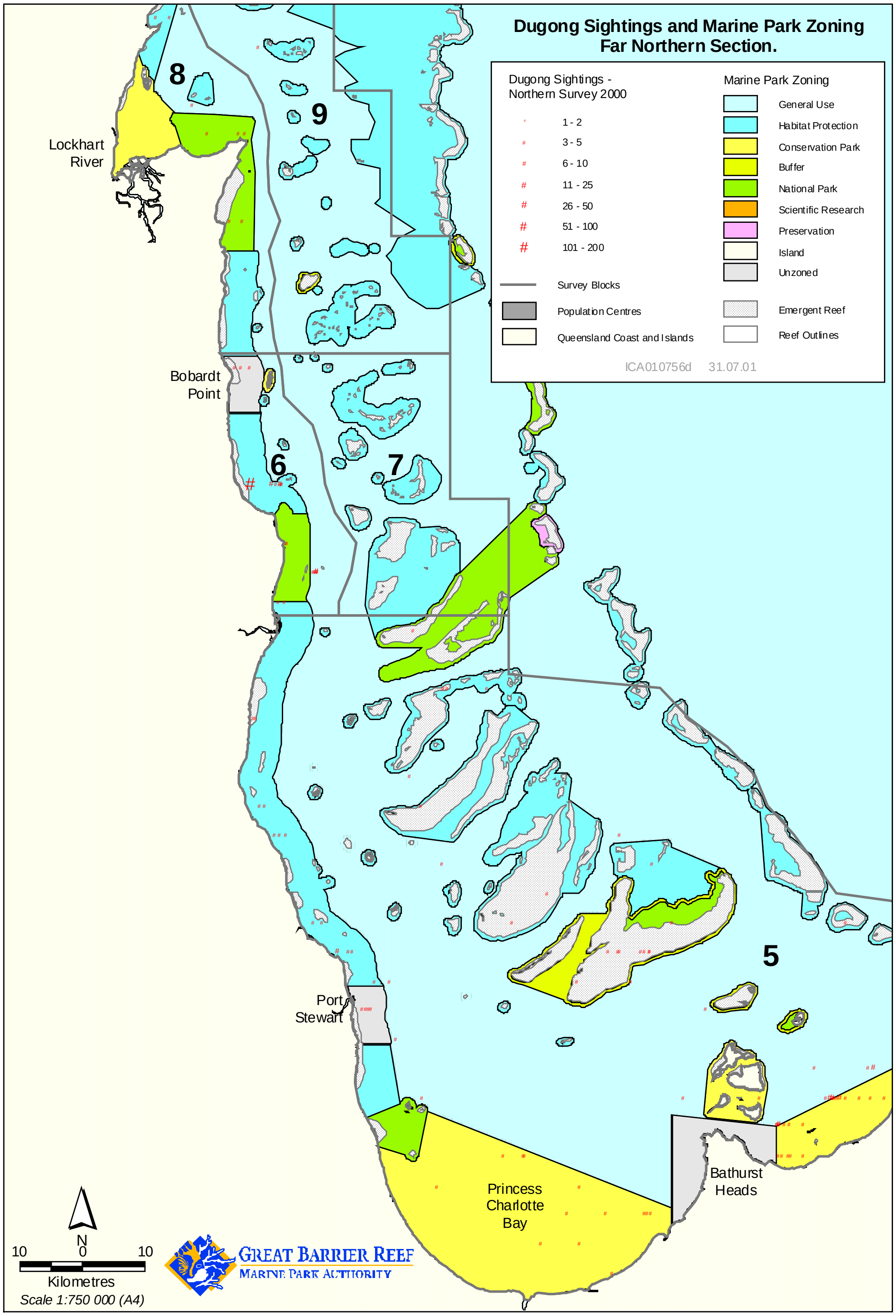

Figure 6. Dugong sightings on the 2000 aerial survey of the Northern GBR in relation to Marine Park Zoning of the area from Princess Charlotte Bay to Lockhart River. Note the differences in survey intensity between survey blocks (Table 1).

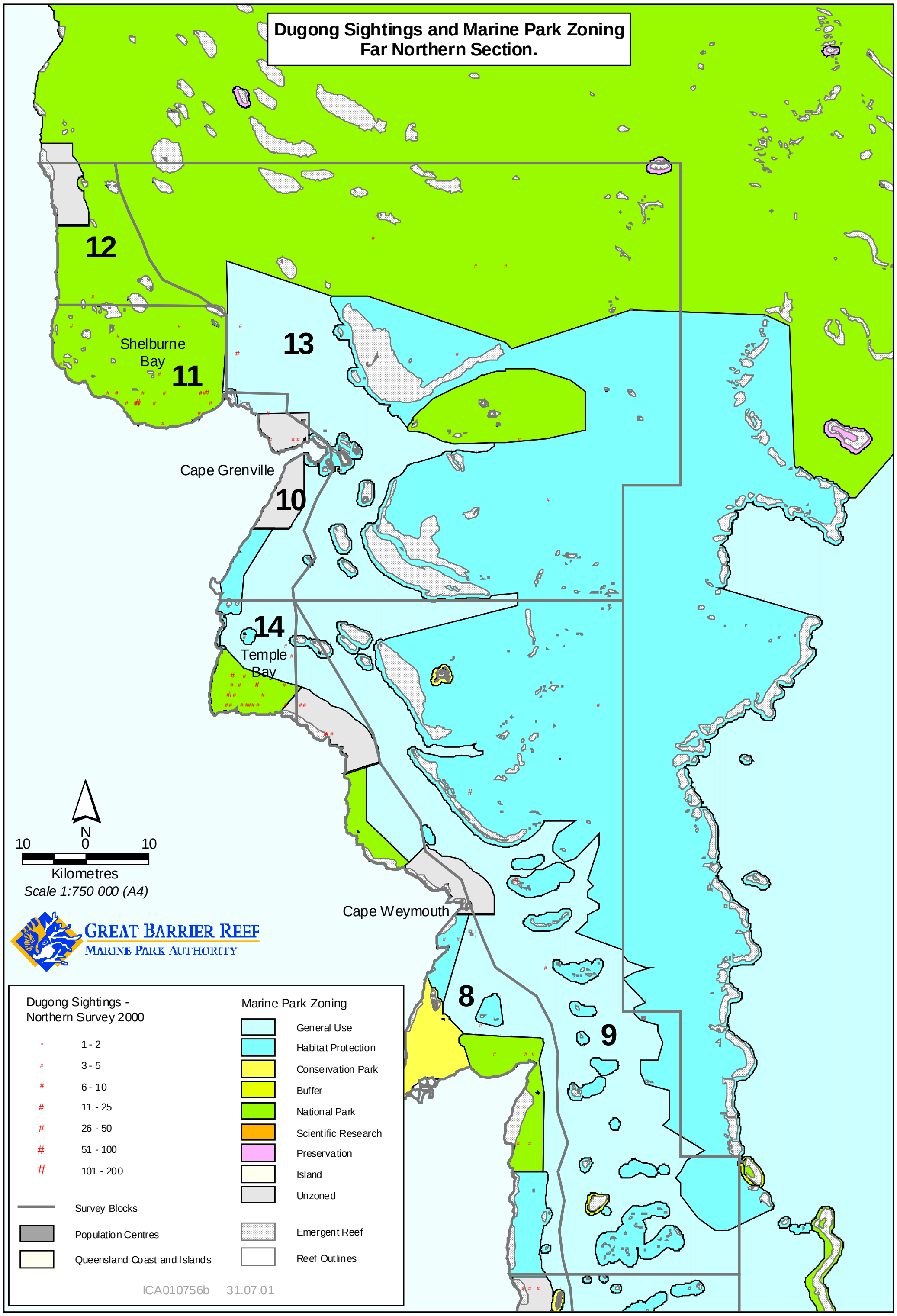

Figure 7. Dugong sightings on the 2000 aerial survey of the Northern GBR in relation to Marine Park Zoning of the area from Lockhart River to Shelburne Bay. Note the differences in survey intensity between survey blocks (Table 1).

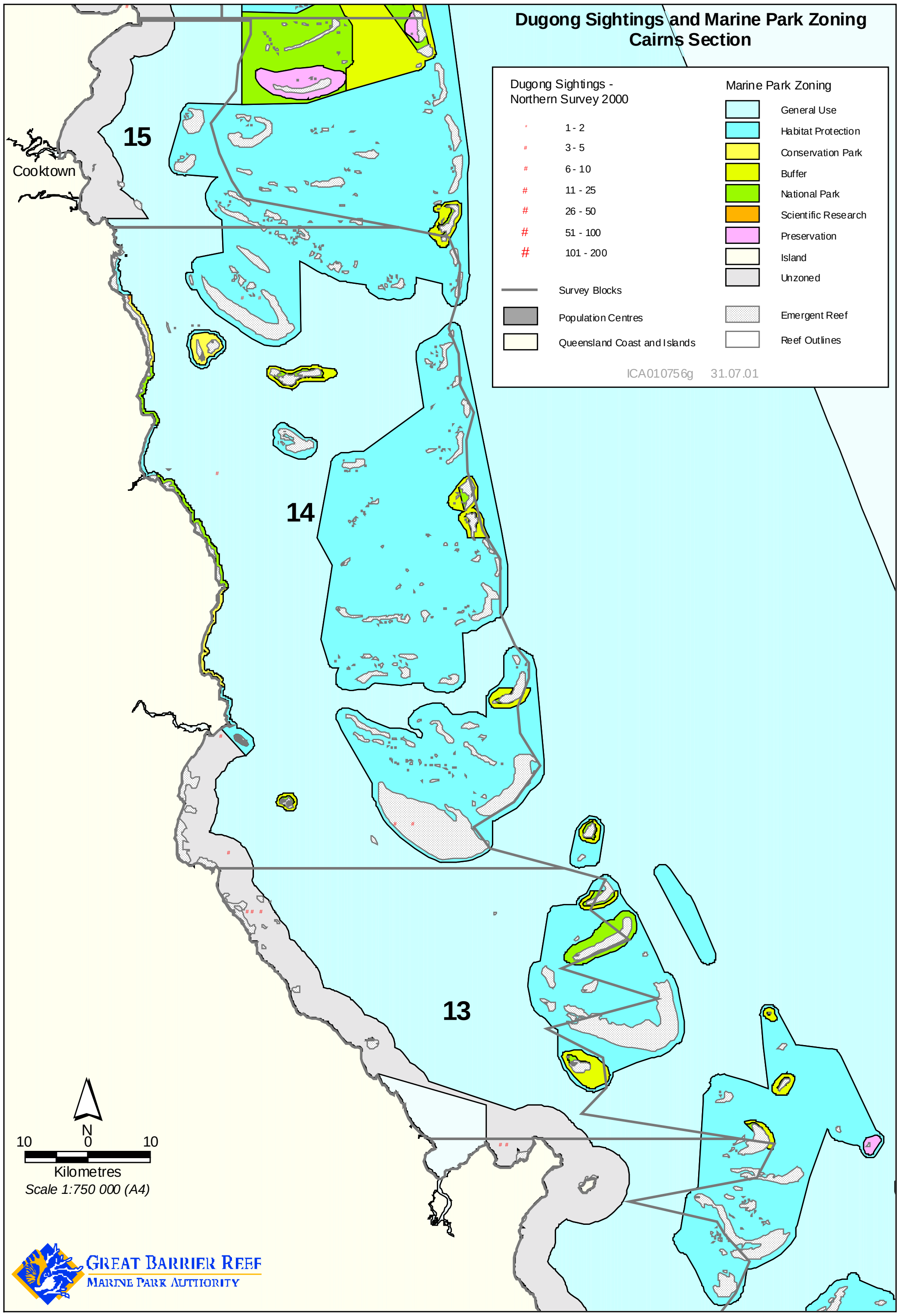

Figure 8. Dugong sightings on the 2000 aerial survey in the region between Cape Bedford and south of Yarrabah in relation to the Marine Park Zoning of the area. Note the differences in survey intensity between survey blocks (Table 1).

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REFERENCES

Bertram, GCL 1981, 'Dugong numbers in retrospect and prospect', *The Dugong: Proceedings of a Seminar/Workshop held at James Cook University 8-13 May 1979*, ed. H Marsh, James Cook University, Townsville, Australia, pp 1-3.

Caughley, G & Grigg GC 1981, 'Surveys of the distribution and density of kangaroos in the pastoral zone of South Australia, and their bearing on the feasibility of aerial surveys in large and remote areas', *Australian Wildlife Research,* 8, pp 1-11.

Eberhardt, LL & O'Shea,TJ 1995, 'Integration of manatee life-history data and population modeling' in *Population Biology of the Florida Manatee (Trichechus manatus latirostris)*, eds. TJ O'Shea, BB Ackerman & HF Percival, National Biological Service, Information and Technology Report 1, pp 269-279.

Great Barrier Reef Marine Park Authority 1981, *Nomination of the Great Barrier Reef by the Commonwealth of Australia for inclusion in the World Heritage List.* Great Barrier Reef Marine Park Authority, Townsville, Australia.

Haines, JA & Limpus CJ 1999, *Marine wildlife stranding and mortality database annual report 1999,* Research Coordination Unit, Parks and Wildlife Strategy Division, Queensland Parks and Wildlife Service.

Haines, JA & Limpus CJ 2000, *Marine wildlife stranding and mortality database annual report 2000,* Research Coordination Unit, Parks and Wildlife Strategy Division, Queensland Parks and Wildlife Service.

IUCN (The World Conservation Union) 2000, *The 2000 Red List of Threatened Species*. IUCN, Gland, Switzerland.

Johannes, RE & MacFarlane, JW 1991, *Traditional fishing in the Torres Strait Islands*, CSIRO Division of Fisheries, Hobart, Australia.

Jolly, GM 1969, 'Sampling methods for aerial censuses of wildlife populations', *East African Forestry Journal,* 34, pp 46-49.

Kwan, D 2002, 'Towards a sustainable Indigenous fishery for dugongs in Torres Strait: A contribution of empirical data and process', Unpublished PhD thesis, James Cook University, Townsville, Australia.

Langtimm, CA, O'Shea TJ, Pradel, R & Beck CA 1998, 'Estimates of annual survival probabilities for adult Florida manatees (*Trichechus manatus latirostris*)', *Ecology,* 79, pp 981-997.

Lanyon, J & Morrice, M 1997, *The status of the dugong in Moreton Bay, south–east Queensland*, Report to the Queensland Department of Environment.

Lawler, I 2001, *Aerial Survey of Dugongs in Moreton Bay and Hervey Bay, April 2001*, School of Tropical Environment Studies and Geography, James Cook University, Townsville.

Marmontel, M 1995, 'Age and reproduction in female Florida manatees', in *Population Biology of the Florida Manatee (Trichechus manatus latirostris),* eds. TJ O'Shea, BB Ackerman & HF Percival, National Biological Service, Information and Technology Report 1, pp 98-119.

Marsh, H 1980, *Age determination of the dugong (Dugong dugon) (Müller) in northern Australia and its biological implications*. Report of the International Whaling Commission Special Issue 3, pp 181-201.

Marsh, H 1995, 'The life history, pattern of breeding and population dynamics of the dugong', in *Population Biology of the Florida Manatee (Trichechus manatus latirostris)*, eds. TJ O'Shea, BB Ackerman & HF Percival, National Biological Service, Information and Technology Report 1, pp 75-83.

Marsh, H 1999, 'Reproduction in sirenians', in 'Reproduction in Marine Mammals', IL Boyd, C Lockyer & HD Marsh, in *Marine Mammals*, eds. JE Reynolds & JR Twiss, Smithsonian Institution Press, pp 243-56.

Marsh, H 2000, 'Evaluating management initiatives aimed at reducing the mortality of dugongs in gill nets in the Great Barrier Reef World Heritage Area'. *Marine Mammal Science* vol, 16, no. 3, pp 684-94.

Marsh, H & Corkeron, P 1996, 'The status of the dugong in the northern Great Barrier Reef Marine Park', Unpublished report to the Great Barrier Reef Marine Park Authority, 47pp.

Marsh, H & Lawler, I 2001, *Dugong distribution and abundance in the southern Great Barrier Reef Marine Park and Hervey Bay: Results of an aerial survey in October-December 1999,* Report to Great Barrier Reef Marine Park Authority, Townsville, Australia.

Marsh, H & Rathbun, GB 1990, 'Development and application of conventional and satellite radio-tracking techniques for studying dugong movements and habitat usage', *Australian Wildlife Research,* 17, pp 83-100.

Marsh, H & Saalfeld, WK 1989, 'The distribution and abundance of dugongs in the northern Great Barrier Reef Marine Park', *Australian Wildlife Research,* 16, pp 429-440.

Marsh, H & Sinclair, DF 1989a, 'An experimental evaluation of dugong and sea turtle aerial survey techniques', *Australian Wildlife Research*, 16, pp 639-650.

Marsh, H & Sinclair, DF 1989b, 'Correcting for visibility bias in strip transect aerial surveys of aquatic fauna', *Journal of Wildlife Management,* 53, pp 1017-1024.

Marsh, H, Corkeron, P, Lawler, IR, Lanyon, JM & Preen, AR 1996, *The status of the dugong in the southern Great Barrier Reef Marine Park.* Great Barrier Reef Marine Park Authority Research Publication 41, 80 pp.

Marsh, H, Corkeron, P, Morissette, N & Preen, AR 1997a, *An assessment of the sustainability of the Indigenous dugong fishery in Torres Strait,* Report to Australian Fisheries Management Authority.

Marsh, H, Harris, ANM & Lawler, IR 1997b, 'The Sustainability of the indigenous dugong fishery in Torres Strait, Australia / Papua New Guinea', *Conservation Biology,* vol. 11, no. 6, pp 1375-1386.

Marsh, H, Prince, RIT, Saalfeld, WK & Shepherd, R 1994, 'The distribution and abundance of dugongs in Shark Bay', *Wildlife Research,* 21, pp 149-61.

Marsh, H, Eros, CM, Corkeron, P & Breen, B 1999, 'A conservation strategy for dugongs: implications of Australian research', *Marine and Freshwater Research,* 50, pp 979-990.

Marsh, H, De'ath, G, Gribble, N & Lane, B 2001, *Shark control records hindcast serious decline in dugong numbers off the urban coast of Queensland*, Report to Great Barrier Reef Marine Park Authority, Townsville, Australia.

Marsh, H, Eros, C, Penrose, H & Hugues, J 2002, *Dugong - Status Report and Action Plans for countries and territories*, UNEP Early Warning and Assessment Report Series 1, pp 162.

Norton-Griffiths, MN 1978, *Counting Animals*, Africa Wildlife Leadership Federation Handbook No.1, Nairobi, Kenya.

Poiner, IR & Peterken, C 1996, 'Seagrasses' in *The state of the marine environment report for Australia*, Technical Annex: 1, eds. LP Zann & P Kailola, Great Barrier Reef Marine Park Authority, Townsville, Australia, pp 40-45.

Preen, AR 1995, 'Dugongs, "hot spots" and meta-herds', in *Proceedings of the 1995 Scientific Meeting of the Australian Mammal Society and Mammals of the Wet Tropics Symposium*, September 1995, Townsville, Australia, p1.

Preen, AR 1999, *Dugongs in the Shoalwater Bay area*, Draft report for the Great Barrier Reef Marine Park Authority, Townsville, Australia.

Preen, AR 2001, *Dugongs, boats, dolphins and turtles in the Townsville-Cardwell region and recommendations for a boat-traffic management plan for the Hinchinbrook Dugong Protection Area*, Final Report to the Great Barrier Reef Marine Park Authority, Townsville, Australia.

Preen, A & Marsh, H 1995, 'Response of dugong to large-scale loss of seagrass from Hervey Bay, Queensland', Australia, *Wildlife Research,* 22, pp 507-519.

Preen, T & Morissette, N 1997, *A system of dugong sanctuaries for the recovery and conservation of dugong populations in the Great Barrier Reef World Heritage Area and adjacent southern waters,* Report to the Great Barrier Reef Marine Park Authority, Townsville, Australia.

Preen, AR, Marsh, H, Lawler, IR, Prince, RIT & Shepherd, R 1997, 'Distribution and abundance of dugong, turtles dolphins and other megafauna in Shark Bay, Ningaloo Reef and Exmouth Gulf, Western Australia', *Wildlife Research,* 24, pp 185-205.

Prince, RIT, Lawler, IR & Marsh, H, 2001, *The distribution and abundance of dugongs and other megavertebrates in Western Australian coastal waters extending seaward to the 20 metre isobath between North West Cape and the De Grey River Mouth, Exmouth, Western Australia, April 2000*, Report for Environment Australia.

Roberts, A, Klomp, N & Birckhead, J 1996, 'Monitoring marine and terrestrial hunting in an Aboriginal community in North Queensland', in *Sustainable Use of Wildlife by Aboriginal People and Torres Strait Islanders*, eds. M Bomford & J Caughley, Australian Government Publishing Service, Canberra, Australia, pp 152-166.

Smith, A & Marsh, H 1990, 'Management of traditional hunting of dugongs (*Dugong dugon* (Müller, 1776)) in the northern Great Barrier Reef', *Australia Environmental Management,* 14, pp 47-55.

Wade, PR 1998, 'Calculating limits to the allowable human-caused mortality of Cetaceans and Pinnipeds'. *Marine Mammal Science,* vol. 14, no.1, pp 1-37.

APPENDICES

Appendix 1. Raw data used for calculation of correction factors for dugongs for the 2000 survey.

a. Correction for perception bias

Blocks: lines	No. of groups of dugongs					
	Port			***Starboard***		
	Mid	*Rear*	*Tandem*	*Mid*	*Rear*	*Tandem*
Northern leg N5-N14 all lines, C14-C15 all lines	21	28	32	50	27	39
Southern leg N1-N4 all lines C12-C13 all lines	36	26	49	41	17	57

b. Correction for availability bias (All sightings used).

Blocks: lines	No. of dugongs in groups less than 10		
	Surface	***Under***	***Total***
Northern leg N5-N14 all lines, C14-C15 all lines	59	209	268
Southern leg N1-N4 all lines C12-C13 all lines	124	215	339

Appendix 2. Beaufort sea state and glare for each transect (see Figure 1 for details of transects)

Glare scale: 0 - no glare, 1 – 0<25%, 2 – 25<50%, 3 - >50%

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	*Max*	*Mode*	*Min*	*Max*	*Mode*	*Min*	*Max*	*Mode*
307	2	2	2	2	2	2	3	3	3
308	2	2	2	2	2	2	3	3	3
309	2	2	2	1	1	1	3	3	3
310	3	3	3	1	1	1	3	3	3
311	2	3	2	2	2	2	3	3	3
312	2	3	2	1	1	1	3	3	3
313	3	3	3	2	2	2	3	3	3
314	3	4	3	2	2	2	3	3	3
315	3	3	3	2	2	2	2	3	2
316	3	4	3	2	2	2	3	3	3
317	2	3	2	3	3	3	2	2	2
318	3	3	3	2	2	2	3	3	3
319	2	2	2	2	2	2	3	3	3
320	1	1	1	3	3	3	3	3	3
321	0	1	0	0	2	0	1	1	1
322	1	1	1	2	2	2	1	1	1
323	1	1	1	0	0	0	1	1	1
324	1	1	1	2	2	2	2	2	2
325	1	2.5	2.5	1	2	1	1	2	1

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	***Max***	***Mode***	***Min***	***Max***	***Mode***	***Min***	***Max***	***Mode***
326	1	2	2	2	3	2	2	3	2
327	2	2	2	2	3	2	2	3	2
328	1	3	1	3	3	3	3	3	3
329	1	2	1	1	1	1	2	2	2
330	1	2	1	3	3	3	2	2	2
331	1	2	1	0	2	0	0	2	0
332	1	2	1	2	2	2	2	2	2
333	1	2	1	1	2	1	1	2	1
334	1	2	1	0	1	0	0	2	0
335	1	2	1	1	1	1	1	1	1
336	1	1	1	0	0	0	1	1	1
337	1	1	1	0	1	0	1	1	1
338	1	1	1	1	1	1	1	1	1
339	1	2	1	1	1	1	1	1	1
340	1	3	1	3	3	3	2	2	2
341	2	2	2	1	2	1	2	2	2
342	1	3	1	2	2	2	2	2	2
343	1	1	1	1	1	1	1	1	1
344	2	2	2	3	3	3	2	2	2
345	1	1	1	1	2	1	2	3	2
346	1	3	1	1	1	1	0	0	0
347	2	3	2	1	2	1	1	2	2

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	***Max***	***Mode***	***Min***	***Max***	***Mode***	***Min***	***Max***	***Mode***
348	2	2	2	1	1	1	1	1	1
349	2	2	2	1	1	1	2	2	2
350	0	3	0	0	3	2	0	3	1
351	1	3	2	0	3	2	0	2	2
352	1	3	1	0	3	3	0	3	0
353	1	3	1	1	3	2	1	2	1
354	2	3	3	0	3	1	0	2	0
355	1	3	3	1	2	2	1	1	1
356	1	3	1	1	2	1	1	2	1
357	1	3	2	1	3	3	2	3	3
358				2	2	2	3	3	3
359	1	3	1	2	3	2	2	3	3
360				3	3	3	2	2	2
361	1	3	1	1	3	1	1	3	1
362	3	3	3	3	3	3	3	3	3
363	2	3	2	1	2	2	2	3	2
364	3	3	3	3	3	3	3	3	3
365	1.5	3	2	2	2	2	2	2	2
366	1	3	2	3	3	3	2	2	2
367	0.5	2.5	2	0	0	0	2	2	2
368	0	2.5	2	2	2	2	1	1	1
370	0	2	2	0	1	0	0	2	0

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	***Max***	***Mode***	***Min***	***Max***	***Mode***	***Min***	***Max***	***Mode***
372	0	2	2	3	3	3	2	2	2
374	1	3	1	2	2	2	2	2	2
376	2	3	2	1	1	1	3	3	3
378	2	3	2	3	3	3	3	3	3
380	1	3.1	2.5	1	2	1	2	3	2
382	2	2	2	3	3	3	2	2	2
383	1	2.5	2	2	2	2	3	3	3
384	2	3	2	2	2	2	0	3	0
385	2	2.5	2	3	3	3	2	2	2
386	1	2	1	3	3	3	2	2	2
387	1	2	2	2	2	2	2	2	2
388	0	2	1	1	2	1	3	3	3
389	2	2	2	3	3	3	2	2	2
390	0	0	0	0	3	0	1	2	1
391	1	2	2	3	3	3	2	2	2
392	0	1	0	3	3	3	1	1	1
393	1.5	2	2	3	3	3	2	2	2
394	0	1	0	1	1	1	1	3	1
395	1	2	1	2	2	2	3	3	3
396	0.5	2	0.5	0	2	0	1	2	1
397	1	1	1	3	3	3	1	1	1
398	0	2	1	0	0	0	3	3	3

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	***Max***	***Mode***	***Min***	***Max***	***Mode***	***Min***	***Max***	***Mode***
399	1	1	1	2	2	2	3	3	3
400	0	2	0	2	3	2	1	3	1
401	2	2	2	3	3	3	2	3	2
402	0	2	0	1	2	1	2	3	2
403	2	2	2	0	3	0	3	3	3
404	0	1	0	1	1	1	1	3	1
405	0	0.5	0	3	3	3	2	2	2
406	0	1	1	0	2	0	0	3	0
407	0.5	0.5	0.5	1	2	1	2	2	2
408	0	1	1	2	2	2	1	2	1
409	1	1	1	1	1	1	2	3	2
410	2	3	2	2	2	2	2	2	2
411	0.5	1	0.5	3	3	3	1	1	1
412	1	2	2	1	2	1	3	3	3
413	0	2	1	0	3	0	1	3	1
414	1	2	1	1	3	1	2	3	2
415	1	1	1	1	2	1	3	3	3
416	0	2	1	2	2	2	1	2	1
417	1	1	1	3	3	3	1	1	1
418	0	2	1	3	3	3	1	1	1
419	1	2	1	1	1	1	3	3	3
420	1	2	2	1	2	1	2	3	2

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	***Max***	***Mode***	***Min***	***Max***	***Mode***	***Min***	***Max***	***Mode***
421	1	1	1	0	1	0	0	0	0
422	1	1	1	0	0	0	0	0	0
423	1	1	1	1	1	1	0	0	0
424	1	1	1	0	0	0	1	1	1
425	1	1	1	0	1	1	0	1	0
426	0	0	0	1	1	1	0	0	0
427	1	1	1	1	1	1	1	1	1
428	1	1	1	1	2	1	0	2	1
429	1	2	1	0	1	0	0	1	1
430	1	1	1	0	1	1	0	2	2
431	0	2	1	0	1	1	0	2	1
432	1	1	1	0	2	0	0	2	0
433	1	2	1	0	2	2	1	2	2
434	2	3	2	0	2	1	2	3	2
435	1	2	1	1	2	1	1	2	1
436	0	2	0	0	1	0	1	2	1
437	0	2	1	0	2	0	0	2	0
438	1	1	1	0	1	1	1	2	1
439	1	2	1	1	2	1	1	2	1
440	1	2	1	0	1	1	2	3	3
441	2	2	2	1	1	1	2	3	2
442	1	1	1	1	1	1	1	1	1

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	***Max***	***Mode***	***Min***	***Max***	***Mode***	***Min***	***Max***	***Mode***
443	2	2	2	1	1	1	1	1	1
444	2	3	2	2	2	2	2	2	2
445	2	3	2	2	2	2	2	2	2
446	2	2	2	1	1	1	2	2	2
447	2	2	2	2	2	2	1	1	1
448	2	2	2	1	2	1	1	2	1
449	2	2	2	1	2	1	1	2	2
450	2	2	2	1	2	1	1	2	1
451	2	2	2	1	2	2	1	2	1
452	2	2	2	1	2	1	1	2	1
453	2	2	2	1	1	1	1	1	1
454	2	2	2	1	2	1	2	2	2
455	2	2	2	0	0	0	2	2	2
456	1	2	1	0	1	0	1	2	1
457	2	2	2	1	1	1	2	2	2
458	1	3	1	0	0	0	2	2	2
459	1	2	1	1	1	1	1	2	2
460	1	2	2	0	0	0	2	2	2
461	2	3	2	1	2	1	2	2	2
462	2	3	2	0	1	0	2	3	2
463	2	2	2	1	1	1	1	1	1
464	1	1	1	1	1	1	1	1	1

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	***Max***	***Mode***	***Min***	***Max***	***Mode***	***Min***	***Max***	***Mode***
465	1	1	1	0	1	0	1	1	1
466	1	1	1	1	1	1	1	1	1
467	1	2	1	0	1	0	0	1	0
468	1	2	1	1	1	1	1	1	1
469	1	2	2	1	1	1	1	1	1
470	2	2	2	2	2	2	2	2	2
471	2	3	2	2	2	2	2	2	2
472	2	3	3	1	1	1	1	2	1
473	3	3	3	1	1	1	1	1	1
474	2	3	2	1	1	1	3	3	3
475	2	3	2	1	1	1	2	2	2
476	2	3	2	1	1	1	1	1	1
477	2	3	2	1	1	1	2	2	2
478	2	2	2	1	1	1	2	2	2
479	3	3	3	1	1	1	1	1	1
480	2	2	2	1	1	1	1	2	1
481	2	2	2	1	1	1	2	2	2
482				2	2	2	3	3	3
483	3	3	3	2	2	2	2	2	2
484	3	3	3	2	2	2	2	3	2
485	3	3	3	1	2	1	1	2	1
486	3	3	3	2	2	2	3	3	3

Transect	Beaufort Sea state			Glare					
				North			South		
	Min	***Max***	***Mode***	***Min***	***Max***	***Mode***	***Min***	***Max***	***Mode***
487	3	3	3	2	2	2	2	2	2
488	3	3	3	2	2	2	2	3	2
489	2	2	2	2	2	2	2	2	2
490	2	3	2	2	2	2	2	2	2
491	2	3	2	1	2	1	2	3	2
492	2	3	2	2	2	2	2	2	2
493	3	3	3	2	2	2	2	2	2
494	3	3	3	2	2	2	2	2	2
495	3	3	3	1	1	1	2	2	2
496				1	2	1	2	2	2
497	3	3	3	1	1	1	3	3	3
498	2	3	2	1	1	1	2	2	2
499				1	1	1	3	3	3
500	3	3	3	2	2	2	2	2	2
501	3	3	3	2	2	2	1	1	1
502	2	3	2	2	2	2	1	2	1
503	2	3	2	2	3	2	2	2	2
504	2	3	3	2	2	2	2	2	2
505	3	3	3	2	3	2	2	3	2
506	2	3	3	2	2	2	2	3	2

Appendix 3. Raw data detailing sightings of dugong groups for each transect in each block used for population estimates.

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
Central GBR				
C12				
307	21.0	8.4	0	0
308	21.1	8.4	0	0
309	21.1	8.4	0	0
310	21.1	8.4	0	0
311	21.1	8.4	0	0
312	21.1	8.4	0	0
313	21.1	8.4	0	0
314	21.1	8.4	0	0
315	29.6	11.8	0	0
316	34.6	13.8	0	0
317	30.0	12.0	0	0
318	13.8	5.5	0	0
319	30.6	12.2	0	0
320	32.3	12.9	0	0
321	6.3	2.5	0	0
322	2.9	1.2	0	0
323	6.8	2.7	0	0
324	5.3	2.1	0	0
325	15.3	6.1	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
C13				
326	25.9	10.4	0	0
327	29.4	11.8	0	0
328	32.3	12.9	0	0
329	31.9	12.8	0	0
330	55.1	22.0	0	0
331	38.8	15.5	0	0
332	53.3	21.3	0	0
333	52.0	20.8	0	0
334	57.2	22.9	0	0
C14				
335	43.5	17.4	1	0
336	42.4	16.9	1	1
337	49.9	20.0	0	0
338	49.9	19.9	0	0
339	45.2	18.1	0	1
340	43.2	17.3	0	0
341	45.8	18.3	0	0
342	45.5	18.2	1	0
343	40.3	16.1	0	0
344	39.6	15.8	0	0
345	41.4	16.6	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km²)	# groups port	# groups starboard
346	41.4	16.5	0	0
347	41.6	16.6	0	0
348	45.4	18.2	0	3
349	46.4	18.6	0	0
350	47.7	19.1	0	0
351	46.2	18.5	0	0
352	43.3	17.3	0	0
353	46.5	18.6	0	0
354	48.1	19.2	0	0
355	50.3	20.1	0	0
356	48.0	19.2	0	0
C15				
357	21.3	8.5	0	0
358	10.6	4.3	0	0
359	21.3	8.5	0	0
360	10.6	4.3	0	0
361	21.3	8.5	0	0
362	10.6	4.3	0	0
363	21.3	8.5	0	0
364	10.6	4.3	0	0
365	21.3	8.5	0	0
366	21.3	8.5	0	0
367	21.3	8.5	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
Northern GBR				
N1				
368	21.0	8.4	0	1
369	22.1	8.8	0	0
370	22.6	9.0	0	1
371	23.0	9.2	0	0
372	23.1	9.3	0	0
373	23.0	9.2	0	0
374	22.4	9.0	0	0
375	21.7	8.7	0	0
376	21.4	8.5	0	1
377	21.3	8.5	0	0
378	21.6	8.6	0	0
379	21.1	8.5	0	0
380	20.9	8.3	0	0
381	19.8	7.9	0	0
382	21.0	8.4	0	0
383	26.7	10.7	1	0
384	25.7	10.3	0	0
385	22.5	9.0	0	0
386	23.3	9.3	0	1
387	22.4	8.9	0	0
N2				

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
388	13.1	5.2	0	0
389	16.4	6.6	3	2
390	22.1	8.9	1	7
391	21.1	8.4	11	8
392	21.3	8.5	12	10
393	22.2	8.9	5	8
394	22.3	8.9	1	1
395	22.2	8.9	1	1
396	23.3	9.3	0	0
397	22.2	8.9	1	2
398	22.2	8.9	2	0
399	21.7	8.7	9	1
400	22.3	8.9	0	1
401	21.6	8.6	0	1
N3				
402	22.8	9.1	11	6
403	22.0	8.8	8	2
404	26.1	10.4	6	9
405	24.2	9.7	5	5
406	22.6	9.0	9	1
407	22.0	8.8	0	3
408	22.3	8.9	1	0
409	22.6	9.0	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
410	22.1	8.9	0	0
411	26.5	10.6	2	2
412	23.6	9.4	1	1
413	23.3	9.3	1	0
414	22.3	8.9	0	1
415	21.6	8.6	0	1
416	23.2	9.3	1	1
417	24.0	9.6	1	1
418	24.2	9.7	0	2
419	23.1	9.2	2	1
420	25.2	10.1	0	0
N4				
368	31.0	12.4	0	0
370	31.9	12.8	1	0
372	31.4	12.5	0	0
374	31.0	12.4	0	0
376	29.0	11.6	0	0
378	24.8	9.9	0	0
380	21.2	8.5	0	0
382	18.3	7.3	0	0
384	25.8	10.3	0	0
386	32.3	12.9	0	0
388	52.1	20.8	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km²)	# groups port	# groups starboard
390	53.8	21.5	1	0
392	59.3	23.7	1	4
394	59.3	23.7	1	1
396	53.4	21.3	0	1
398	57.8	23.1	0	1
400	70.1	28.0	0	1
402	77.0	30.8	0	1
404	70.4	28.2	1	1
406	74.3	29.7	1	0
408	68.3	27.3	0	2
410	58.1	23.3	0	0
412	51.9	20.8	1	2
414	48.3	19.3	0	2
416	34.3	13.7	1	0
418	20.5	8.2	0	0
420	14.8	5.9	0	0
N5				
421	25.6	10.3	0	1
422	35.2	14.1	0	2
423	43.8	17.5	4	1
424	48.4	19.4	1	1
425	50.0	20.0	2	1
426	12.7	5.1	4	1

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
427	78.9	31.6	4	3
428	83.4	33.4	6	8
429	82.4	33.0	2	1
430	121.5	48.6	1	0
431	119.2	47.7	2	3
432	119.5	47.8	2	2
433	119.7	47.9	6	4
434	115.7	46.3	1	4
435	84.3	33.7	0	1
436	81.9	32.8	1	1
437	81.2	32.5	2	2
438	80.4	32.2	1	2
439	79.7	31.9	1	0
440	74.2	29.7	0	0
441	67.9	27.2	2	0
442	63.1	25.2	2	1
443	38.3	15.3	0	0
444	35.8	14.3	0	1
N6				
445	10.4	4.1	0	2
446	10.8	4.3	2	3
447	11.3	4.5	2	0
448	9.8	3.9	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km²)	# groups port	# groups starboard
449	13.4	5.3	1	4
450	13.8	5.5	0	0
451	12.9	5.2	0	0
452	8.5	3.4	0	0
453	8.3	3.3	1	2
N7				
445	26.2	10.5	0	0
446	24.4	9.8	0	0
447	23.5	9.4	0	0
448	26.8	10.7	0	0
449	19.4	7.8	0	0
450	20.0	8.0	0	0
451	21.4	8.6	0	0
452	25.8	10.3	0	0
453	26.2	10.5	0	0
N8				
454	8.6	3.4	0	0
455	7.7	3.1	0	0
456	8.5	3.4	0	0
457	7.0	2.8	0	0
458	9.7	3.9	1	1
459	7.1	2.8	0	0
460	4.6	1.8	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
461	23.5	9.4	1	2
462	22.2	8.9	0	1
463	17.6	7.0	0	0
464	9.7	3.9	0	0
465	7.2	2.9	0	2
466	1.1	0.4	0	0
467	6.4	2.5	0	0
468	9.5	3.8	0	0
469	11.6	4.7	0	0
470	7.9	3.2	0	0
471	5.3	2.1	0	0
472	9.7	3.9	3	1
473	9.4	3.8	0	2
476	6.6	2.7	0	0
479	4.1	1.7	0	0
482	1.2	0.5	0	0
N9				
454	27.3	10.9	0	0
455	27.9	11.2	0	0
456	27.1	10.8	0	0
457	28.1	11.2	0	0
458	17.5	7.0	0	0
459	19.1	7.6	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km²)	# groups port	# groups starboard
460	19.3	7.7	0	0
461	19.1	7.6	0	0
462	20.0	8.0	0	0
463	13.4	5.4	0	0
464	19.7	7.9	0	1
465	21.8	8.7	0	0
466	23.8	9.5	0	0
467	25.1	10.0	0	1
468	30.7	12.3	0	0
469	31.5	12.6	0	0
470	34.6	13.9	0	1
471	37.7	15.1	0	0
472	38.8	15.5	0	0
473	41.3	16.5	0	1
476	42.9	17.2	0	0
479	46.8	18.7	0	0
482	49.6	19.8	0	0
N10				
483	12.9	5.2	0	0
484	12.0	4.8	0	0
485	8.1	3.2	0	0
486	7.3	2.9	0	0
487	7.7	3.1	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km²)	# groups port	# groups starboard
488	8.3	3.3	0	3
489	5.4	2.2	1	0
N11				
490	9.1	3.7	1	0
491	12.7	5.1	1	0
492	16.3	6.5	3	3
93	21.0	8.4	7	0
494	21.6	8.6	0	3
495	25.0	10.0	0	0
496	26.5	10.6	0	2
497	27.0	10.8	0	0
498	27.0	10.8	0	0
499	27.2	10.9	0	0
500	27.0	10.8	1	2
501	26.7	10.7	0	0
N12				
502	21.8	8.7	0	1
503	15.0	6.0	0	0
504	13.2	5.3	0	0
505	11.6	4.6	0	0
506	10.5	4.2	0	0
N13				
483	51.2	20.5	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
484	48.0	19.2	0	0
485	49.5	19.8	0	0
486	47.1	18.8	1	0
487	54.1	21.6	1	0
488	55.9	22.3	0	1
489	61.3	24.5	0	0
494	70.8	28.3	0	0
497	70.8	28.3	1	1
500	70.8	28.3	0	1
502	75.1	30.0	0	0
503	82.0	32.8	0	0
504	84.1	33.6	0	2
505	86.2	34.5	0	1
506	87.8	35.1	0	0
N14				
473	13.4	5.4	0	2
474	13.5	5.4	1	3
475	13.2	5.3	0	5
476	13.0	5.2	0	0
477	12.4	5.0	0	0
478	11.9	4.8	0	1
479	12.3	4.9	0	0
480	12.1	4.9	0	1

Block, Transect Number	Transect length (over sea only) (km)	Transect area(km^2)	# groups port	# groups starboard
481	11.2	4.5	0	0
482	11.7	4.7	0	0