An assessment of the sustainability of the Indigenous dugong fishery in Torres Strait

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1. EXECUTIVE SUMMARY

- This report is presented in two sections. In the first section, we report the results of a third survey of dugong distribution and abundance in Torres Strait conducted over four days in November 1996. In the second section, we estimate the size of a sustainable dugong catch in Torres Strait using the Potential Biological Removal Method (PBR) method developed in the United States. We then evaluate the sustainability of the dugong fishery by comparing aerial survey estimates of the size of the dugong population in 1987, 1991 and 1996, and catch statistics from the TSPZ since 1991 in the context of current knowledge of dugong life history parameters.

- A total of 384 groups comprising 602 dugongs were sighted in Torres Strait during the 1996 survey. A total of 73 animals were identified as calves (12.1% of the population), a proportion not significantly different from those observed in 1987 and 1991. As in 1987 and 1991 more than 75% of groups were solitary dugongs or cow-calf pairs.

- A minimum population estimate of 27,881 ± s.e. 3,216 dugongs at an overall density of 0.912± s.e. 0.102 dugongs km^{-2} was calculated for the region on the basis of the 1996 survey. Population estimates for 1987, 1991 and 1996 differ significantly. Post-hoc comparisons demonstrate that the significant differences were between 1987 and both 1991 and 1996. However, there was no difference between the estimates for 1991 and 1996. This result reduces rather than eliminates concerns that the Torres Strait dugong fishery may not be sustainable because declines have to be large to be detected by aerial surveys.

- The PBR method suggests that an annual harvest of 500 per year should be sustainable. In at least some years since 1990, the annual dugong catch has been substantially higher than this figure in the Protected Zone e.g. 1226 ± 204 in 1991-93. The total harvest for the area must have been even higher than this as these estimates do not include the catches from south of the Protected Zone or from Papua New Guinea.

- The dugong fishery will not be effectively managed until the Islanders and the government management agencies develop mutually acceptable management objectives for this fishery. We suggest that the Torres Strait Regional Authority and the Islander Co-ordinating Council be empowered to manage dugong resources under Australian jurisdiction in a formal co-operative management arrangement with the Australian Fisheries Management Authority. Parallel arrangements should be developed for the fishery in Papua New Guinean waters.

2. INTRODUCTION

The dugong, *Dugong dugon* (Order Sirenia), is a large, herbivorous marine mammal. It is listed as vulnerable to extinction by the International Union for the Conservation of Nature (IUCN 1996). The listing is supported by the results of population simulations (Marsh, 1995a) which indicate that dugong numbers are unlikely to increase at more than about 5% per year, even if all the females in a population are breeding maximally (Marsh, 1995a). In addition, recent information on the pattern of natural mortality in the Florida manatee (Eberhardt and O'Shea 1995, Langtimm *et al.* in press) suggests that this rate of increase may be to high (Marsh 1998).

Dugong meat is ranked highest among traditional foods by the peoples of Torres Strait (Johannes and MacFarlane 1991). In 1985, Australia and Papua New Guinea entered into the Torres Strait Treaty to resolve the maritime boundaries in this region and to protect the way of life and livelihood of its traditional inhabitants. The Treaty established the Torres Strait Protected Zone (TSPZ; Figure 1) within which each country exercises sovereign rights for marine life according to agreed jurisdictions. The traditional dugong fishery in the TSPZ is managed jointly by Australia and Papua New Guinea under Article 22 of the Treaty (TSPZJA 1994).

Mitochondrial DNA has been used to investigate the stock structure of female dugongs (Tikel 1997). Tikel's study suggests that Australian dugongs are genetically distinct from those in Asia and that there is significant structure within the Australian dugong population with two major haplotype structures: North and West Australian and South East Queensland. Animals from both haplotype clusters occur in the Great Barrier Reef-Torres Strait region within which there is evidence of further genetic structure. The most obvious cause of this overall pattern is the former Torres Strait land bridge. The persistence of genetic structure despite the sea level being constant in the region for the last 6000 years, suggests that, if the dugong is eliminated from part of its range, recolonisation will be very slow.

Some local people (see Johannes and MacFarlane 1991) and scientists (e.g. Hudson 1986; Marsh 1986; Johannes and MacFarlane 1991) have been concerned about the sustainability of traditional dugong catches by the communities of Torres Strait since the early 1980s. Of particular concern is the increase in the availability of outboard-powered dinghies which might be expected to improve the effective hunting effort.

Theoretically, hunting *per se* should be unlikely to drive a species to extinction because hunting pressure declines with the density of the prey species since it takes longer to find animals when density is low. However, this inbuilt safeguard does not necessarily apply when hunting is targeted towards more than one species (Bomford and Caughley 1996). In Torres Strait, dugongs and green turtles are hunted together. Thus unregulated dugong hunting would be expected to cease only when the combined density of dugongs and green turtles is so low that hunting is not worthwhile. As aerial surveys indicate that turtles are much more abundant than dugongs in this region (Marsh and Saalfeld 1989a; Marsh and Lawler 1992), there is a danger of dugongs being seriously impacted by hunting in Torres Strait. Accordingly, the Australian Fish Management Authority has funded research to: (1) determine the stock structure of dugongs (see Tikel 1997 above), (2) estimate trends in dugong catches (Harris *et al.* 1994, 1997; Dews 1995; Marsh *et al.* 1997a) and, (3) abundance (Marsh and Saalfeld 1991, Marsh *et al.* 1997a) with the overall objective of evaluating the sustainability of the Indigenous catch of dugongs in Torres Strait.

Marsh and Sinclair (1989a and b) developed techniques which attempted to correct counts for the biases inherent in the survey technique: perception bias (the proportion of dugongs visible in the transect which are missed by observers), and availability bias (the proportion of dugongs that are invisible due to water turbidity). These techniques were applied in surveys of the Torres Strait region in 1987 and 1991. In contrast to the consistent estimates obtained by repeat surveys of other regions using this technique (Marsh, 1995b), the dugong population estimates for Torres Strait were extremely variable. The estimate in November-December 1991 summed to 24,225 $\pm$ S.E. 3,276 dugongs compared with 13,319 $\pm$ S.E. 2,136 dugongs in November 1987 (Marsh et al. 1997a). The difference cannot be explained by natural increase or differences in weather conditions between surveys which were marginally worse in 1991 than in 1987. Marsh et al. (1997a) concluded that the difference was due to either: (1) a change in the distribution of the animals in the survey region within or between the surveys, or (2) animals migrating into Torres Strait, probably from the west.

To examine the likelihood of dugongs undertaking significant local movements within Torres Strait during a large-scale aerial survey, the region around Badu and extending north across Orman Reef around Buru Island and east to Gabba Island were resurveyed on two successive days in 1993 and four days in 1994 (Marsh et al. 1996a). The variation between dugong counts per grid cell on successive days was not significant suggesting low rates of movement between sampling days within the years 1993 and 1994. The mean count of dugongs per transect did not vary significantly over the short term, however, there was a significant difference between years. These results suggest that provided a large-scale survey of Torres Strait is completed within a matter of days, dugong movements within the survey area should not confound the results (Marsh et al. 1996a)

The methods and results sections of this report are presented in two sections. In the first section, we discuss the results of a third survey of dugong distribution and abundance in Torres Strait conducted over four days in November 1996. In the second section, we estimate the size of a sustainable dugong catch in Torres Strait using the Potential Biological Removal Method (PBR) method developed in the United States. The PBR concept has been extensively examined by bodies such as the International Whaling Commission and the US National Marine Fisheries Service (Barlow 1995, Wade in press) and has generally stood up to this scrutiny. There have been extensive simulation trials to develop and test the formula.

In the General Discussion of this report, we evaluate the sustainability of the dugong fishery by comparing aerial survey estimates of the size of the dugong population in 1987, 1991 and 1996, and catch statistics from the TSPZ since 1991 in the context of current knowledge of dugong life history parameters (Marsh 1995a, 1998).

We conclude that, although it is still not possible to be certain about the status of the dugong in this area without more data, there is some cause for concern about the sustainability of the current catch. The special significance of the dugong to the peoples of Torres Strait has been recognised formally by the Torres Strait Treaty. Mechanisms need to be developed and implemented to empower these peoples to take a leading strategic and operational role in managing their dugong fishery.

3. THE 1996 AERIAL SURVEY

3.1 METHODS

Survey design

The western and central waters of Torres Strait north of 11^0S were surveyed between the 10th and 13th of November 1996 using two survey crews on two Partenavia 68B aircraft to minimise the chance of the population estimates being confounded by local movements of dugongs within the survey period. As in the 1987 and 1991 surveys, the area was divided into eight blocks (Figure 2) on the basis of sampling intensity and transect placement. Transects were aligned in an east-west direction south of Buru (Turnagain) Island (9° 34'S, 142° 18'E), and north-south along the coast of Papua New Guinea. Transect lines were spaced 5' apart in Blocks 0, 1B, 3 and 4; and at intervals of 2.5' in Blocks 1A, 2A, 2B and 5.

The survey design was determined by: (1) the boundaries of Australian air space, (2) the known distribution of suitable dugong habitat, (3) the endurance of the aircraft from Horn Island, the only site in Australian territory in the region where aircraft fuel could be purchased, and (4) the aircraft time available for the survey. The design (Figure 2) was the same as that used in the previous surveys except that: (1) of the seven easternmost transects in Block 1A, the two short transects were not flown and the remaining five were truncated at 9°10'S (Figure 1) because we were unable to enter Papua New Guinea air space close to Daru, and (2) as in 1991, the survey intensity in Blocks 0 and 1B was halved from that used in 1987 by increasing the interval between successive transects from 2.5' in 1987 to 5'.

A total of 30,568 km^2 were surveyed in 1996. A global positioning system mounted in the aircraft facilitated precise and accurate navigation. The aircraft was fitted with a radar altimeter for accurate height control.

In order to increase repeatability, the survey was conducted only when the weather conditions were good (usually Beaufort Sea State $\leq$ 3; Table 1 and Appendix Table 1). Whenever possible, daily schedules were arranged to avoid severe glare associated with a low or midday sun.

Block areas (Table 2) were estimated from 1:100,000 digitised topographic coverage (AUSLIG) using the ArcInfo GIS package. The areas of all islands were excluded from the block areas. The length of each transect was also estimated from these digitised maps.

Survey methodology

As in 1987 and 1991, we used the strip transect aerial survey methodology as detailed by Marsh and Sinclair (1989a and b) and Marsh and Saalfeld (1989b). We chose to continue using this methodology rather than the line transect methods now routinely used for dolphin surveys (e.g. Barlow et al. 1997) because: (1) consistent methodology is essential to a reliable time series, (2) Marsh and Saalfeld (1990) verified that the strip width used is sufficiently narrow to preclude detectable variation in dugong sightability across the transect, and (3) dugongs are generally more difficult to sight than dolphins. Dugongs are most often seen as solitary individuals or adult female-calf pairs in turbid water and exhibit cryptic surfacing behaviour. We therefore preferred to use a technique in which the observers do not have to take their eyes off the water to read an inclinometer.

The transect width (200 m on either side of the aircraft at the survey altitude of 137 m) was demarcated with calibrated fibre glass rods attached to artificial wing struts on either side of the aircraft. Each sighting was recorded as being made in the upper, middle or lower third of the transect to facilitate deciphering whether simultaneous sightings by tandem observers were the same group of animals.

Correction factors

As in the previous surveys, population estimates were corrected for perception bias (the groups of animals visible on the transect line that were missed by observers) and availability bias (the groups of animals unavailable to the observers due to water turbidity). The standard errors of the corrections factors were included in the population estimates as outlined in Marsh and Sinclair (1989a).

There was a tandem team of observers on either side of each aircraft (Marsh and Sinclair 1989a). Each team of observers was visually and acoustically isolated from the other team in the same aircraft and reported their sightings in standard format in separate tracks of a two-track tape recorder. After each flight, the tape record of each transect (Appendix Figure 2) was used to verify and edit the computer records of the flight, so that each sighting could be coded as made by one specific member or both members of a tandem observing team (Marsh and Sinclair 1989a). The corrections for perception bias were calculated using the Peterson Mark Recapture Model on the basis of the proportion of the relevant sightings seen by one (specified) or both members of each tandem team of observers. Separate corrections for perception bias were calculated for each of the four teams of observers used in the survey (Table 3; Appendix Table 2). The perception correction factor requires that all groups of dugongs are equally sightable. Marsh and Sinclair (1989a) showed that this is a reasonable assumption for the small groups of dugongs usually observed.

Corrections for availability bias were calculated by standardising the proportion of dugongs sighted by each team during the survey to the number seen on the surface in clear water where all dugongs were potentially available (Marsh and Sinclair, 1989a). The corrections for availability bias for dugongs make the untested assumption that a constant proportion of the target species is at the surface.

Analysis

As the transects were variable in area, the Ratio Method (Jolly 1969; Caughley and Grigg, 1981) was used to estimate the density, population size and associated standard errors for each taxon for each block. Any statistical bias resulting from this method is considered inconsequential due to the relatively high sampling intensity (Table 2, see also Caughley and Grigg, 1981). Input data were the estimated number of dugongs (in groups of fewer than 10 animals) for each tandem team per transect calculated with the corrections for perception and availability biases. The resultant standard errors of the population estimates were adjusted to incorporate the errors associated with the various correction factors as outlined in Marsh and Sinclair (1989a). The numbers of dugongs in groups of more than 10 was added to the estimates of the populations and density of the appropriate block at the end of the analysis, as outlined in Norton-Griffiths (1978). The population estimate for the whole survey area was obtained by summing the estimates for each block. The standard error of the population estimates for the entire region was calculated as the square root of the sum of the variances of the population estimates of each block. this method assumes that the population estimates for each block are independent. Marsh et al. (1996) showed that this is a reasonable assumption as any spatial autocorrelation in dugong distribution occurs at a much smaller spatial scale than the survey blocks.

Differences between this survey and the previous surveys in the numbers of dugongs were tested using analysis of variance. Input data were the ln (x+1) corrected counts of dugongs per transect. Adjustments were made for any inter-survey changes in survey design. Fixed factors in the model were time and block. Transect was treated as a random factor nested within block. The analysis was run with the modal Beaufort sea state for each transect as a covariate to compensate for differences in weather conditions between surveys. Input data for all analyses were the corrected counts of dugongs per transect based on mean group sizes and the estimates of the correction factors for perception and availability bias, each transect contributing one corrected count per survey based on combined corrected counts of both tandem teams. All significance tests were two tailed.

Density diagrams, adjusted for sampling intensity, were produced using the Arc/Info GIS package. A coverage of 5 x 5 nm square grids overlaying the survey area was used to calculate the densities of dugongs.

Density in each cell was calculated as:

Density km^2 = Corrected number of dugongs sighted in each cell / Area surveyed in each cell

where, Area surveyed in cell = Transect length in km * Transect width (i.e. 0.4 km).

3.2 *RESULTS*

Group size and composition

A total of 384 groups comprising 602 dugongs were sighted in the Torres Strait during the 1996 aerial survey. A total of 73 animals were identified as calves (12.1% of the population). This proportion was not significantly different from those observed in November 1987 (13.6 %) and 1991 (11.8 %) (Chi-square = 0.5.905, 2 d.f.; p=0.744).

As in the 1987 and 1991 surveys more than 75% of groups were solitary dugongs or cow-calf pairs. The largest group observed during the 1996 survey was a herd estimated at 22 animals, seen in block 2A. The largest group seen in 1991 was eight dugongs, compared with five dugongs in 1987 (Marsh et al. 1997a). These group sizes are typical for Torres Strait according to the pilots of the Custom's aircraft who traverse the region daily (Travis Aitken pers comm. 1996; Custom's pilot with 15 years experience in Torres Strait).

Population and density estimates

The mean group sizes and correction factors used to calculate the population and density estimates in 1996 are in Table 3. Appendix Tables 2 and 3 list the raw data. The estimates of the numbers of dugongs in the various survey blocks in 1996 are compared with the corresponding data for 1987 and 1991 in Table 4. Appendix Figure 2 shows the locations of the dugong sightings during the 1996 survey.
The highest numbers of dugongs were in Blocks 2A and 3 which, as in the 1987 and 1991 surveys, contained over half the dugongs in the survey area (Table 4 and Figure 3).

A minimum population estimate of 27,881 $\pm$ s.e. 3,216 dugongs at an overall density of 0.912$\pm$ s.e. 0.102 dugongs km^{-2} was calculated for the region on the basis of the 1996 survey (Table 4). Population estimates for 1987, 1991 and 1996 differ significantly (Table 5). Post-hoc comparisons demonstrate that the significant differences were between 1987 and 1991, and 1987 and 1996 (Table 5).

DISCUSSION

Estimates of the dugong population

The results of the 1996 survey, which was completed in four days, were not significantly different from the results of the 1991 survey which took nearly one month to complete. This results lends support to the hypothesis that the differences between the 1987 and subsequent surveys were due to changes in population size rather than being an artefact of the survey technique. Marsh et al. (1997a) were concerned that dugongs may have been counted twice if they moved during the 1991 survey. Our analysis also suggests that the difference between surveys is unlikely to be due to sighting conditions, which were slightly worse in 1991 than in 1987 or 1996 (Table 1).

We consider that the most likely explanation for the observed difference between surveys is that dugongs moved into the survey area between 1987 and 1991, probably from the coastal waters of Irian Jaya. Torres Strait supports one of the largest seagrass areas in Australia. A total of 17,500 km^2 of 'seagrass-supporting habitat' has been identified and mapped in the Australian waters of the Strait (Poiner and Peterkin 1995). Open ocean seagrass communities occur subtidally to around 40 m depth in the extensive waters of northwestern Torres Strait. It is likely that our survey area, which was constrained by the endurance of the aircraft, fuel availability and the proximity of the Irian Jayan border, did not cover all the seagrass-supporting habitat in the region. Nothing is known of the distribution of seagrasses or dugongs along the Irian Jayan coast.

The stimulus for this movement of dugongs (if it occurred) is unknown. The most plausible explanation would be a large-scale loss of seagrasses along the Irian Jayan coast. Seagrasses are susceptible to dieback events in northern Australia (Poiner and Peterkin 1995, Preen and Marsh 1995). There is anecdotal evidence of a massive dieback of seagrasses in Torres Strait in the mid 1970's (Johannes and MacFarlane 1991) and several hundred square kilometres of seagrass disappeared from northwestern Torres Strait in 1991-92. This event has been linked with high turbidities from flooding of the Mai River in Papua New Guinea (Poiner and Peterkin 1995).

4. ESTIMATING THE SIZE OF A SUSTAINABLE DUGONG CATCH IN TORRES STRAIT

4.1 *METHODS*

Using the PBR concept to estimate a sustainable catch

The PBR (Barlow et al. 1995; Wade in press) 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 that is not more than four years old);

- the maximum rate of increase r_m; the default value for Florida manatees which breed earlier and more often that dugongs is 0.04;

- a 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_m or errors in the determination of stock structure. Population simulations 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.

The PBR can be compared with measurable estimates of mortality (such as the number of animals harvested in an Indigenous fishery) to judge whether the number of animals killed exceeds a 'safe' level or whether mitigation measures need to be adopted.

Some of the features of the method and the simulation testing (Barlow et al. 1995; Wade in press) are as follows:

- It is assumed that the maximum productivity of the stock is at 50% or 60%K (carrying capacity) and this is the threshold level against which the recovery of that stock is measured.

- If five years or more have transpired since the last survey to determine the abundance of a stock, the recovery factor for that stock should be reduced by 0.1 for each subsequent year until a value of 0.1 is reached.

4.2 *RESULTS*

Estimating the parameter values required for a PBR for dugongs in Torres Strait

In applying the PBR method to estimate a sustainable harvest rate for the dugong in Torres Strait, the following factors were considered.

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 due to water turbidity). The availability correction factor of Marsh and Sinclair (1989a, see Table 3) was developed as a means of standardising fluctuating availability bias for repeat surveys of the same area under conditions of varying water turbidity. It was developed in Moreton Bay where all the dugongs were in extremely clear, shallow (<5m) water over white sandbanks with sparse seagrass. It was therefore assumed that all animals were potentially available. By comparing the uncolluded observations of tandem observers, Marsh and Sinclair (1989b) showed that there was good agreement between the observers in reports of how many dugongs in groups of ≤ 5 were at the surface. This proportion (80/480 or 16.7%) was not significantly different from that obtained independently from vertical colour photographs that were taken by a dedicated photogrammetry aircraft from 300m under excellent conditions on the same sandbanks. Marsh and Sinclair (1989a) tentatively proposed 80/480 as an unbiased estimator of the proportion of dugongs at the surface for dugongs in aerial surveys of other areas of shallow water when the sea is calm. In subsequent surveys, the proportion of dugongs recorded at the surface has been adjusted against this standard to correct for availability bias. This adjustment makes the untested assumption that this standard is appropriate for all conditions. Marsh *et al.* (1997a) note that this assumption is unlikely to be valid in Torres Strait where a significant number of dugongs are sighted in deeper water than in Moreton Bay.

Marsh and Sinclair (1989a) also reported that this standard was likely to be conservative as is was much greater than the proportion of dugongs observed at the surface during shore based observations of dugongs in muddy water by Anderson and Birtles (1978). Marsh and Sinclair (1989a) suggested that a more accurate assessment of availability bias will require more data on dugong diving and surfacing under different environmental conditions.

Anderson and Birtles (1978) observed that the surface time for 48 observations averaged 1.4 $\pm$ S.E. 0.1 s and ranged from 0.6 to 4 s. A total of 370 dives was timed. The mean time was 73.3 $\pm$ 2.7 s (range 3-400 s). This suggests that the diving and surfacing behaviour of dugongs is very variable even at the same site. A crude estimate of the proportion of time at the surface is 1.4/73.3 s or 1.9%, which is 8.74 times less than the proportion observed during the aerial survey in Moreton Bay. We did not know how shore-based observations relate to those obtained from an aircraft travelling at 137 m ASL and 100 knots and recently videotaped dugongs from a helicopter to find out.

Marsh *et al.* (1997b) videotaped dugongs in clear shallow water over the sandbanks in Moreton Bay from a helicopter flying at approximately 250m ASL. The video images were subsequently analysed using professional Sony Hi8 video equipment which encoded a time code on the image accurate to 0.04 s. Two methods were used to record dugong diving behaviour:

- focal animal sampling of 38 individual in 12 groups of < 6 dugongs;

- scan sampling at five second intervals of the total number of dugongs in the field of view in groups of >5 dugongs. The total number of animals in the field of view and the number at the surface were recorded.

Both methods indicated that the dugongs spent a small and variable proportion of their time at the surface. The average surface interval for the 38 focal dugongs was 1.84 s (range 0.5 to 3.67 s, S.E. 0.1 s). The average time between surfacings was 83 s (S.E. 3.35 s) which suggested that the animals were spending an average of 2.2% of their time at the surface (7.5 times less than assumed by the present availability correction factor). The scan sampling suggested that the proportion of the herd at the surface ranged from 2.7% to 5.5% (6 and 3 times less than assumed by the present availability correction factor).

Based on these results we have used a series of multipliers (2, 4, 8) to convert the most recent index of population size (the 1996 estimate) for Torres Strait into estimates of N_{min}. In so doing, we have assumed that the coefficient of variation (CV) is constant and the same as that obtained from the index. Given the variation in dive times, it is clear that the CV for an absolute estimate should be higher than that for the index and that the corrected values of N_{min} will be too high by an unknown amount.

Maximum rate of increase r_m

The application of population models to estimate r_m has been hampered by uncertainty about the estimates of the population parameters as discussed by Marsh (1995a, 1998):

- The method of 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 also accords with that for Florida manatees, a rate which has been verified using tetracycline marking (Marmontel 1995).

- The apparent pregnancy rate (all possible pregnancies) calculated for dugongs killed in the Daru fishery ranged from 0.107 $\pm$ S.E. 0.036 in 1978-79 (calving interval 9.3 years) to 0.353 $\pm$ S.E. 0.116 in 1983 (calving interval 2.8 years) indicating significant temporal variation in dugong fecundity in Torres Strait (Marsh 1995a). More recent estimates are not available.

- Estimates of the calving intervals of these populations may be biased by hunters targeting pregnant females (Johannes and MacFarlane 1991; Roberts et al. 1995).

- 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 10 years (Townsville) and 12 years (Daru) (Marsh 1995a).

- 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 1998; Table 6) uses a pattern of natural mortality based on that obtained from longitudinal studies of manatees (Eberhardt and O'Shea 1995, Langtimm et al. in press) which is likely to be more realistic.

The Recovery Factor RF

We used the following RF values in the calculation of PBRs for dugongs in Torres Strait:

- the default for stocks of unknown status (0.5);
- the maximum value of 1.

A PBR for the dugong in Torres Strait

Taking into account the above ranges and uncertainties gives the scenarios for the PBR in Table 7. We cannot assign formal to assign weightings or probabilities to these scenarios. A qualitative analysis of their relative likelihood is provided below.

The most pessimistic scenarios are unlikely as the aerial surveys did not detect a population change between 1991 and 1996, despite an estimated Indigenous harvest in the Australian Sector of the Protected Zone of 1226 $\pm$ S.E. 204 between June 1991 and May 1993 (Marsh et al. 1997a) and 860 $\pm$ S.E. 241 in 1994 (Harris et al. 1997). The total catch must have been higher than this as the data do not include the catch from: (1) Australian communities south of the Protected Zone (estimated to be 283 in 1996 (Mick Bishop AFMA pers comm. 1997), or (2) Papua New Guinea. Illegal hunting for dugongs has also been reported (Johannes and MacFarlane 1991). The limited mortality that may occur from gill net bycatch in the region is considered to come primarily from illegal shark fishing by Indonesian vessels, primarily in Indonesian waters. The use of nets to kill dugongs in Torres Strait was made illegal in 1994.

The most optimistic scenarios are also unlikely as: (1) the values for N_{min} are not adjusted for the increase in the CV due to the variation in diving behaviour, and (2) assume that r_m is higher than suggested by Table 6 (which does not take into account the impact of the hunters targeting pregnant females).

A precautionary RF of 0.5, an intermediate N_{min} of 25,200 x 4, and a r_m of 0.02

suggests that an annual harvest of 500 dugongs for the entire region should be sustainable.

5. *DISCUSSION*

Temporal variation in the size of the dugong catch

The data summarised in Table 8 suggest considerable temporal variation in the size of the dugong catch since the mid 1970s. In contrast, the turtle catch has remained relatively stable during this period. As dugongs and turtles tend to be hunted together, Johannes and MacFarlane (1991) interpret this results as indicating that the overall hunting effort has remained relatively stable during this period. However, no reliable data are available to accept or reject their hypothesis. Nietschmann (1984) suggests that the dugong catch was high during the 1970s because of the unusually high numbers of dugongs seen close to the major hunting islands. We attribute this to a large scale dieback of deepwater seagrass at this time (Marsh 1995a). The high catches recorded in the early 1990s (Harris et al. 1994, 1997) may also have been associated with the movement of dugongs into the survey area suggested by our aerial surveys (Table 4). Unlike dugongs, green turtles are believed to be philopatric to their feeding grounds (Bjorndahl 1980) which may explain why turtle catch rates are relatively more stable than those of dugongs (Table 8).

Johannes and MacFarlane (1991) report anecdotal evidence of local depletion of dugongs close to the major hunting islands during the period of apparently low dugong catches in the mid 1980s (Table 8). Given the essentially local nature of the hunting grounds of each community (see Johannes and MacFarlane 1991), it seems likely that the magnitude of the dugong catch in Torres Strait is influenced by changes in the local distribution of the target species. If so, the interpretation of the time series of catch data will be very difficult without parallel data on: (1) the spatial distribution and magnitude of hunting effort, and (2) the spatial distribution of both dugongs and seagrass dieback events.

Is the dugong catch sustainable?

The PBR method (Table 7) suggests that an annual harvest of 500 per year should be sustainable. In at least some years the dugong catch is clearly substantially higher than this figure (Table 8). Although there was no detectable change in the distribution and abundance of dugongs in Torres Strait between 1991 and 1996, this result reduces rather than eliminates concerns (Hudson 1986, Marsh 1986, Johannes and MacFarlane 1991) that the Torres Strait dugong fishery may not be sustainable.

Recommended management initiatives

Even though there is concern about the sustainability of the dugong catch in Torres Strait, it is important to appreciate that the situation is very different from that in the southern Great Barrier Reef. This needs to be reflected in the management response. In the southern Great Barrier Reef, the aerial survey data indicate a serious decline in dugong numbers between Dunk Island and Hervey Bay (Marsh et al. 1996b). In contrast, the aerial survey data from Torres Strait indicate that there are more than 15 times as many dugongs in Torres Strait than in the southern Great Barrier Reef, and do not provide evidence that dugong numbers are declining in Torres Strait (Tables 4 and 5). The legal situation is also different in the two regions. The Torres Strait dugong fishery is one of the article 22 fisheries specifically cited in the Torres Strait Treaty between Australia and Papua New Guinea. The Torres Strait Islanders hunt dugongs as part of their traditional way of life protected by the Treaty. Although the *Great Barrier Reef Marine Park Act Commonwealth 1976* provides for traditional hunting under permit in the Great Barrier Reef Marine Park, the rights of traditional hunters are not as explicitly protected in the Great Barrier Reef as they are in Torres Strait.

A more robust assessment of the sustainability of the dugong catch in Torres Strait will require longer, more comprehensive and most importantly, more accurate, time series data for both the dugong population and the dugong catch, as well as more reliable data on life history parameters, especially adult survivorship. This will take many years given: (1) the interannual fluctuations in both the population estimates and the catch (Tables 4 and 8): (2) the logistical and jurisdictional problems associated with surveying the entire area of seagrass supporting habitat in the region; (3) the difficulties in detecting trends in populations of long-lived species such as dugongs (Taylor and Gerrodette 1993, Marsh 1995c), and (4) the difficulties in quantifying the bias in the population estimates (Marsh 1995c).

The support and co-operation of Torres Strait Islanders is crucial to the success of any initiative to regulate hunting. Given the remoteness of the area, it will be impossible to enforce management restrictions without the co-operation and involvement of local peoples. Although the present dugong sanctuary (Figures 1 and 3) was designated in 1985 after extensive community consultation, it is a 'paper park', the existence of which is probably irrelevant to most hunters as it is outside the traditional hunting grounds of the major dugong hunting communities (Figure 3).

The dugong fishery will not be effectively managed until the Islanders and the government management agencies develop mutually acceptable management objectives for the dugong fishery. We suggest that the Torres Strait Regional Authority and the Islander Co-ordinating Council be empowered to manage dugong resources under Australian jurisdiction in a formal co-operative management arrangement with the Australian Fisheries Management Authority, the government agency which currently manages the fishery. Parallel arrangements should be developed for the fishery in Papua New Guinean waters. There are several models for co-operative management of Indigenous hunting of marine mammals in Alaska which could be used as a basis for negotiations (e.g. Freeman 1989, Richard and Pike 1993, Marine Mammal Commission 1995). It might be appropriate for Islander leaders to be sponsored to visit North America to learn of these models first hand with a view to designing an appropriate local version for the Indigenous co-management of dugongs in Torres Strait. Given that dugongs and green turtles are hunted together, complementary co-management processes should be developed for both species.

The public profile of the dugong has recently increased due to the concern about its status in the southern Great Barrier Reef region and it has become an icon of the conservation movement. This higher profile could be used to promote a co-operative management arrangement which would enable Torres Strait Islanders to play a key role in the design of appropriate educational, research and management strategies which will ensure that dugong and turtle hunting in the region is sustainable. It is important that co-management arrangements be negotiated before external pressures force restrictions on the dugong harvest.

6. *RECOMMENDED PRIORITIES FOR RESEARCH*

In order to evaluate the sustainability of the dugong catch in Torres Strait, the following information is needed:

- Accurate estimates of the catch (and preferably effort and catch location) for the entire region.
- Up to date estimates of the life history parameters. The AFMA funded project on the life history parameters should lead to better estimates of the pre-reproductive period and calving interval). However, reliable estimates of mortality will be impossible to obtain as estimates based on age frequency distributions assume that the population is stable and that the rate of change is known.
- Information on the diving behaviour of dugongs under different environmental conditions. The critical information here is the proportion of time at the surface as seen from an aircraft. We suggest two methods of obtaining this information. They make untested assumptions and the resultant estimates would be more robust if both were used.
    - Estimates of the time at the surface based on video observations of solitary dugongs from a helicopter as attempted in Moreton Bay by Marsh et al. (1997b). This method assumes that the diving behaviour of the dugongs is unaltered by the helicopter.
    - Information on the diving and surfacing behaviour of dugongs from time depth recorders (TDRs) attached to the animals. Problems with this method include: (1) the capacity of the time depth recorders to record the depth of the dugong accurately at intervals of less than one second; (2) recovery of the TDRs, in Torres Strait they would probably best be connected to satellite PTTs; extrapolating the results of the TDR observations to observations of dugongs from aircraft during aerial surveys.

7. *ACKNOWLEDGMENTS*

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Figure 1. The communities of the Torres Strait Protected Zone and the boundaries of the sanctuary established to protect dugongs in 1985.

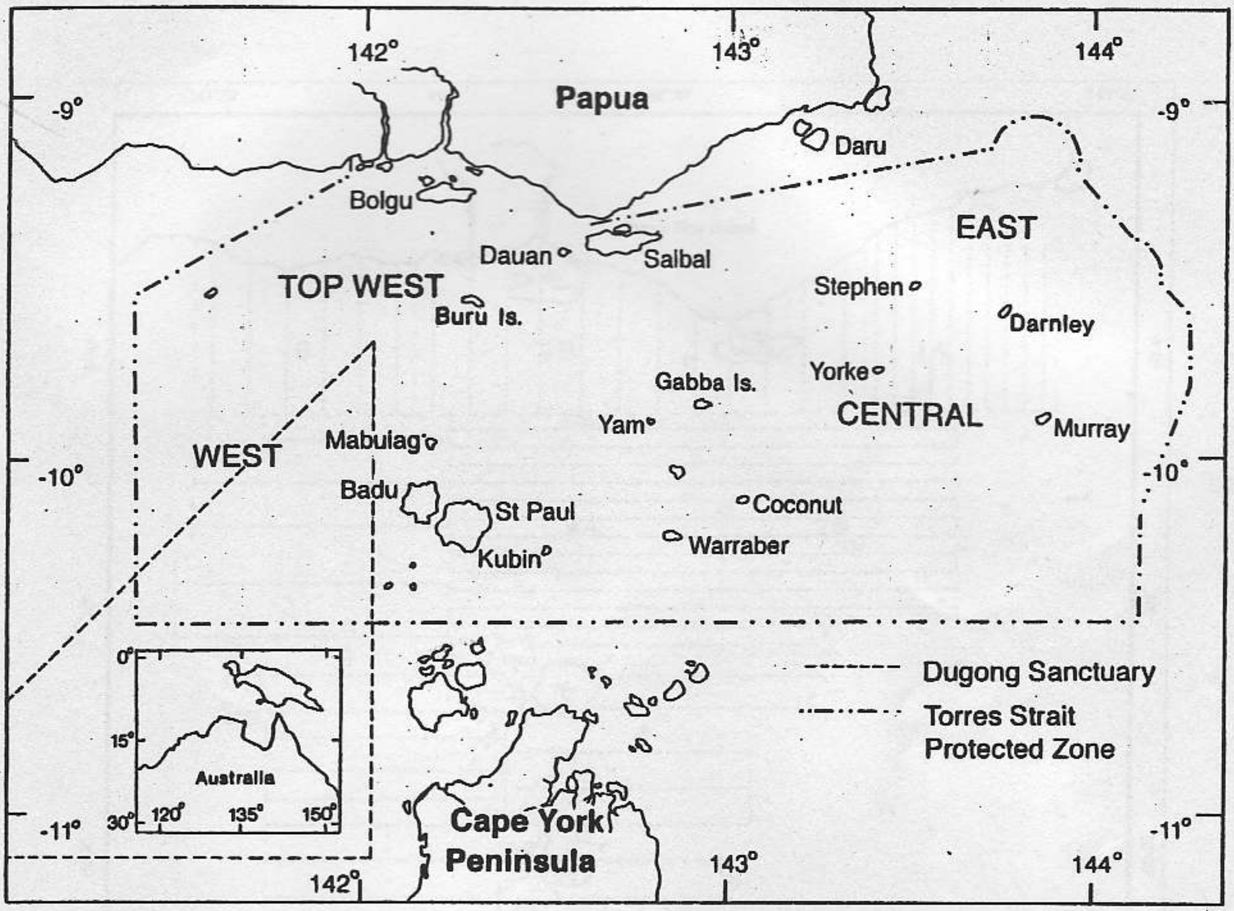


Figure 2. Torres Strait showing the transects flown in the 1996 dugong survey and their arrangement into blocks. Note the transects that were truncated or omitted on the eastern side of block 1A because we were unable to access Papua New guinea air space in the vicinity of Daru.

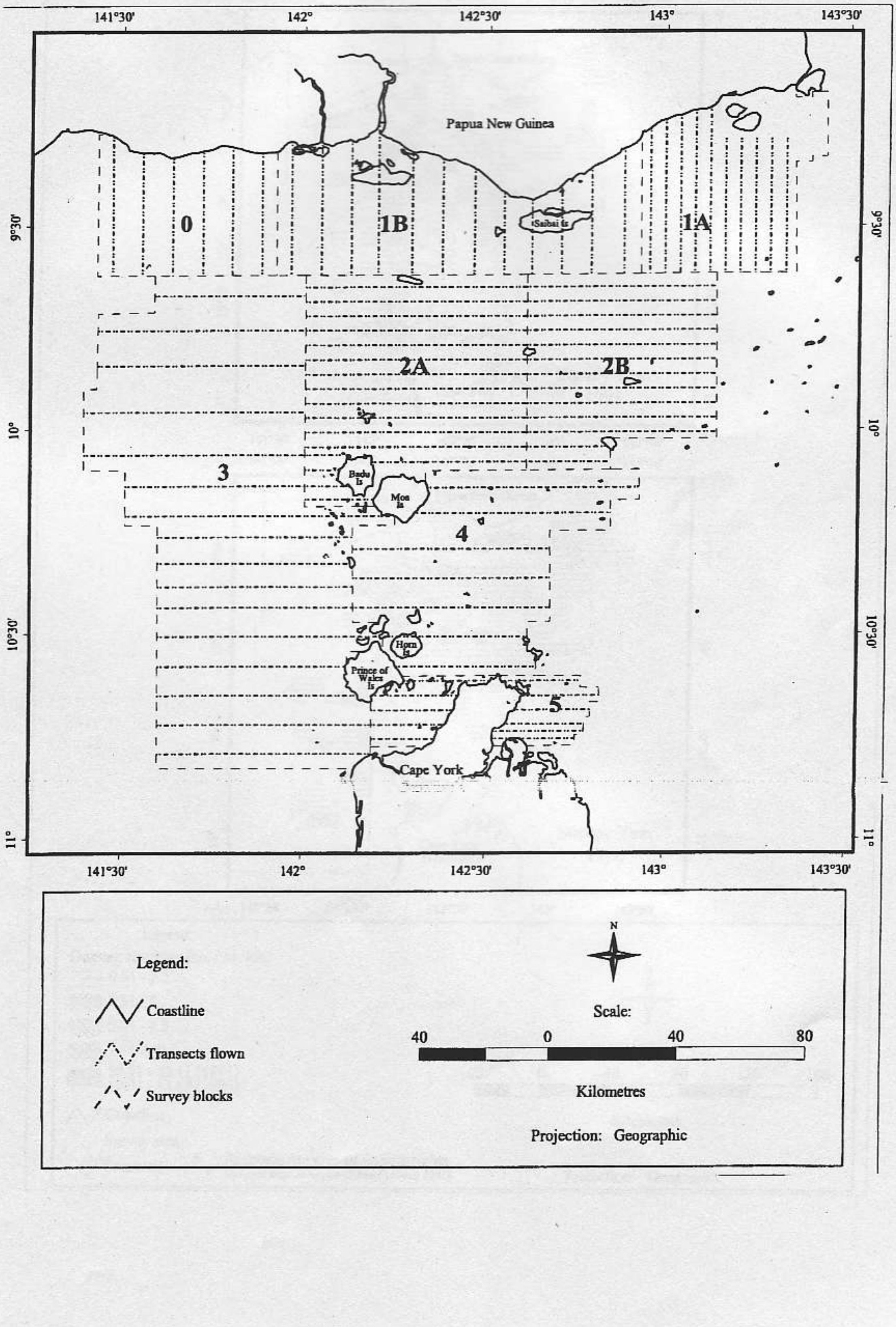


Figure 3. Density distribution maps (5 min latitude x 5 min longitude grid) for dugongs in Torres Strait based on the 1991 and 1996 surveys. The 2744 km^2 sanctuary established to protect dugongs in 1985 and the areas of fishing rights for the major dugong hunting communities are marked on the maps.

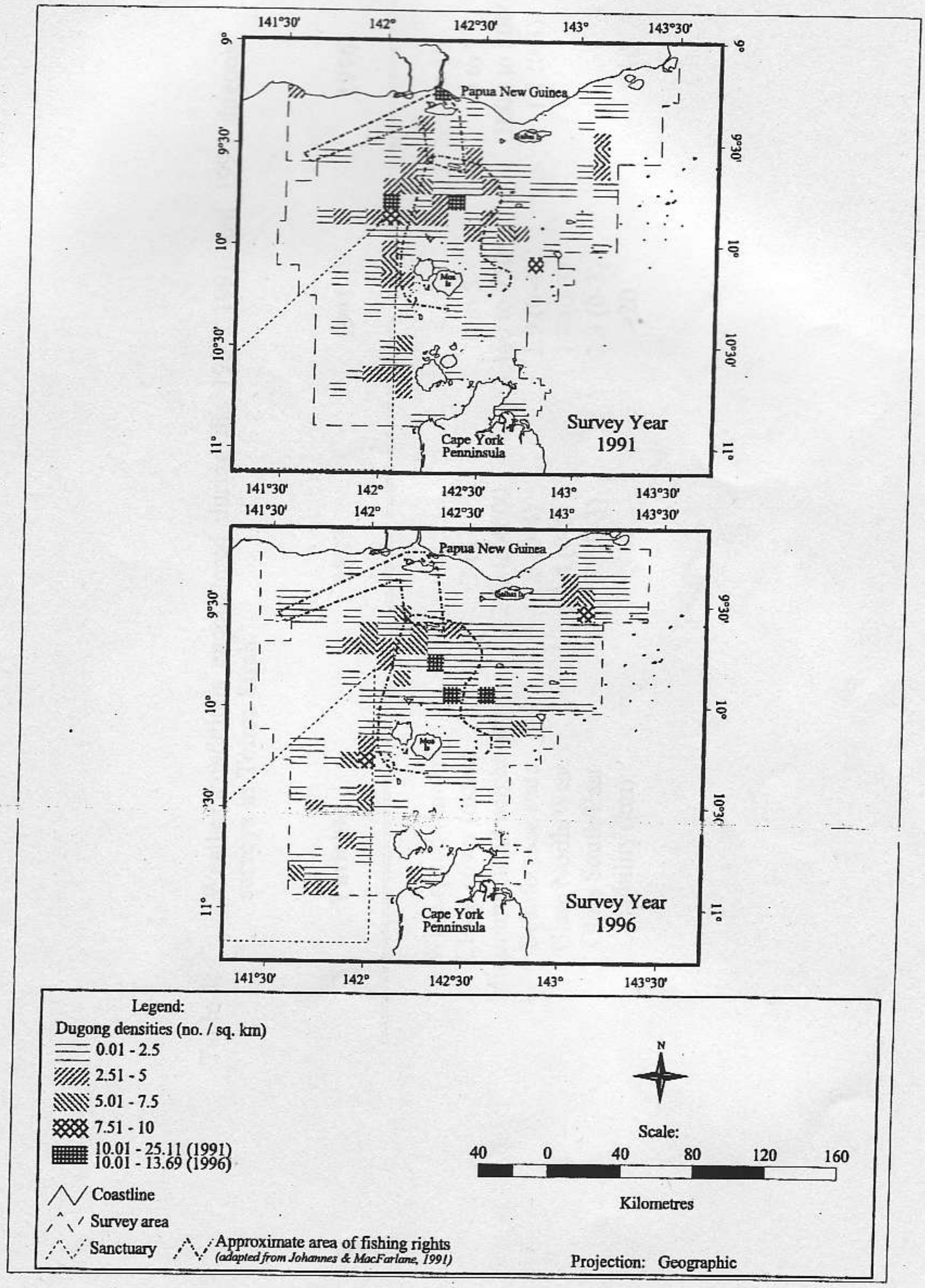


Table 1: Weather conditions encountered during the 1987, 1991 and 1996 dugong surveys in Torres Strait.

Variable	1987	1991	1996
Wind speed (km/hr)	< 15	< 15	< 10
Cloud cover (oktas)	1 to 8	0 to 5	0 to 7
Minimum cloud height (m)	270 to 4000	460 to 750	1000 to 5000
Beaufort sea state	1.3 (0-4)	1.9 (0-4)	1.1 (0-3)
Glare North/West	1.4 (0-3)	1.7 (0-3)	
Glare South/East	0.75 (0-3)	2.3 (0-3)	
Visibility (km)	N/A	>20	>10

Table 2: Block areas and sampling intensities for the 1996 survey of Torres Strait.

Block number	Block area in sq km	Percentage of the block surveyed
0	2174	5.17
1B	3785	4.63
1A	2656	9.23
2A	4340	9.35
2B	3289	9.35
3	9657	4.92
4	3636	6.03
5	1031	13.04
all	30568	6.6

Table 3: Details of dugong group size estimates and correction factors used in the population estimates for the dugong survey in 1996.

Perception correction factors

Crew	Number of observers	Transects involved	*Starboard* estimate	cv	*Port* estimate	cv
Aircraft 1	2	201;306-316	1.25	0.0125	1.2683	0.03
Aircraft 1	3	411;412;3051;3061 202-204	1.0135	0.005	1.2683	0.0212
Aircraft 1	4	All other transects	1.0455	0.012	1.1002	0.0239
Aircraft 2	2	303	1.2381	0.0032	1.2414	0.0049
Aircraft 2	4	All other transects	1.0384	0.0096	1.0889	0.0261

Availability correction factors

Crew	estimate	cv
Aircraft 1	2.8554	0.1149
Aircraft 2	2.8296	0.1295

Dugong group sizes

Crew	Group size mean	cv
Aircraft 1	1.4906	0.0357
Aircraft 2	1.4915	0.0624

Table 4: Estimated numbers of dugongs per block in 1987, 1991 and 1996 and the corresponding density estimates for 1996.

Block	Population estimate 1987	Population SE 1987	Population estimate 1991	Population SE 1991	Population estimate 1996	Population SE 1996
0	0		696	238	1152	381.491
1A	1131	278	1669	999	2427	662.816
1B			3705	1529	1681	614.784
2A	6424	1679	9113	1798	10869	1600.338
2B	2019	573	1467	399	1905	370.335
3	2822	1102	6740	1958	8623	2411.136
4	848	347	518	197	984	312.721
5	76	55	320	277	240	70.169
Total	13319	2136	24225	3276	27881	3126.177

Block	Density estimate 1996	Density SE 1996
0	0.53	0.1755
1A	0.914	0.24957
1B	0.444	0.16242
2A	2.5045	0.36875
2B	0.579	0.11258
3	0.893	0.24969
4	0.2705	0.08601
5	0.233	0.06806
Total	0.9121	0.1023

Table 5: Summary of analysis of variance comparing observed dugong density in Torres Strait in 1987, 1991 and 1996 with Beaufort sea state as a covariate. Data were transformed by $\ln_{10}(x+1)$

Source of Variation	SS	DF	MS	F	Signifiance of F
WITHIN+RESIDUAL	18.01	83	0.22		
REGRESSION	0.00	1	0.00	0.00	0.00
TRANSECT W BLOCK (ERROR 1)	30.56	84	0.36	1.68	0.01
YEAR	0.65	1	0.65	3.02	0.86
YEAR * BLOCK	1.64	7	0.23	1.08	0.382
Error 1	29.92	83	0.36		
REGRESSION	1.29	1	1.29	3.57	0.062
BLOCK	26.26	7	3.75	10.41	0.00

Post-hoc comparisons	t-Value	Significance of t
1996 compared with 1991	-0.96309	0.33689
1996 and 1991 comapred with 1987	-4.21085	0.00004

Table 6. Annual rate of increase of stable dugong populations estimated using a stage-based Leslie Matrix population model for various combinations of pre-reproductive period and interbirth interval. The model assumes annual survival based on empirical data for the Florida manatee (Eberhardt and O'Shea 1995, Langtimm et al. in press). The model is truncated at age 45. Extending it beyond this age makes only a trivial difference.

Mean age of first birth (yr)	Mean interbirth interval (yr)		
	2.5[1]	3.0	5
10	0.0335	0.0245	0.00300
12	0.0272	0.0190	-0.000546
14	0.0217	0.0142	-0.00379

[1] This is likely to be the minimum possible mean calving interval for sirenians and is close to the value observed for the Florida manatee (Marmontel 1995).

Table 7. Estimates of the annual sustainable anthropogenic mortality of dugongs in Torres Strait.

RF=0.5

r_m	n_{min}			
	25,200	25,200 x 2	25,200 x 4	25,200 x 8
0.01	63	126	252	504
0.02	126	252	504	1008
0.04	252	504	1008	2016

RF= 1

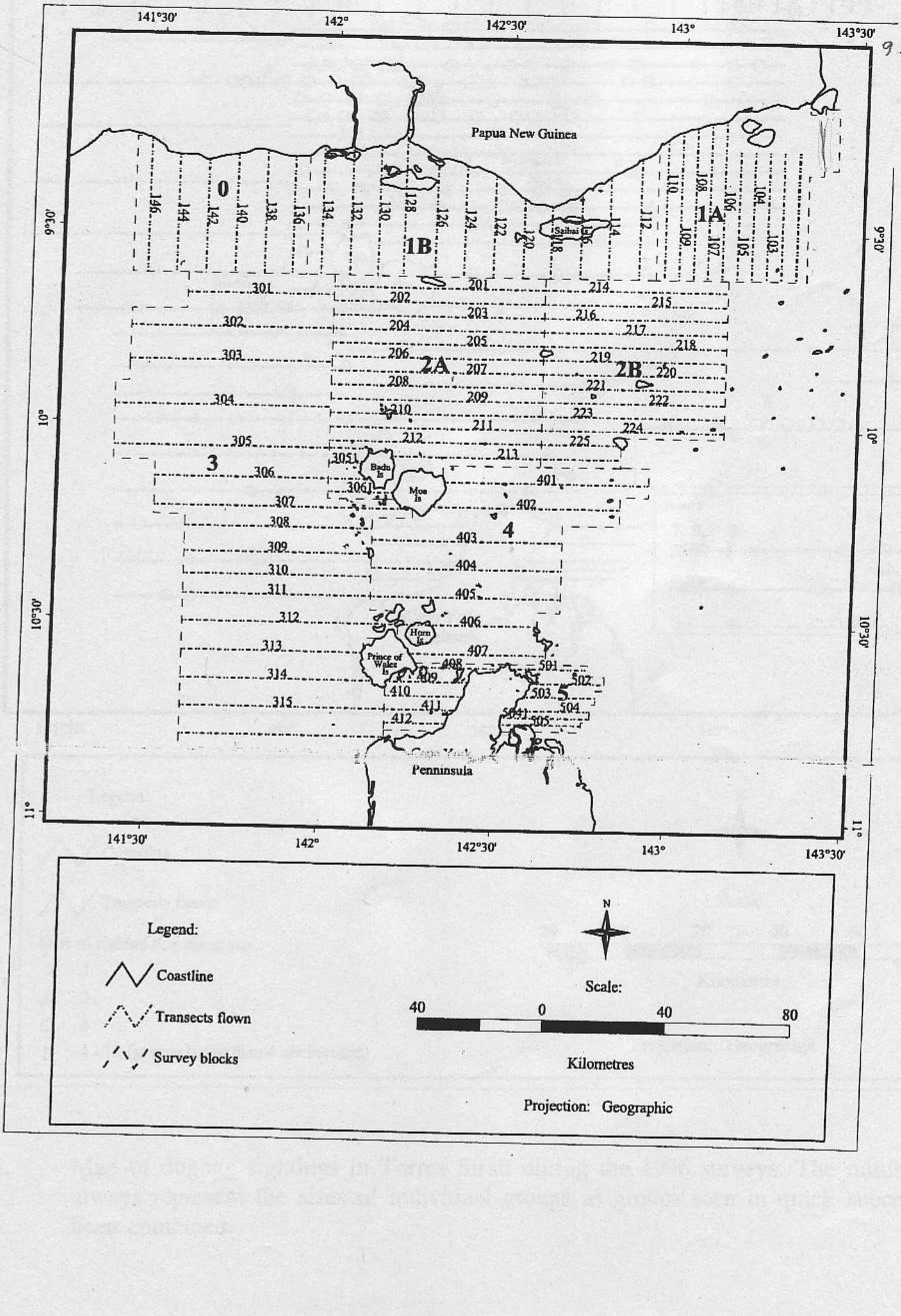
r_m	n_{min}			
	25,200	25,200 x 2	25,200 x 4	25,200 x 8
0.01	126	252	504	1008
0.02	252	**504**	**1008**	2016
0.04	504	1008	2016	4032

Table 8: Comparison of the available catch statistics for dugongs and green turtles in various parts on Torres Strait.

Area	Date	Estimated annual dugong catch	Estimated annual turtle catch	Reference
Boigu, Badu, Mabuiag Islands	1977	274[1]	515[1]	Nietschmann 1984
	mid 1980s	75[1]	671[1]	Johannes & MacFarlane 1991
	1994-5	623 (se 197)		Harris et al. 1997
TSPZ communities	1976-78	750[1]	2100[1]	Nietschmann 1984
	mid 1980s	110[1]	2500[1]	Johannes and MacFarlane 1991
	1991-93	1226 (se 204)	2504 (se 358)	Harris et al. 1994 Marsh et al. 1997a
	1991-92	954[2]	1597[2]	Harris and Nona submitted
	1994	860 (se 241)	2600 (se 378)	Harris et al. 1997
	1995-6	241 (se 92)[1]	1896 (se 445)[1]	Skewes et al. 1997
Thursday Island, Bamaga	mid 1980s	5-8[1]		Johannes and MacFarlane 1991
	1997	116[2]	110[2]	M. Bishop 1997
Daru	1979-			Hudson 1986
	1992-94	17[6]		Karre 1995

1 limited sampling only; estimate for 'Torres Strait communities'
2 school based sampling
3 sold in Daru market between 1992 and 1994; does not include dugongs caught for home consumption

Figure 1. Torres Strait showing the numbering of the transects flown in the 1996 dugong survey and their arrangement into blocks. Note the transects that were truncated or omitted on the eastern side of block 1A because we were unable to access Papua New guinea air space in the vicinity of Daru.



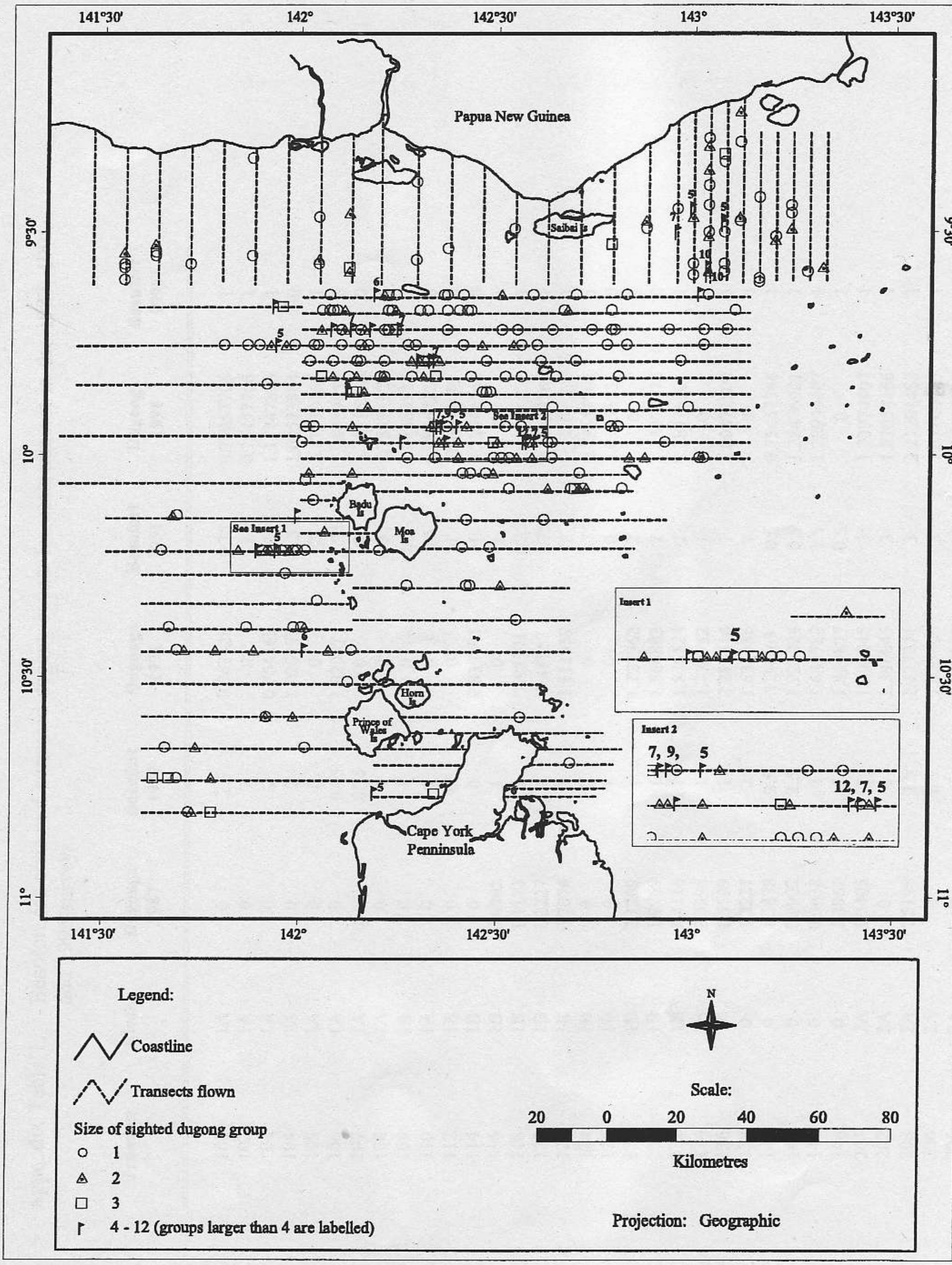


Figure 2. Map of dugong sightings in Torres Strait during the 1996 surveys. The numbers do not always represent the sizes of individual groups as groups seen in quick succession have been combined.

Appendix Table 1. Beaufort sea state and corrected dugong counts for each transect in the 1987, 1991 and 1996 surveys.

Transect	Block	Dugongs 1987	Beaufort 1987	Dugongs 1991	Beaufort 1991	Dugongs 1996	Beaufort 1996
101	1A	0	2.5	0.763428	0.75	0.75457766	1
102	1A	0	2	0	1	0.75457766	1
103	1A	0	2	0.754369	2	1.17747878	1
104	1A	0	2	1.020373	1.5	1.00573804	0
105	1A	0	0	0	2	1.17070166	1
106	1A	0	0.25	1.020373	2.75	1.28739859	0
107	1A	0.7076	0.75	0	0	1.70316236	0
108	1A	0	1	0	0	1.73931121	1
109	1A	0	1	0	0.5	1.27283911	1
110	1A	0	1	0	0.5	0.98967225	0
112	1B	0	1.5	0	1	0.9990435	0
114	1B	0	0	0.839491	1	0.73094369	0
116	1B	0.6902	1	0	1	0	1
118	1B	1.1173	1	1.95791	1.25	0	1
120	1B	1.2227	1	1.48857	1.75	0.75457766	1
122	1B	0.7076	1	1.111939	2	0	1
124	1B	0	2	0	2.75	0.75457766	1
126	1B	0	1	0	0	1.01556931	0
128	1B	2.1209	1	1.727962	2	0	1
130	1B	1.9969	1	1.564803	2	1.44970976	0
132	1B	1.4116	1	1.876524	2	1.28476901	1
134	1B	2.0298	1	1.771752	1	0	1
136	0	1.5599	1	2.286316	1	1.00573804	1
138	0	1.2227	2	1.633386	1	0	1
140	0	1.2878	2.5	1.34363	0.5	0.75457766	1
142	0	0.6902	2.5	1.921024	0.5	1.28476901	1
144	0	0.9638	2	1.683782	1.5	1.28999007	1
146	0	1.3962	2	1.859877	0.5	0	1
201	2A	1.2405	3	1.396045	3	1.73774907	1
202	2A	0	1	1.396045	3	1.81054166	1
203	2A	1.5198	1.5	1.177271	3	2.11201482	1
204	2A	0	0.5	1.025306	3	1.87146785	1
205	2A	0	2	0.754369	3	1.94616723	1

Transect	Block	Dugongs 1987	Beaufort 1987	Dugongs 1991	Beaufort 1991	Dugongs 1996	Beaufort 1996
206	2A	1.1173	1	0	2	1.7816046	0
207	2A	1.3284	2	1.400203	3	1.77992101	1
208	2A	1.5752	0.5	0	3	1.17070166	1
209	2A	1.1139	0.5	1.391655	3	2.02493287	2
210	2A	1.4048	0.5	1.88842	3.5	2.01025754	2
211	2A	0.9542	0.25	1.015383	3	1.67328822	2
212	2A	1.3284	0.2	1.400203	3	1.50943104	0
213e	2B	0	1	1.310701	2	0.73094369	2
214	2B	0	1	0.754369	2.5	0	2
215	2B	0.6902	0.5	0	2	1.36806364	1
216	2B	0.6902	0.5	1.025306	3	1.50943104	1
217	2B	0	2	1.015383	3.5	1.15718468	2
218	2B	0	2.25	1.400203	3	0.98967225	0
219	2B	0.6902	2	1.025306	2	0.98967225	1
220	2B	0.7924	2	1.648088	3	0	2
221	2B	0	2.5	1.191189	3	1.16988007	1
222	2B	0	2	0	3	1.28739859	1
223	2B	0	1	0.754369	3	1.15718468	1
224	2B	1.2355	2	0.754369	3	1.360063	1
225	2B	0	2	0.754369	3	0.74787771	1
301	3	0.9494	2	0.7731	2	1.16354896	3
302	3	0	3	1.015383	3	1.56716758	2
303	3	0.9638	2	0	3	0.79511499	2
304	3	0.7076	0.5	0	2.5	0	2
305	3	0	0.5	0	3	0	1
305	2A	0.7924	2	0.754369	2	0.73094369	1
306	3	0	2	0	3	1.23340228	1
306	2A	0	2.5	0	3	0	1
307	3	0	2.5	0	3	2.07605031	2
308	3	0	2.25	0	3	0.80604424	2
309	3	0	2	0	2.5	0.80604424	1
310	3	0	2.25	0	3	1.52258767	1
311	3	0	2	0	2	1.58606944	1

Transect	Block	Dugongs 1987	Beaufort 1987	Dugongs 1991	Beaufort 1991	Dugongs 1996	Beaufort 1996
312	3	0.7076	2	0	2.5	0.80071708	1
313	3	0	2	0	3	1.22945145	1
314	3	0	2.5	1.478007	2.5	1.2314441	2
315	3	0	1	0	2	1.52258767	1
316	3	0	2	0	2	1.23340228	2
401	4	0	1	0	1	1.0082168	0
402	4	0	1.5	0	1.25	0.98967225	1
403	4	0.7076	2	0	0.5	1.27283911	0
404	4	0	1	0	2	0.73094369	1
405	4	0.9494	1	1.472627	1	0	1
406	4	0	1	1.184131	0	0	1
407	4	0.9494	0.75	1.830025	0	0.74787771	2
408	4	0.9542	1	1.537708	0	0	1
409	4	0.9542	1	0.754369	0.5	0	2
410	4	0.6902	2	1.025306	0.5	0	2
411	4	0.9542	1.5	0.7731	3	0	0
412	4	1.2355	0.5	1.396045	2	1.06885349	1
501	5	1.4082	1	1.396045	2	0	1
502	5	0.9638	0.5	1.391655	1.5	0	1
503	5	1.1139	0.5	0	1.5	0.74787771	2
504	5	1.1239	1	0	0.5	0	2
505	5	0.6902	1	0	1	1.0082168	1
3051	2A	0.7076	0.5	0.754369	1.5	0.80071708	1
3061	2A	0	0.5	0.754369	1.5	1.07173476	0
5041	5	1.3263	1.5	1.035443	1.5	0	2
213	2A	1.6884	0	1.310701	2	1.61588695	3

Appendix Table 2. Raw data used to calculate the correction factors.

Perception bias

Crew	**Number of observers**	**Number of transects**	**Starboard**			**Port**		
			mid	*rear*	*both*	*mid*	*rear*	*both*
Aircraft 1	2	16	25	15	60	45	11	41
Aircraft 1	3	3	3	3	23	26	11	41
Aircraft 1	4	27	8	12	37	31	11	41
Aircraft 2	2	1	2	10	42	2	7	29
Aircraft 2	4	42	10	10	42	21	7	29

Availability bias

Crew	**Total**	**Surface**	**Underwater**
Aircraft 1	395	188	207
Aircraft 2	176	83	93

Appendix Table 3. Beaufort sea state and raw and corrected dugong counts for each side of the aircraft and each transect in the 1996 survey.

Transect	Block	Median Beaufort sea state	Raw count of dugongs - stbd	Raw count of dugongs - port	Adjusted count of dugongs - stbd	Adjusted count of dugongs - port	Adjusted count of dugongs - total	Team	Number of observers
101	1A	1	0	1	0	4.683	4.683	Aircraft 1	4
102	1A	1	0	1	0	4.683	4.683	Aircraft 1	4
103	1A	1	0	3	0	14.048	14.048	Aircraft 1	4
104	1A	0	1	1	4.45	4.683	9.133	Aircraft 1	4
105	1A	1	1	2	4.45	9.365	13.815	Aircraft 1	4
106	1A	0	0	4	0	18.382	18.382	Aircraft 2	4
107	1A	0	5	6	21.912	27.573	49.485	Aircraft 2	4
108	1A	1	6	6	26.294	27.573	53.867	Aircraft 2	4
109	1A	1	3	1	13.147	4.596	17.743	Aircraft 2	4
110	1A	0	2	0	8.765	0	8.765	Aircraft 2	4
112	1B	0	1	1	4.382	4.596	8.978	Aircraft 2	4
114	1B	0	1	0	4.382	0	4.382	Aircraft 2	4
116	1B	1	0	0	0	0	0	Aircraft 2	4
118	1B	1	0	0	0	0	0	Aircraft 1	4
120	1B	1	0	1	0	4.683	4.683	Aircraft 1	4
122	1B	1	0	0	0	0	0	Aircraft 1	4
124	1B	1	0	1	0	4.683	4.683	Aircraft 1	4
126	1B	0	0	2	0	9.365	9.365	Aircraft 1	4
128	1B	1	0	0	0	0	0	Aircraft 1	4
130	1B	0	4	2	17.8	9.365	27.165	Aircraft 1	4
132	1B	1	2	2	8.9	9.365	18.265	Aircraft 1	4
134	1B	1	0	0	0	0	0	Aircraft 1	4
136	0	1	1	1	4.45	4.683	9.133	Aircraft 1	4
138	0	1	0	0	0	0	0	Aircraft 1	4
140	0	1	0	1	0	4.683	4.683	Aircraft 1	4
142	0	1	2	2	8.9	9.365	18.265	Aircraft 1	4
144	0	1	1	3	4.45	14.048	18.498	Aircraft 1	4
146	0	1	0	0	0	0	0	Aircraft 1	4
201	2A	1	4	6	21.281	32.389	53.67	Aircraft 1	2
202	2A	1	11	3	47.451	16.195	63.646	Aircraft 1	3
203	2A	1	11	15	47.451	80.973	128.424	Aircraft 1	3
204	2A	1	7	8	30.196	43.186	73.382	Aircraft 1	3

Transect	Block	Median Beaufort sea state	Raw count of dugongs - stbd	Raw count of dugongs - port	Adjusted count of dugongs - stbd	Adjusted count of dugongs - port	Adjusted count of dugongs - total	Team	Number of observers
205	2A	1	7	12	31.149	56.193	87.342	Aircraft 1	4
206	2A	0	6	7	26.7	32.779	59.479	Aircraft 1	4
207	2A	1	7	6	31.149	28.096	59.245	Aircraft 1	4
208	2A	1	1	2	4.45	9.365	13.815	Aircraft 1	4
209	2A	2	12	11	53.399	51.51	104.909	Aircraft 1	4
210	2A	2	7	15	31.149	70.241	101.39	Aircraft 1	4
211	2A	2	3	7	13.35	32.779	46.129	Aircraft 1	4
212	2A	0	4	3	17.53	13.787	31.317	Aircraft 2	4
213e	2B	2	1	0	4.382	0	4.382	Aircraft 2	4
214	2B	2	1	3	0	0	0	Aircraft 2	0
215	2B	1	3	2	13.147	9.191	22.338	Aircraft 2	4
216	2B	1	4	3	17.53	13.787	31.317	Aircraft 2	4
217	2B	2	2	1	8.765	4.596	13.361	Aircraft 2	4
218	2B	0	2	0	8.765	0	8.765	Aircraft 2	4
219	2B	1	2	0	8.765	0	8.765	Aircraft 2	4
220	2B	2	0	0	0	0	0	Aircraft 2	4
221	2B	1	0	3	0	13.787	13.787	Aircraft 2	4
222	2B	1	0	4	0	18.382	18.382	Aircraft 2	4
223	2B	1	2	1	8.765	4.596	13.361	Aircraft 2	4
224	2B	1	5	0	21.912	0	21.912	Aircraft 2	4
225	2B	1	0	1	0	4.596	4.596	Aircraft 2	4
301	3	3	1	2	4.382	9.191	13.573	Aircraft 2	4
302	3	2	4	4	17.53	18.382	35.912	Aircraft 2	4
303	3	2	0	1	0	5.239	5.239	Aircraft 2	2
304	3	2	0	0	0	0	0	Aircraft 2	4
305	3	1	0	0	0	0	0	Aircraft 2	4
305	2A	1	1	0	4.382	0	4.382	Aircraft 2	4
306	3	1	1	2	5.32	10.796	16.116	Aircraft 1	2
306	2A	1	0	0	0	0	0	Aircraft 1	2
307	3	2	8	14	42.563	75.575	118.138	Aircraft 1	2
308	3	2	0	1	0	5.398	5.398	Aircraft 1	2
309	3	1	0	1	0	5.398	5.398	Aircraft 1	2
310	3	1	1	5	5.32	26.991	32.311	Aircraft 1	2

Transect	Block	Median Beaufort sea state	Raw count of dugongs - stbd	Raw count of dugongs - port	Adjusted count of dugongs - stbd	Adjusted count of dugongs - port	Adjusted count of dugongs - total	Team	Number of observers
311	3	1	3	4	15.961	21.593	37.554	Aircraft 1	2
312	3	1	1	0	5.32	0	5.32	Aircraft 1	2
313	3	1	3	0	15.961	0	15.961	Aircraft 1	2
314	3	2	2	1	10.641	5.398	16.039	Aircraft 1	2
315	3	1	1	5	5.32	26.991	32.311	Aircraft 1	2
316	3	2	1	2	5.32	10.796	16.116	Aircraft 1	2
401	4	0	0	2	0	9.191	9.191	Aircraft 2	4
402	4	1	2	0	8.765	0	8.765	Aircraft 2	4
403	4	0	3	1	13.147	4.596	17.743	Aircraft 2	4
404	4	1	1	0	4.382	0	4.382	Aircraft 2	4
405	4	1	0	0	0	0	0	Aircraft 2	4
406	4	1	0	0	0	0	0	Aircraft 2	4
407	4	2	0	1	0	4.596	4.596	Aircraft 2	4
408	4	1	0	0	0	0	0	Aircraft 2	4
409	4	2	0	0	0	0	0	Aircraft 2	4
410	4	2	0	0	0	0	0	Aircraft 2	4
411	4	0	0	0	0	0	0	Aircraft 2	4
412	4	1	1	1	5.32	5.398	10.718	Aircraft 1	2
501	5	1	0	0	0	0	0	Aircraft 1	2
502	5	1	0	0	0	0	0	Aircraft 2	4
503	5	2	0	1	0	4.596	4.596	Aircraft 2	4
504	5	2	0	0	0	0	0	Aircraft 2	4
505	5	1	0	2	0	9.191	9.191	Aircraft 2	4
3051	2A	1	1	0	5.32	0	5.32	Aircraft 2	4
3061	2A	0	0	2	0	10.796	10.796	Aircraft 1	2
5041	5	2	0	0	0	0	0	Aircraft 1	2
213	2A	3	5	4	21.912	18.382	40.294	Aircraft 2	4
								Aircraft 2	4