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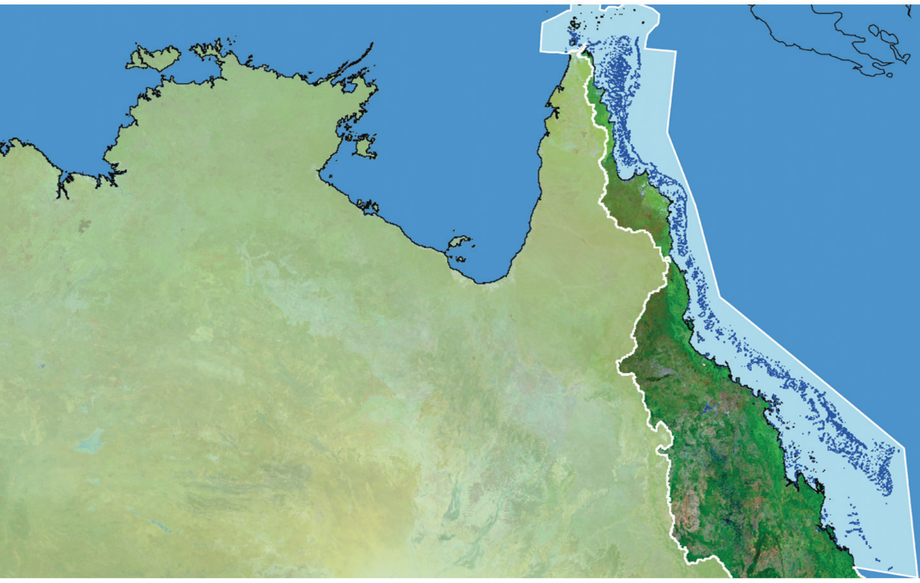

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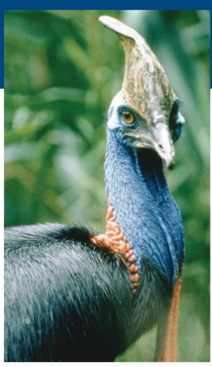
Including identification and evaluation of the key threats and evaluation of available management options to improve its status

Helene Marsh, Amanda Hodgson, Ivan Lawler, Alana Grech and Steven Delean




JAMES COOK UNIVERSITY

Australian Government

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Condition, status and trends and projected futures of the dugong in the Northern Great Barrier Reef and Torres Strait; including identification and evaluation of the key threats and evaluation of available management options to improve its status

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Contents

List of Figures

List of Tables

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Executive Summary

- This survey is the second of an integrated series of three aerial surveys which aim to survey the entire Queensland coast for dugongs over three field seasons. It provides the first synopsis of the distribution and abundance of the dugong on the remote coast of Queensland from Cooktown north including Torres Strait. The results of previous surveys of sections of this region have been difficult to interpret because of the potentially confounding influences of unpredictable dugong movements between areas within the region.
- The results of the 2006 survey of the whole region of almost 56,000 km^2 suggest a total population of some 23500 $\pm$ 2900 dugongs close to the estimate of some 23000 $\pm$2600 for the combined 2000 survey of the Northern Great Barrier Reef (GBR) and 2001 surveys of Torres Strait. Both estimates are based on the method of Pollock *et al.* (2006).
- The time series of surveys since the mid 1980s suggests considerable movement of dugongs between survey blocks within the Northern GBR region. Population movement between the Northern and Southern GBR are also likely and may also explain some of the variation in the dugong population estimates of both regions.
- The overall result of the time series of aerial surveys for the whole Northern GBR/Torres Strait region suggests that the fluctuations in the estimates in the size of the Torres Strait dugong population are unlikely to result from significant movements at a population level between the Northern GBR and Torres Strait. This result accords with new genetic evidence.
- A likely reason for the movement of dugongs within the Torres Strait region is the susceptibility of the region to episodic seagrass diebacks, which are now believed to be largely natural events, the frequency of which may be exacerbated by climate change.
- The aerial surveys of the Northern GBR and Torres Strait since the mid 1980s for dugongs have not demonstrated a significant decline in dugong numbers, despite concern about the sustainability of the traditional harvest of dugongs in this region and the limited arrangements to regulate this harvest to date. However, given the difficulty in detecting declines in marine mammal stocks, we caution about using this result as a reason for postponing community-based management initiatives, especially as: (1) the whole area of dugong habitat in Torres Strait has not been surveyed because the region to the west of the survey area is inaccessible from light aircraft based in Australia; (2) there is considerable uncertainty surrounding the impact of climate change on the frequency of seagrass diebacks; (3) there is evidence that the life history and reproductive rate of female dugongs are reduced by seagrass diebacks; and (4) the fact that dugongs in Torres Strait are breeding at younger ages, smaller sizes and more often than has been recorded elsewhere may be a density-dependent response to declining population size.
- The discrepancy between the estimated sustainable catch and the anecdotal catch estimates, particularly for Torres Strait, suggests that one of the following may be true: (1) the aerial surveys underestimate the actual dugong population size, probably because: (a) the availability correction factor is underestimated; and/or (b) the assumption of full independence between the two observers in a tandem team is violated; (2) dugongs are breeding faster than estimated, either because of a density-dependent response to declining population size and/or environmental conditions that have improved the food supply; and/or (3) the anecdotal estimates of the harvest rate are too high.
- The data generated using PBR modelling suggest annual sustainable anthropogenic mortality limits of 56-112 dugongs in the Northern GBR. We suggest that an annual

sustainable anthropogenic mortality limit of 56 would be a prudent interim management target given the World Heritage Status of the region and the management objective of population recovery for dugongs in the Great Barrier Reef Marine Park.

- PBR modelling suggests annual sustainable anthropogenic mortality limits of about 100-200 dugongs per year for Torres Strait depending on the value given to the Recovery Factor. The latter is a policy decision linked to the objective of the management arrangements.
- The dugong population in the Northern GBR/Torres Strait region is substantial (>20,000 individuals) and is genetically healthy. We believe that there is time to work with local Traditional Owners and commercial fishers to develop appropriate management arrangements without dugongs becoming locally extinct within this region. This approach accords with the Torres Strait Treaty 1985 between Australia and Papua New Guinea. The Treaty recognizes the importance of: (1) 'protecting the traditional way of life and livelihood of Australians who are Torres Strait Islanders and of Papua New Guineans who live in the coastal area of Papua New Guinea in and adjacent to the Torres Strait'; and (2) 'the marine environment' of the region.
- Index Blocks in Hervey Bay in southern Queensland were also surveyed to provide a context for the survey at a larger spatial scale. Despite the high correlation between the population estimates for the Index Blocks and their total region, the Index Blocks were not particularly robust indices of the dugong population in their region because they represent an unknown and probably variable proportion of the population. Index blocks external to a survey region add considerably to the expense and logistical problems associated with a regional survey and we consider that the practice of surveying Index Blocks should be discontinued.

Recommendations

Management Arrangements

1. That dugongs continue to be managed in the Great Barrier Reef World Heritage Area (GBRWHA) separately from Torres Strait, given the very different jurisdictional arrangements in the two areas and the preliminary evidence of genetic structure between the dugongs in the two regions.
2. That consideration be given to: (1) coordinating management across the dugong's range in Australia, preferably under a National Wildlife Conservation Plan as required for a listed migratory species such as the dugong under the *EPBC Act Cw'lth* 1999; and (2) developing policy for managing dugong hunting by the Northern Peninsula Area communities whose hunting grounds straddle the boundaries of the two jurisdictions.
3. That high priority be given to discussions with Papua New Guinea to canvass ways in which arrangements for managing the harvest of dugongs and turtles can be redeveloped in the Western Province.
4. That the major priority for dugong management in the Great Barrier Reef and Torres Strait continue to be the development of culturally acceptable and scientifically robust mechanisms to manage Indigenous hunting via the 'National Partnership Approach'. We suggest that initiatives to manage the Indigenous harvest of dugongs and turtles be embedded within generic caring for sea-country initiatives developed in the context of the current social and political reforms for remote Indigenous communities.
5. That funding for community-based initiatives to manage the Indigenous harvest of dugongs and turtles in Northern Australia be continued with high priority. We suggest that such funding should preferably be performance-contingent, long-term program funding rather than short-term project funding.
6. That relevant management authorities and Traditional Owners hold negotiations to determine whether the regional objective for dugong management in Torres Strait should be to maintain the population at its present level or to allow it to increase. This decision is a fundamental pre-requisite to setting a total allowable catch.
7. That negotiations be conducted to determine the social and cultural objectives of dugong management in the Northern GBR and Torres Strait. Such negotiations could be undertaken as part of the development of a National Wildlife Conservation Plan for Dugongs.
8. That GBRMPA give high priority to negotiations regarding the development and accreditation of Traditional Resource Use Management Agreements (TUMRAs) in the Northern GBR, given that these negotiations are likely to be protracted.
9. That GBRMPA continue to negotiate with Queensland about banning netting north of Lookout Point in the Starke River region, Bathurst Head (currently partly covered by some of the PCBSMA provisions) and Friendly Point, as part of the current review of the Queensland East Coast Inshore Fin Fishery. Adoption of these recommendations should assist negotiations between Traditional Owners and Management Agencies about the management of dugong hunting in the Northern GBR.

Future Aerial Surveys

1. That the dugong aerial surveys be continued at five-year intervals for the combined region of the Northern GBR and Torres Strait.
2. That the Pollock *et al.* (2006) method be used to estimate dugong population size.

3. That the correction for availability bias in the Pollock *et al.*(2006) method be reviewed using the data on dugong diving behaviour collected by Sheppard *et al.* (in review), stratified to reflect the time of day of the aerial surveys.
4. That future aerial surveys discontinue the use of Index Blocks.
5. That consideration be given to the feasibility of using Unmanned Aerial Vehicles rather than manned aircraft to conduct the surveys from 2011 to: (1) reduce costs; (2) reduce human risk; and (3) deliver superior data on species identification.

Introduction

As the only surviving member of the family Dugongidae (Marsh *et al.* 2003), the dugong is a species of high biodiversity value. The dugong is listed as vulnerable to extinction by the IUCN (IUCN 2006), along with the other three species in the order Sirenia, the manatees (family Trichechidae). Anecdotal evidence suggests that dugong numbers have decreased throughout most of their range (Marsh *et al.* 2002). Significant populations persist in Australian waters, which are now believed to support most of the world's dugongs. Consequently, Australia has an international obligation to ensure that dugong stocks are conserved in Australian waters (Bertram 1981).

Dugongs occur along much of the tropical and sub-tropical coast of Australia from Shark Bay in Western Australia to Moreton Bay in Queensland. The Northern Great Barrier Reef and Torres Strait support globally significant populations of dugongs (Marsh *et al.* 2002).

The dugong population in Torres Stait supports an important traditional fishery undertaken by Torres Strait Islanders for meat and oil. The fishery is authorised under *Article 22* of the Torres Strait Treaty between Australia and Papua New Guinea. The Torres Strait Islanders hunt dugongs as part of their traditional way of life and livelihood, which is protected by the Treaty. On the basis of wet-weight landings, the fishery is the largest island-based fishery in the Torres Strait Protected Zone (Harris *et al.* 1994). Under the Treaty, Torres Strait Islanders include persons who: (1) are Torres Strait Islanders who live in the Protected Zone or the adjacent coastal area of Australia (thus, the Northern Peninsula Area or NPA); (2) are citizens of Australia, and (3) maintain traditional customary associations with areas or features in or in the vicinity of the Protected Zone in relation to their subsistence or livelihood or social, cultural or religious activities.

The sustainability of their dugong fishery is a major imperative for Torres Strait peoples who greatly value dugongs for their nutritional, cultural, social, economic and ideological significance. The issue is also a priority for managers in relevant government environment agencies, particularly the Australian Fisheries Management Authority (AFMA) and some scientists (Hudson 1986, Johannes and MacFarlane 1991; Marsh 1996; Marsh *et al.* 1997; Marsh *et al.* 2002). Consequently, AFMA has supported research on dugongs in Torres Strait since the 1980s and has funded most of the historical surveys of dugongs in Torres Strait reported here.

In contrast to the situation in Torres Strait where the dugong is managed as the target species of a traditional fishery, the significance of the adjacent Great Barrier Reef (GBR) region for dugongs was a reason for its World Heritage listing (GBRMPA, 1981). Thus the GBR dugong stock, which is also subject to anthropogenic mortality including legal traditional harvest, is an explicit World Heritage Value and the status and trends in the distribution and abundance of dugongs is a critical information need for the management of the World Heritage Area and the associated network of no-take MPAs. Consequently, GBRMPA has also supported research on dugongs since the 1980s and funded the historical surveys of dugongs in the Northern Great Barrier Reef reported here.

Aerial surveys using the standardised techniques developed by Marsh & Sinclair (1989) have provided much of the information used to manage dugongs in Australia (Marsh *et al.* 2002). The Northern GBR Region was surveyed in 1985, 1990, 1995 and 2000; Torres Strait in 1987, 1991, 1996, 2001. The objective of these surveys has been to provide an assessment of the distribution and abundance of the dugong in these regions, a time series for temporal comparisons and an estimate of the annual sustainable mortality from all causes.

The results of these surveys confirm that there is considerable temporal variability in the size and/or distribution of the dugong population of most survey regions, even though these regions have been very large (typically >30,000 km^2). This variability is likely to be the result of several confounded factors: (1) temporal and spatial changes in the distribution of the dugong's seagrass food; (2) dugong movements between survey regions exacerbated by different jurisdictions being surveyed in different years for logistical and funding reasons; (3) uncorrected fluctuations in the availability of dugongs to observers because of temporal and spatial variability in sighting conditions; and (4) temporal changes in the size of the population.

In this report, we addressed the confounding effect of dugongs moving between regions between surveys by surveying the entire region from Cooktown through Torres Strait in November 2006, as the second stage of a three-year program to survey the entire Queensland cost for dugongs over three field seasons. The 2006 survey reported here is the first time that the Northern GBR and Torres Strait have been surveyed in the same year. We also addressed the fluctuations in the availability of dugongs to observers by using the improved methodology developed by Pollock *et al.* (2006). The results of the survey form the basis of this report on the condition, status and trends and projected futures of the dugong in the Northern Great Barrier Reef and Torres Strait.

Survey Methodology

Surveys Prior to 2006

All surveys were based on the aerial survey technique developed by Marsh & Sinclair (1989). The Great Barrier Reef Region between Cooktown (15° 29'S) and Hunter Point (11° 30'S) was surveyed in four years between 1985 and 2000 as funding permitted using a standardised design; Torres Strait was similarly surveyed on four occasions between 1987 and 2001 (see Table 1 for summaries of surveys). To minimise any seasonal effects, all surveys of the Northern GBR and Torres Strait reported here were conducted in good to excellent weather conditions in November-December. Index Blocks were not part of the surveys listed in Table 1.

2006 Survey

With input from statisticians and stakeholders, we rationalised the design of the 2006 aerial survey by: (1) plotting the dugong sightings from previous surveys on a common GIS database; (2) truncating offshore transects over areas where no dugongs have been sighted on any survey; and (3) modifying the survey design for the region between Hunter Point (11° 30'S) and Newcastle Bay (10 ° 50'S) on the east coast of Cape York. This region (Block N15) had not previously been surveyed because of its remoteness from aircraft fuel supplies and reported persistently low dugong abundance (see Figure 1a). This rationalisation and the use of two aircraft operating concurrently enabled us to survey the entire region (~56,000km^2) from Cooktown (15° 29'S) through Torres Strait in November 2006 (Figure 1 a and b), the first time that the entire region had been surveyed in one field season.

The sampling intensity in the bocks surveyed using transects perpendicular to the coast ranged from approximately 4.3% in Block TS3 to 25% in Block N11 (Figure 1a and b). The sampling intensity in the areas between Hunter Point and Newcastle Bay was 12.3% (Figure 1a; Block N15).

Index Blocks

The results of the previous surveys suggest that the populations of the Index Blocks (Hervey Bay Blocks HB1 and HB2 and Torres Strait Block TS2A; Figure 1) are significantly correlated with the population estimates for their region. These Index Blocks were flown in 2005 and 2006 to provide a regional context for the surveys flown in 2005 (QLD/NSW border to Cooktown) and 2006 (Cooktown through Torres Strait), because of the logistical impossibility of surveying the entire region from the QLD/NSW border through Torres Strait in a single season.

Estimating the Size of the Dugong Population

Two methods were used to estimate dugong abundance: (1) Marsh & Sinclair (1989), which attempts to provide standardised estimates of relative abundance (all surveys); and (2) Pollock *et al.* (2006), which attempts to provide an absolute estimate (surveys since 2000 only). Both methods attempt to correct for availability bias (animals not available to observers because of water turbidity), and perception bias (animals visible in the survey transect but missed by observers; Marsh & Sinclair, 1989). However, we believe the methodology of Pollock *et al.* (2006) to be superior because the correction for availability bias addresses the spatial heterogeneity in sighting conditions within each survey whereas the Marsh & Sinclair (1989) method averages these conditions within surveys and only corrects for differences in availability bias between surveys.

Dugong abundance was estimated separately for each of the blocks surveyed using transects perpendicular to the coast. Input data were the corrected number of dugongs (in groups of <10 animals) for each side of the aircraft per transect. The standard error estimates incorporated the errors associated with the correction factors. Any dugongs in groups of ≥10 were added to the estimates of population size and density as outlined in Norton-Griffiths (1978). All population estimates are ± standard error.

Statistical Analysis

Differences in dugong density among survey years for the complete time series of blocks surveyed in the Torres Strait, the Northern GBR, and Hervey Bay (Blocks HB 1 and HB 2 only) between 1985 and 2006 were examined by linear mixed-effects modeling using the data generated by the method of Marsh & Sinclair (1989), because not all the environmental data required for the improved technique of Pollock *et al.* (2006) were collected prior to 2005. Variation in dugong density estimated using the Pollock *et al.* (2006) method was assessed for the Northern GBR and Torres Strait surveys from 2000. The survey data for the Northern GBR were unbalanced. Block N14 was not sampled in 1985 and 1990. The approach used to deal with the imbalance was to model the data excluding Block N14, and then to check the interpretation regarding temporal change over 1995-2006 by analysing all blocks (including Block 14) over 1995-2006 only.

Blocks and years were treated as fixed effects, transects within blocks as a random effect. Mixed effects models were employed to estimate the random components of variance and to provide appropriate tests for differences between years, blocks and the block-year interaction. The parameters of these models were estimated by restricted maximum likelihood. Dugong density in each transect within blocks for each survey was the response. The data were log transformed (i.e. ln (y + 0.1)) to ensure a constant mean-variance relationship.

Approximate F-ratios were calculated for the fixed effects, however the statistical significance of the fixed effects was determined by simulation using Monte Carlo Markov Chains based on the estimated mixed-effects model parameters and using a uniform prior. Posterior distributions for the model parameters estimated with Monte Carlo Markov Chains were also used to estimate 95% credible intervals for these parameters.

Repeated contrasts (1 d.f.) between sequential pairs of years were used to identify significant changes in density between survey years. This same form of contrast was also used within each block where significant year by block interactions were observed. Where there were significant average differences between blocks, Bonferroni-corrected multiple comparison tests were used to identify which blocks differed from one another.

Power of Surveys to Detect Population Declines

We used the method of Gerrodette (1987) to estimate the power of two hypothetical time series of aerial surveys to detect declines in dugong abundance (1-tailed test for annual declines of 0.05, 0.03 and 0.01) over a time period similar to our long-term monitoring. We assumed two scenarios: five surveys, five years apart over 20 years from the first survey; eight surveys, three years apart over 21 years from the first survey. The coefficients of variation were based on the dugong data from the 2006 surveys based on the Pollock *et al.* (2006) method for the Northern GBR only (0.2); Torres Strait (0.16) and the entire survey region (0.127). We used the Pollock *et al.* method because it is designed to reduce the noise in the data based on the spatial heterogeneity of sighting conditions. We made the following assumptions: (1) that the rate of decline was exponential; (2) that the likelihood of a Type 1 Error was 0.05; (3) that the coefficient of variation varied as 1/square root of dugong population size as demonstrated empirically for dugong surveys by Marsh (1995); (4) that the population variance was known (z distribution).

Estimating the Size of Sustainable Human-induced Dugong Mortality

The maximum number of animals, not including natural mortalities that may be removed from the Northern Great Barrier Reef and Torres Strait populations was calculated for the 2006 survey data using the Potential Biological Removal (PBR) Technique (Wade, 1998) and the dugong population estimates generated using the Pollock et al. (2006) method. In view of the uncertainty associated with our understanding of dugong life history, we used a range of estimates for both R_{max} (0.01, 0.03, 0.05) and the recovery factor (0.5, 1) following Marsh *et al.* (2004).

Results

Estimates of Dugong Density and Population Size

Northern Great Barrier Reef

Using the method of Pollock *et al.* (2006), the standardised estimate of the dugong population in 2006 was 8812 ± 1769 compared with the corresponding estimate of 9730 ± 1485 for the 2000 survey (Figure 2). The estimates obtained using the Marsh & Sinclair (1989) method were 7925 ± 1068 in 1985, 10176 ± 1575 in 1990, 7843 ± 1155 in 1995, 9193 ± 917 in 2000 and 8239 ± 992 in 2006 (see Figure 2).

As observed previously, there were large temporal changes between surveys in the distribution of dugongs between survey blocks (Figure 2). The most noticeable changes compared with 2001 were the lower numbers in Blocks N2 and N3 south of Cape Melville, the absence of dugongs in Blocks N6 and N7 and the increased number in Blocks N4 and N8.

No population estimates were generated for the area between Hunter Point and Newcastle Bay that was surveyed using the low intensity zigzag transects across the depth gradient, because only three dugongs were sighted in this region.

Using the estimates derived from the Marsh & Sinclair method, there was no average difference in the dugong density among survey years (1985 to 2006) in the Northern GBR (Table 2). However, there were significant differences in dugong density among blocks, and these block differences were not consistent among years (Table 2 and Figure 3), suggesting dugong movements between blocks between surveys. In Block N3 (inshore south of Cape Melville), there was a weak increase in density between 1990 and 1995 ($P = 0.052$), and a significant decrease between 2000 and 2006 ($P < 0.0001$). In Block N4 (offshore between Cape Melville and the southern boundary of the survey region), there was significant increase between 1995 and 2000 ($P = 0.026$). In Block N6 (inshore north of Princess Charlotte Bay), there was a significant decrease between 2000 and 2006 ($P = 0.008$).

The differences between the 2001 and 2006 survey years in dugong density calculated using the Pollock *et al.* (2006) method were also not significant (Table 2). Nonetheless, substantial average differences in density among survey blocks were also evident (Figure 4). However, there was little evidence that these block differences changed between 2001 and 2006 (Table 2).

The average block differences (Figure 4) resulted from the higher density in Block N2 (Starcke River) compared with all other Blocks except N3 (inshore south of Cape Melville), N11 (Shelburne Bay) and N14 (Temple Bay), the higher density in Block N3 (inshore south of Cape Melville) compared with the offshore Blocks N7, N9, and N13, the higher density in Block N5 (Princess Charlotte Bay) compared with N7 and N9, and the lower densities in offshore N7 and N9 compared with inshore N11 and N14.

Torres Strait

Using the method of Pollock *et al.* (2006), the standardised estimate of the dugong population in 2006 (Figure 5) was 14767 ± 2292, compared with the estimate of 13465 ± 2152 in 2001. The population estimates for the Marsh & Sinclair (1989) method were 13319 ± 2136 in 1987, 24225 ± 3276 in 1991, 27881 ± 3095 in 1996, 14106 ± 2314 in 2001, and 19583 ± 995 in 2006.

There were significant differences in dugong density among years across the nineteen-year time series of dugong population estimates generated using the Marsh and Sinclair (1989) method (Figure 6a), and density varied substantially among blocks (Table 2). The differences between years were independent of block variation suggesting movement beyond the spatial scale of the surveyed region. There was a significant increase in density between 1991 and 1996 ($P = 0.012$), and a significant decrease between 1996 and 2001 ($P < 0.0001$). The average block differences resulted from the higher density of dugongs in Block TS2A (Buru Island/ Orman Reef area) compared with all other blocks, the higher density in Blocks TS2B and TS3 compared with Block TS5, and the lower density in Block TS0 compared with Block TS3 (Figure 6b). The random variance component corresponding to the among-transect within-block variation among years (error) was much larger than the corresponding value for the variance among transects within blocks suggesting that, dugongs also make substantial small-scale movements within blocks over time in Torres Strait (Table 2).

Similar among block differences were evident in the Torres Strait using data from the 2001 and 2006 surveys based on the method of Pollock *et al.* (2006) (Figure 6c). The average block differences were due to the higher density of dugongs in Block TS2A compared to all other blocks except TS3, the higher density in Blocks TS1A, TS3 and TS4 compared with TS5, and the lower density in Block TS0 compared with Block TS3.

Index Blocks

The dugong population estimates for the Index Blocks in Hervey Bay (Block HB1 and HB2) were significantly correlated with the corresponding population estimate for that entire Bay (Figure 7 a). Similarly the population estimate for the Torres Strait Index Block was significantly correlated with the estimate for the entire Torres Strait region (Figure 7b); Hervey Bay Block 2 and total Hervey Bay $r = 0.71$, $p = 0.048$; Hervey Bay Blocks 1 and 2 combined and total Hervey Bay $r = 0.83$, $p = 0.01$; Torres Strait Block TS2A and total Torres Strait $r = 0.88$; $p = 0.048$).

There were significant differences in dugong density among years in Blocks HB1 and HB2 in Hervey Bay (Table 2); however these temporal differences varied substantially among blocks (Table 2 and Figure 8). In Block HB1, there was a weakly significant increase in density between November 2001 and 2005 ($P = 0.046$), and a significant decline in density between 2005 and 2006 ($P < 0.0001$). In contrast, in Block HB2 there was a significant increase in density between April and November 2001 ($P = 0.012$), but no significant sequential changes between other years.

Comparison Between Methodologies

The population estimates for 2000 and 2006 derived using the method of Pollock *et al.* (2006) were slightly (~6-7%) higher for the Northern GBR than the corresponding estimates using the older, less accurate, methodology of Marsh & Sinclair (1989; Table 3). In contrast, the estimates for the Torres Strait surveys in 2001 and 2006 and the Torres Strait and Hervey Bay Index blocks derived using the Pollock *et al.* methodology were all lower than the estimates obtained using the method of Marsh & Sinclair by ~1-25% Table 3). These differences between regions are the result of regional differences in the spatial heterogeneity of sighting conditions and the difficulty in estimating availability bias using the Marsh and Sinclair (1989) method, particularly the difficulty in deciding whether a dugong is at the surface in clear water.

Power of Aerial Surveys to Detect Population Declines

The power of the two hypothetical time series of aerial surveys to detect a decline in dugong abundance over a 20 year time period was >65% for annual declines of ≥ 3% but much lower (19%-43%) for an annual decline of 1% (Table 4). The power of the hypothetical time series was greater if the Northern GBR and Torres Strait regions were surveyed together than if the two regions were surveyed separately because of the improved precision in the population estimate (Table 4). As expected, conducting the surveys every three rather than every five years improved the power of the surveys to detect trends but if the entire region is surveyed in one field season the improvement is relatively small except if the population is declining very slowly when the power of the surveys to detect trends is low (Table 4). These calculations assume that a constant proportion of the population is in the survey region which is unlikely to be true, especially for Torres Strait. Thus the power of the surveys conducted since 1985 to detect a declining trend is likely to be lower than estimated here. We conclude that the possibility that the dugong populations of Torres Strait and the Northern GBR are declining slowly cannot be ruled out, even though the surveys have not detected such a decline.

Estimating a Sustainable Level of Human-induced Mortality for Dugongs in the Northern GBR and Torres Strait

The range of estimates for sustainable anthropogenic mortality (PBR) is summarised in Table 5 for the 2006 estimates of absolute population size for the Northern GBR and Torres Strait (Pollock *et al.*, 2006). The middle value for the estimated maximum rate of increase (R_{max} = 0.03) suggest that a total annual anthropogenic mortality of ≥56 dugongs would be required for population recovery in the Northern GBR if the recovery factor (RF) was 0.5; or 112 (RF = 1) (Table 5). The corresponding estimate of total annual anthropogenic mortality for Torres Strait are 97 (RF = 0.5); or195 (RF = 1).

Discussion

This survey provides the first survey of the distribution and abundance of the dugong on the remote coast of Queensland from Cooktown north including Torres Strait in a single field season. The results of previous surveys of sections of this region have been difficult to interpret because of the confounding influences of unpredictable dugong movements between areas within the region. Taken together, the results for the 2006 survey of the whole region of almost 56,000 km^2 suggest a total population of some 23500 ± 2900 dugongs close to the estimate of some 23000 ± 2600 for the combined 2000 survey of the Northern GBR and 2001 surveys of Torres Strait. Both these estimates were generated using the methodology of Pollock *et al.* (2006), which corrects for the spatial heterogeneity of sighting conditions within and between regions and reduces the noise in the data that may otherwise obscure trends in the dugong population.

Condition, Status and Trends of Dugong Population in the Northern GBR and Torres Strait

Northern Great Barrier Reef

All the population estimates obtained by the method of Marsh & Sinclair (1989) of the time series of aerial surveys of the Northern GBR 1985-2006 have been relatively similar at approximately 8,000-10,000 (Figure 2). The results of the surveys are also robust to the methodological differences in correcting for availability bias inherent in the approaches of Pollock *et al.* (2006) and Marsh & Sinclair (1989) suggesting limited spatial and temporal variability in sighting conditions both within blocks and between surveys. Thus we conclude that the noise in the data resulting from variability in sighting conditions in this region is low relative to most other regions surveyed for dugongs.

Nonetheless, the time series of surveys suggests considerable movement of dugongs between survey blocks within the Northern GBR region (Figure 2). In addition, movement of dugongs between the Northern and Southern GBR has been established by satellite tracking (Sheppard *et al.* 2006) and is suggested by the genetic evidence below. Thus population movement between the Northern and Southern GBR may explain some of the variation in the dugong population estimates of both regions (Figure 2 and Marsh *et al.* 2006). Some of this variability may be the result of seagrass diebacks (Marsh and Kwan in press) but data are not available to accept or reject this hypothesis.

The aerial surveys of the Northern GBR conducted since the mid 1980s have not demonstrated a significant decline in dugong numbers despite ongoing concern about the sustainability of the traditional harvest of dugongs in this region (Heinsohn *et al.* 2004) and the lack of significant management arrangements to regulate this harvest to date. (The several attempts at management intervention, especially for the Hope Vale Aboriginal community have largely been unsuccessful (Smith and Marsh 1990; Marsh 1996; Marsh 2007). However, we caution about using the result of our surveys as a reason for postponing management actions. Taylor *et al.* (2007) demonstrate that scientists' ability to detect declines in marine mammal stocks is weak, even when the decline is precipitous. Thus the fact that our time series of aerial surveys has not detected a decline in abundance does not prove that the present levels of harvest are sustainable, especially if the rate of decline is low (which if decline is occurring it almost certainly is; Table 4). The data generated using the PBR approach suggest annual sustainable anthropogenic mortality limits of 56-112 dugongs in the Northern GBR (Table 5). Although these estimates of dugong population size may be conservative (largely because of the difficulty in estimating availability bias and the high risk of the members of a tandem team violating the assumption of observer independence), we suggest that 56 dugongs per year would be a prudent management target given the World Heritage Status of the region and the management objective of population recovery for dugongs in the GBRWHA.

Torres Strait

The variation in the dugong population estimates for Torres Strait based on the Marsh & Sinclair method (approximately 12,000-28,000; Figure 5) is much larger than for the Northern GBR, and occurred both between surveys and between the methodologies used to generate dugong population estimates for the same survey. We suggest two reasons for this result:

1. We cannot assume that the proportion of the Torres Strait dugong population that is being surveyed is constant across surveys. It is not logistically possible to survey all dugong habitat in the Torres Strait region with light aircraft based in Australia because of: (1) the region's proximity to West Papua (which is a province of Indonesia); (2) the limited endurance of survey aircraft; and (3) the limited availability of fuel supplies. The spatial distribution of dugong sightings clearly suggests that the habitat extends to Indonesian waters to the west of the survey region (Appendix Figure 4). Thus some of the variation in the dugong population estimates for Torres Strait (Figure 5) is likely to result from dugong movements between the survey region and the region to the west.
2. Some of the differences between years in Torres Strait, especially as reported by Marsh *et al.* (1997 and 2004), may have resulted from noise in the data resulting from uncorrected fluctuations in the availability of dugongs to observers. These fluctuations result from: (1) differences between surveys in the spatial heterogeneity of water turbidity; and (2) the difficulty in estimating availability bias using the Marsh and Sinclair (1989) method, particularly the difficulty in observers deciding whether a dugong is at the surface. The high risk of the members of a tandem team violating the assumption of observer independence is another unresolved problem.

Comparison of the differences between the results of the 2001 and 2006 surveys using the method of Marsh & Sinclair (1989) with corresponding values using the method of Pollock *et al.* (2006), provide evidence for the limited capacity of the older method to correct fluctuations in the availability bias. As predicted, the differences between surveys using the newer method were much less than those calculated using the older methodology. However, it is not possible to separate changes in the actual population size from the confounding influences of movements into and out the survey area among surveys and the problems with correcting for availability bias.

The discrepancy between the estimated sustainable catch and the anecdotal catch estimates, particularly for Torres Strait (see Kwan 2002, Marsh *et al.* 2004, Kwan *et al.* 2006) suggests that the Pollock *et al.* (2006) methodology is underestimating dugong population size, despite the considerable attempts to correct for availability bias. Sheppard *et al.* (in review) has recently demonstrated, using GPS satellite technology at several locations in southern and central Queensland , that dugongs tend to be closer to shore at night than during the morning when the aerial surveys are conducted. This result concurs with traditional knowledge from Torres Strait. Chilvers *et al.* (2004) could find no diel differences in dugong diving behaviour and the availability correction factors developed by Pollock *et al.* (2006) were based on dugong diving records across the diel cycle. The new data of Sheppard *et al.* (in review) suggest that the method for estimating the Availability Correction Factor should be reviewed using the dive data collected between 8:00am and 3:00pm only (the times when the aerial surveys are conducted) from both the fifteen dugongs sampled by Chilvers *et al.* (2004) and the additional twelve dugongs tracked by Sheppard *et al.* (in review).

The overall result of the time series of aerial surveys for the whole Northern GBR and Torres Strait regions suggests that the significant fluctuations between surveys in the size of the Torres Strait dugong population (Marsh *et al.* 1997 and 2004; Figure 5) are unlikely to result from significant movements at a population level between the Northern GBR and Torres Strait. This result accords with the new genetic evidence discussed below. A likely reason for the movement of dugongs within Torres Strait is the susceptibility of the region to episodic seagrass diebacks, which are now believed to be mostly natural events (Marsh and Kwan in press) caused largely by light deprivation resulting from sediment resuspension from two major depocentres on either side of the Strait (Saint-Cast in press). Prolonged periods of monsoon winds and/or extreme weather events enhance sediment resuspension. For example, Poiner and Peterkin (1996) report the loss of several hundred square kilometres in north-western Torres Strait in 1991-1992, which they tentatively attribute to high turbidities from flooding of the Mai River in Papua New Guinea. Marsh *et al.* (2004) provide anecdotal evidence of another dieback event in the Orman Reef area north-east of Mabuiag Island (9.95°S, 142.15°E) in 1999-2000. Seagrass diebacks have not been reported from the Northern GBR, but the data are too sparse to come to any conclusions about their incidence in this region.

Similar to the Northern GBR, the time series of aerial surveys of Torres Strait since the mid 1980s for dugongs has not demonstrated a significant decline in dugong numbers, despite long-standing concern about the sustainability of the traditional harvest of dugongs in this region (Hudson 1986, Johannes and McFarlane 1991, Heinsohn *et al.* 2004, Marsh *et al.* 1997, 2004; Anon 2006) and the limited management interventions to regulate this harvest to date. Again we caution against using this result as a reason for postponing management action, because: (1) of the difficulty of detecting trends in the abundance of marine mammals (Taylor *et al.* 2007); (2) the whole area of dugong habitat has not been surveyed; (3) the uncertainty surrounding the impact of climate change on the frequency of seagrass diebacks in Torres Strait; and (4) the evidence that the life history and reproductive rate of female dugongs are adversely affected by sea grass loss (Marsh and Kwan in press), and the evidence of Kwan (2002) and Hamann *et al.* (2005) that dugongs in Torres Strait are breeding at exceptionally small sizes/young ages which may be a sign that the population is declining.

The PBR approach which is now mandatory in the United States (Wade 1998) suggests annual sustainable anthropogenic mortality limits of about 100-200 per year for Torres Strait depending on the value given to the Recovery Factor. The appropriate level of the Recovery Factor depends on the objective of the management arrangements. This objective needs to be negotiated between the relevant fisheries managers and Torres Strait Islander representative bodies.

Reliable harvest estimates of current harvest are not available. Two modelling approaches (Heinsohn *et al.* 2004, Marsh *et al.* 2004) suggest that the dugong harvest in the 1990s was too high to be sustainable. Nonetheless, these results do not prove that the harvest is unsustainable; other explanations are possible as listed below:

1. The aerial surveys significantly underestimate absolute dugong population size because of the availability bias is underestimated, perhaps because of diel differences in dugong diving behaviour discussed above.
2. Dugongs are moving into Torres Strait from the west in response to a decline in the population in the main hunting areas around the Western and North Western Islands. Changes in conditions can result in distributional shifts may occur with a declining population trend (Taylor *et al.* 2007).
3. The dugong catches recorded by Kwan *et al.* (2006) were exceptionally high.

4. Dugongs are breeding faster than the PBR model assumes. For example if dugong are producing maximally r=0.05 p.a, the sustainable harvest would be 324 per annum for a Recovery Factor of 1. Kwan and Marsh (in press) report that the dugong sampled at Mabuiag in 1997-98 were breeding at earlier ages and more frequently than in any other dugong population sampled to date. Kwan (2002) and Hamann *et al.* (2005) also record dugongs in Torres Strait breeding at exceptionally small sizes/ young ages, which may result in a high rate of population increase. Breeding at an exceptionally young age may also be a sign that the population is declining as discussed above in by Marsh and Kwan (in press).

Projected Future

Longevity of Indigenous Harvest

Archeological evacuations indicate that dugongs have been harvested in Torres Strait for at least four thousand years (Crouch *et al.* 2007). For example, evacuation of a ritual dugong mound on Mabuiag Island revealed the remains of 10,000 to 11,000 dugongs hunted between c. 1600 and 1900 A.D. (McNiven *et al.* 2007). McNiven *et al.* estimate that the community of Mabuiag has been harvesting dugongs at a rate of up to 100 per year for the past 300 years and assume that this evidence indicates that this prolonged harvest must have been sustainable. This conclusion is not necessarily correct. A population which is harvested at slightly below the sustainable yield can persist for hundreds of years (e.g. a population which is harvested at 0.3% above the sustainable yield will be 40% of its original value after 300 years). It is likely that dugongs have also been harvested in the Northern GBR for a prolonged period although the archaeological evidence for this is not as strong.

The data of Kwan *et al.* (2006) indicate that the harvest at Mabuiag in 1997 and 1998 was at least 50% higher than that suggested by the archaeological data of McNiven *et al.* (2007). Kwan *et al.* (2006) recorded a landed catch of 145 dugongs in eight months in 1998 and 170 dugongs in the same period in 1999. Thus the archaeological evidence cannot be used as proof that the present harvest is sustainable.

Status of Present Population

Irrespective of whether the current anthropogenic impacts on the dugong population of the Northern GBR and Torres Strait are sustainable, the dugong population size in the region is substantial (>20,000 individuals) and is genetically healthy exhibiting high haplotypic diversity (Blair *et al.* in review). We believe there is time to work with local Traditional Owners and commercial fishers to develop appropriate management arrangements without dugongs becoming locally extinct within this region or parts thereof. This approach would accord with the Torres Strait Treaty 1985 between Australia and Papua New Guinea. The Treaty recognizes the importance of ‘protecting the traditional way of life and livelihood of Australians who are Torres Strait Islanders and of Papua New Guineans who live in the coastal area of Papua New Guinea in and adjacent to the Torres Strait’; and (2) ‘the marine environment’ of the region.

Long-term Risk

Experience with other large mammals (Johnson 2006) demonstrates that even very low-levels of anthropogenic mortality can drive species to extinction if all individuals in the prey population are exposed to mortality at some stage of their lives. This situation is most likely if: (1) animals are exposed to anthropogenic mortality in all the habitats in which they live; (2) human population size does not depend strongly on access to megafauna; and/or (3) animals in low density populations are still exposed to the risk of being killed. The second of these conditions certainly applies to dugongs in Northern GBR and Torres Strait waters, except perhaps off the coast of Papua New Guinea where there may by an issue of food security. Condition (3) also applies in Torres Strait where dugongs are hunted incidentally by cray fishers and turtle hunters (Marsh *et al.* 1997; Kwan *et al.* 2006). However, the first condition does not apply in either the Great Barrier Reef or Torres Strait. Significant numbers of dugongs occur in areas where commercial netting and Indigenous hunting do not occur. For example, in the Northern GBR, netting no longer occurs in >90% of dugong habitat as explained below (Grech *et al.* in review) and hunting generally does not occur in water deeper than about 5 m and > 3 nm (approx. 5.4 km) from the coast (C. Turner and T. Stokes, *pers. comm.*). In addition, much of the Torres Strait dugong habitat is remote and probably not harvested and there is a dugong sanctuary in western Torres Strait (Kwan *et al.* 2006), although its location has not been widely publicized and the enforcement presence is low. Nonetheless, the fact that dugongs in Torres Strait are breeding at younger ages, smaller sizes and more often than has been recorded elsewhere may be a density-dependent response to over-harvest (Kwan 2002, Marsh and Kwan in press) which should not be ignored.

Key Threats

Dugongs are long-lived, slow to mature and subject to several threats. If these threats persist, they will threaten the integrity of wild populations of dugongs in Australia and elsewhere (Marsh *et al.* 2002). The main threats in the Northern GBR and Torres Strait are:

1. The bycatch of dugongs in commercial gill net fisheries (Northern GBR);
2. Unknown levels of harvest by Indigenous Australians (both regions);
3. Unknown levels of harvest by neighboring countries of the Asia/Pacific region, especially Papua New Guinea (Torres Strait);
4. Illegal poaching by Australians and foreign fishers (both regions but especially Torres Strait); and
5. Marine debris (unquantified but likely in both areas).

In our opinion, the major threats to the dugong in this region are 2, 3 and 4 above. It is impossible to evaluate the relative impact of these threats without additional data. Nonetheless, industry restructuring and new zoning and management arrangements in operation since January 2005 have greatly reduced the risk to dugongs from commercial netting in the Northern GBR region by area closures and effort reduction. Commercial netting is now banned from approximately 64% of the high density dugong habitat, 44% of medium density dugong habitat and 31% of low density habitat. However the actual area where netting is currently conducted is now much less than these figures indicate: 4% of the high density dugong habitat; 9% of medium density dugong habitat; and 7% of low density habitat (Grech *et al.* in review). Grech *et al.* (in review) have identified three areas where additional spatial closures would significantly reduce the remaining risk of netting to dugongs (Lookout Point in the Starke River region Block N2), Bathurst Head in Princess Charlotte Bay Block N5 (the last region is partly covered by some of the Princess Charlotte Bay Special Management Area where commercial gill-netting is limited to nominated license holders) and Friendly Point in Block N6.

This information has been contributed to the current review of the Queensland East Coast Inshore Finfish Fishery. Adoption of these recommendations should assist negotiations between Traditional Owners and Management Agencies about the management of dugong hunting in the Northern GBR.

Management Options

We consider that the major priority for dugong management in the Great Barrier Reef and Torres Strait should be the development of culturally acceptable and scientifically robust mechanisms to manage Indigenous hunting. The 'National Partnership Approach' to the management of Indigenous hunting of turtles and dugongs is being implemented by the Commonwealth Department of the Environment, Water, Heritage and The Arts in cooperation with the relevant states and Northern Territory governments (Anon 2005). We suggest that this policy should be embedded in generic caring for sea-country initiatives developed in the context of the current social and political reforms. The implementation of the 'National Partnership Approach' is being achieved, in part, by grants to the North Australian Indigenous Land and Sea Management Alliance (NAILSMA) and the Torres Strait Regional Authority (TSRA). Funding for the TSRA and NAILSMA Dugong and Turtle Project is scheduled to end in June 2008. We consider that it will be very important to continue funding for community-based initiatives to manage the Indigenous harvest of dugongs and turtles in Northern Australia. We suggest that this funding should preferably be performance-contingent, long-term program funding rather than short-term project funding.

A Regional Activity Plan for Torres Strait (RAPTS) was developed by the TSRA in collaboration with the CRC Torres Strait to guide the implementation of activities under the NAILSMA/TSRA project. The RAPTS includes four key components: community management plans; monitoring programs; catch sharing; and education and awareness-raising. The TSRA has secured funding to implement the RAPTS on a pilot basis for a two-year period from 30 January 2006. The TSRA Board has nominated eight candidate communities to take part in the pilot phase: Boigu, Badu, Iama, Mer, Erub, Mabuiag, Dauan and Horn Islands, and planning is progressing, e.g. Mura Badulgal Dugong and Turtle Management Plan; Ngurupai (Horn Island) management planning.

Within the Great Barrier Reef region, the policy is to regulate the dugong and turtle harvest through the development of Traditional Resource Use Management Agreements or TUMRAs (Havemann *et al.* 2005). The two TUMRAS accredited to date (Girringun and Woppaburra) have included a ban on dugong hunting, a management arrangement which applies south of Cooktown only and which has been decreed by the GBR Ministerial Council and the GBRMPA. Thus the TUMRAs for the communities adjacent to the Northern GBR, such as Lockhart River and Hope Vale, are likely to be more challenging to negotiate than those negotiated to data. Given that protracted negotiations are likely to be required to negotiate TUMRAs in the Northern GBR, we recommend that these negotiations are given high priority by GBRMPA.

The priorities of Indigenous peoples and government agencies are almost certainly different, as Nursey-Bray (2006) has convincingly documented in her evaluation of the development and implementation of the Hope Vale Aboriginal community Green Turtle and Dugong Hunting Management Plan. Nursey-Bray demonstrated that Indigenous people prioritise social justice, community and culture whereas management agencies prioritise biodiversity conservation and species viability. Consequently, a process needs to be developed to promote the development of management initiatives that satisfy the needs of both groups with an associated increase in mutual understanding and trust.

A wide range of tools is available to manage the Indigenous harvest of dugongs including:

- Adopting closed areas, seasons or times (e.g. banning night hunting). The spatial information on dugong distribution based on the times series of aerial surveys could be use to identify candidate areas for closed areas in association with the cultural mapping to be conducted as part of the Marine and Tropical Sciences Research Facility (MTSRF) Year 2 research activites (or 'MTSRF ARP2').

- Limiting hunting to the Traditional sea country of each community or clan group.
- Limiting hunting to the provision of food for special occasions only.
- Adopting gear restrictions such as pre-European contact technology. This option as has been proposed by some Indigenous leaders and was adopted for a time in the late 1970s in the Maza Wildlife Management Area in the Papua New Guinean waters of Torres Strait (Hudson 1986).
- Agreeing on a total allowable catch shared between communities and families and/or designated (permitted) hunters within communities and monitored by either: (1) data sheets; (2) monitoring at designated butchering sites.

If a total allowable catch is adopted it will be very important to monitor hunting effort and technology as changes in these factors can greatly influence hunting success. A total allowable catch may become mandatory in Torres Strait as a result of the Torres Strait Fisheries (Amendment) Bill. The proposed amendment requires the Minister to establish a total allowable catch, total allowable effort or combination of both for each Torres Strait fishery for each season (Paul Havemann pers comm. 2007).

In developing management arrangements, the various management tools such as those listed above should be evaluated against agreed criteria which recognise the differing values of Indigenous communities and government. These criteria are to be negotiated and might include:

- Effect on dugongs in the jurisdiction and neighboring jurisdictions;
- Cultural acceptability to local Indigenous peoples and wider community;
- Local capacity required for effective implementation;
- Cost of effective implementation;
- Socio-economic cost/benefit to local community; and/or
- Effect on ecosystem including other harvested marine species, especially green turtles.

The relative importance of these criteria will differ for Indigenous people and government policy makers. These differences are legitimate and need to be recognised in a transparent process.

If the communities wish to consider spatial closures as a management tool, the time series of aerial surveys can be used to provide spatial information about dugong density in both the Northern GBR and Torres Strait using the spatially explicit dugong population modelling technique of Grech & Marsh (2007). In 2007/2008 as part of MTSRF ARP2, Grech and Marsh will conduct cultural mapping in Torres Strait communities.

The outputs will be integrated with the spatially explicit dugong population model and other scientific information to form a GIS-based decision support system, which will be returned to the communities in an accessible format to assist Traditional Owners develop strategies for managing the dugongs in their sea country.

Need for Coordinated Management at an Ecologically-Appropriate Scale

Recent research using mitochondrial DNA (which is maternally inherited) demonstrates some regional differentiation of dugong populations (Blair *et al.* in review). Along the east coast of Queensland, three regional groups of populations are tentatively distinguished: Moreton Bay to Shoalwater Bay; Townsville to the Starcke River region; and Torres Strait. No samples are yet available for the region between Cape Melville and Torres Strait and so the boundary between the Townsville to Starcke and Torres Strait stocks is uncertain and may not be clear cut. The region between Hunter Point and Newcastle Bay which supports very low densities of dugongs may form a boundary between the two regions. The regional differentiation of dugong stocks north and south of Townsville also needs further investigation.

Nonetheless, the genetic, satellite tracking and aerial survey data all indicate that the appropriate ecological scale for management is some hundreds of kilometres (Blair *et al.* in review; Sheppard *et al.* 2006). Thus effective dugong management requires initiatives to be co-ordinated across jurisdictions. Although we consider that it is sensible to continue to manage dugongs in the Great Barrier Reef World Heritage Area separately from Torres Strait, given the very different jurisdictions operating in the two areas, we suggest that priority be given to the policy for managing dugong hunting by the Northern Peninsula Area communities and coordinating management across the two regions. In addition, it will be important to: (1) coordinate management across the dugong's entire range in Australia, preferably under a national Wildlife Conservation Plan as required for a listed migratory species such as the dugong under the *EPBC Act Cw'lth 1999*; and (2) initiate discussions with Papua New Guinea to canvass ways in which arrangements for management the harvest of dugongs and turtles can be redeveloped in the Western Province. In the late 1970s and early 1980s, the Western Province of Papua New Guinea led the world in the community-based management of dugongs (Hudson 1986).

The GBRMPA recently determined that the ecological objective of dugong management in the GBRWHA should be population recovery. The relevant management authorities and Traditional Owners need to decide whether the regional objective for dugong management in Torres Strait should be to maintain the population at its present level or to allow it to increase. A decision about this objective is a fundamental pre-requisite to setting a total allowable catch for the Torres Strait dugong fishery. It would also be important that the total allowable catch include the harvest of the New Guinean villagers.

The social and cultural objectives of management in both jurisdictions also need to be negotiated at regional as well as local scales. Such negotiations could be undertaken as part of the development of a National Wildlife Conservation Plan for Dugongs.

Options for Future Monitoring of Dugongs in the Northern GBR and Torres Strait

Review of the Aerial Survey Design and Methodology

Survey Design

The approach used for the 2006 aerial survey demonstrated that it is logistically feasible to survey the entire region of ~56,000 km^2 from Cooktown through Torres Strait in a single month using two aircraft and three survey crews. Nonetheless, we consider that a survey of this magnitude is at the limit of logistical feasibility given the difficulties in recruiting trained observers and hiring suitable aircraft.

Index Blocks

Despite the high correlation between the population estimates for the Index Blocks and their total region, we consider that the Index blocks were not particularly robust indices of the dugong population in their region (Figure 7) because they represent an unknown and probably variable proportion of the population. Index blocks external to a survey region add considerably to the expense and logistical problems associated with a regional survey and we consider that the practice of surveying Index Blocks should be discontinued.

Survey Methodology

The differences between the dugong population estimates for the Northern GBR resulting from the 2000 and 2006 surveys were similar for both the Pollock *et al.* (2006) and the Marsh & Sinclair (1989) methods. In contrast for Torres Strait the results of the 2001 and 2006 surveys were closer for the Pollock *et al.* method, suggesting that the new method was superior in correcting for availability bias. As noted above, the Pollock *et al.* method should be improved by revising the method for estimating availability bias by stratifying the dugong dive data within the diel cycle.

Taylor *et al.* (2007) suggest ways in which the power of surveys to detect trends in the abundance of marine mammals can be improved. We review the aerial surveys of dugongs in Torres Strait in the context of their suggestions below.

1. **To increase the precision of the population estimates.** The precision (coefficient of variation) of the dugong population estimates (20% for Northern GBR and 16% for Torres Strait) is already quite high for marine mammal surveys (see Taylor *et al.* 2007) and will not be improved without a significant increase in survey sampling effort with a concomitant increase in cost and logistical difficulties. However, surveying the combined region of the northern GBR and Torres Strait together reduces the precision to 12.7% without increasing costs. This precision is very good for marine mammal surveys (Taylor *et al.* 2007) demonstrating the advantage of surveying both the GBR and Torres Strait together.
2. **To reduce the noise which obscures trends.** The Pollock *et al.* (2006) method addresses this problem by accounting for the spatial and temporal heterogeneity in sighting conditions. However, this approach does not reduce the noise resulting from dugong movements in and out of the survey region in Torres Strait.
3. **To reduce the area surveyed and increase the effort in the chosen area.** This approach was the rationale behind our use of Index Blocks. Nonetheless, we recommend that Index Blocks be discontinued because this approach requires the

strong assumption that the proportion of the total population in the Index Block is constant across time (Taylor *et al.* 2007). This assumption is not valid for dugongs as evidenced by Figure 5 and the data from Gales *et al.* (2004), Marsh *et al.* (2004 and 2007) and Holley *et al.* (2006). Taylor *et al.* (2007) point out an additional danger with this approach: changes in conditions may result in distributional shifts with a declining trend in population abundance. For example, if dugongs in Torres Strait moved into the survey area from the west in response to improved seagrass conditions resulting from unsustainable harvest in Torres Strait, the population could appear to be stable when it is declining.

4. **To identify demographically independent populations and survey at the level of these stocks.** The new data on the regional differentiation of dugong stocks along the east coast of Australia needs further investigation and may provide a basis for improving the design of future aerial surveys.

Recent advances in the development of Unmanned Aerial Vehicles mean that they may be a viable and attractive alternative to manned aircraft for wildlife surveys to: (1) reduce costs; (2) reduce human risk; and (3) deliver superior data on species identification. The feasibility of this alternative has yet to be tested particularly in remote regions such as Torres Strait but warrants investigation.

We recommend that: (1) the dugong aerial surveys be continued at five year intervals for the combined region of the northern GBR and Torres Strait; (2) that the Pollock *et al.* (2006) method be used to estimate population size; (3) that the correction for availability bias in the Pollock *et al.* method be reviewed using the data on dugong diving behaviour collected by Sheppard *et al.* (in review) stratified to reflect the time of day of the aerial surveys; and (4) that consideration be given to the feasibility of using Unmanned Aerial Vehicles rrather than manned aircraft to conduct the surveys from 2011.

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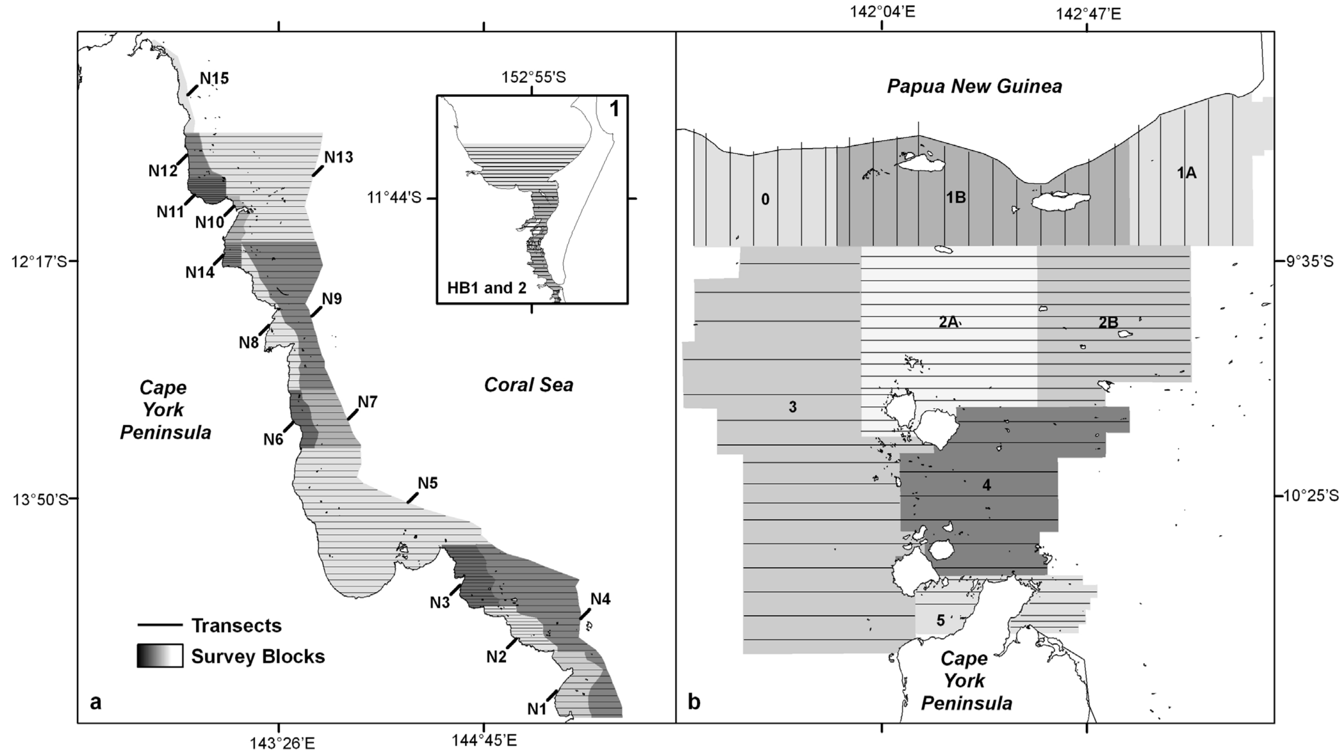


Figure 1: Maps showing the blocks and transects surveyed during the aerial survey for dugongs conducted in November 2006: (a) The Northern GBR region with the Hervey Bay Index Blocks (inset); and (b) Torres Strait. Block N15 was surveyed using zigzag transects across the depth gradient.

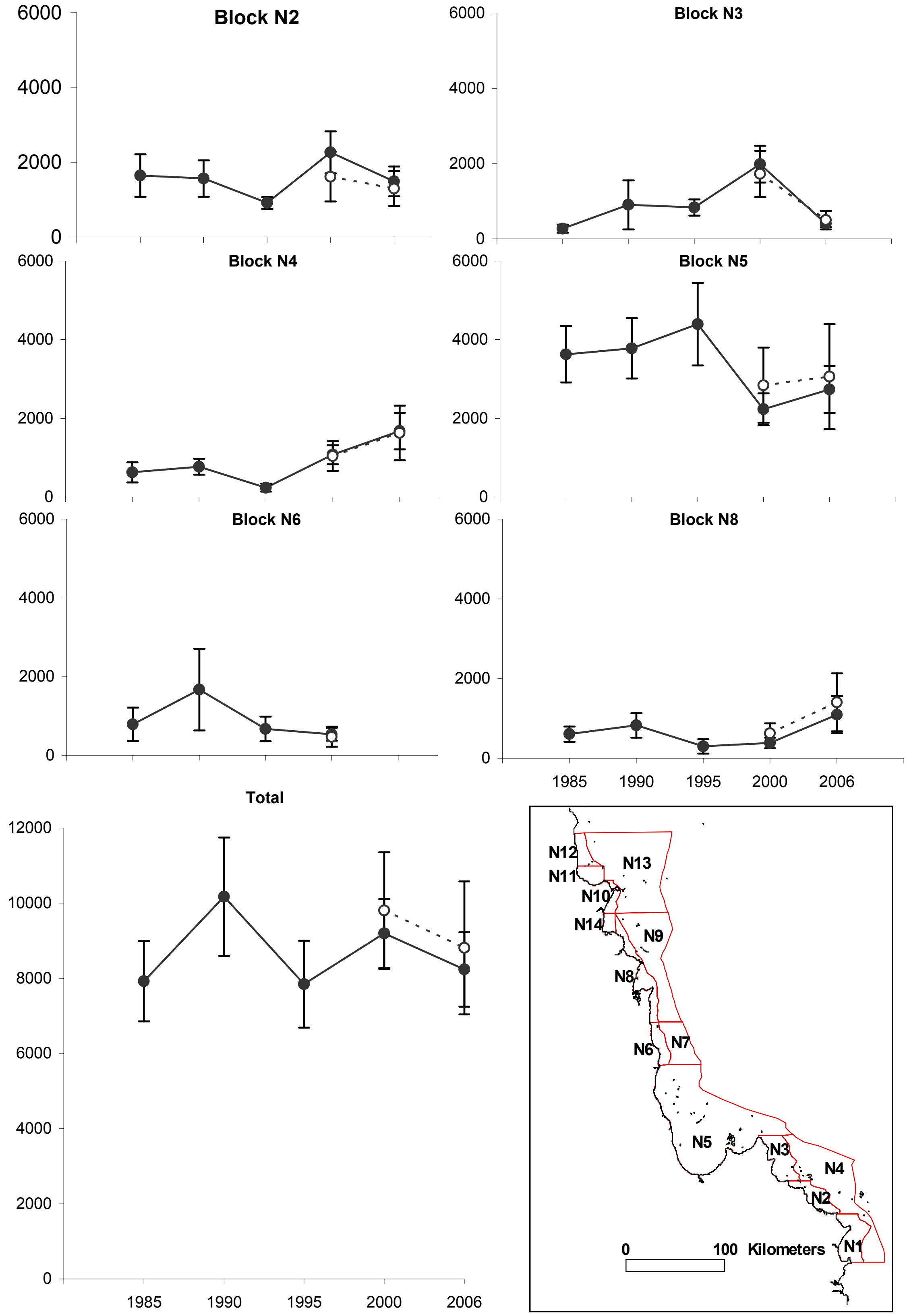


Figure 2: Temporal changes in the estimated number of dugongs (± standard error) in the whole Northern GBR Region between Cooktown and Hunter Point and each of the survey blocks (Blocks 2, 3, 4, 5, 6, 8) that supported an estimated 500 dugongs or more on at least one of the aerial surveys. The estimate were obtained using the technique of Marsh & Sinclair (1989) (unbroken line all surveys) and Pollock *et al.* (2006) (dotted line 2000 and 2006 only).

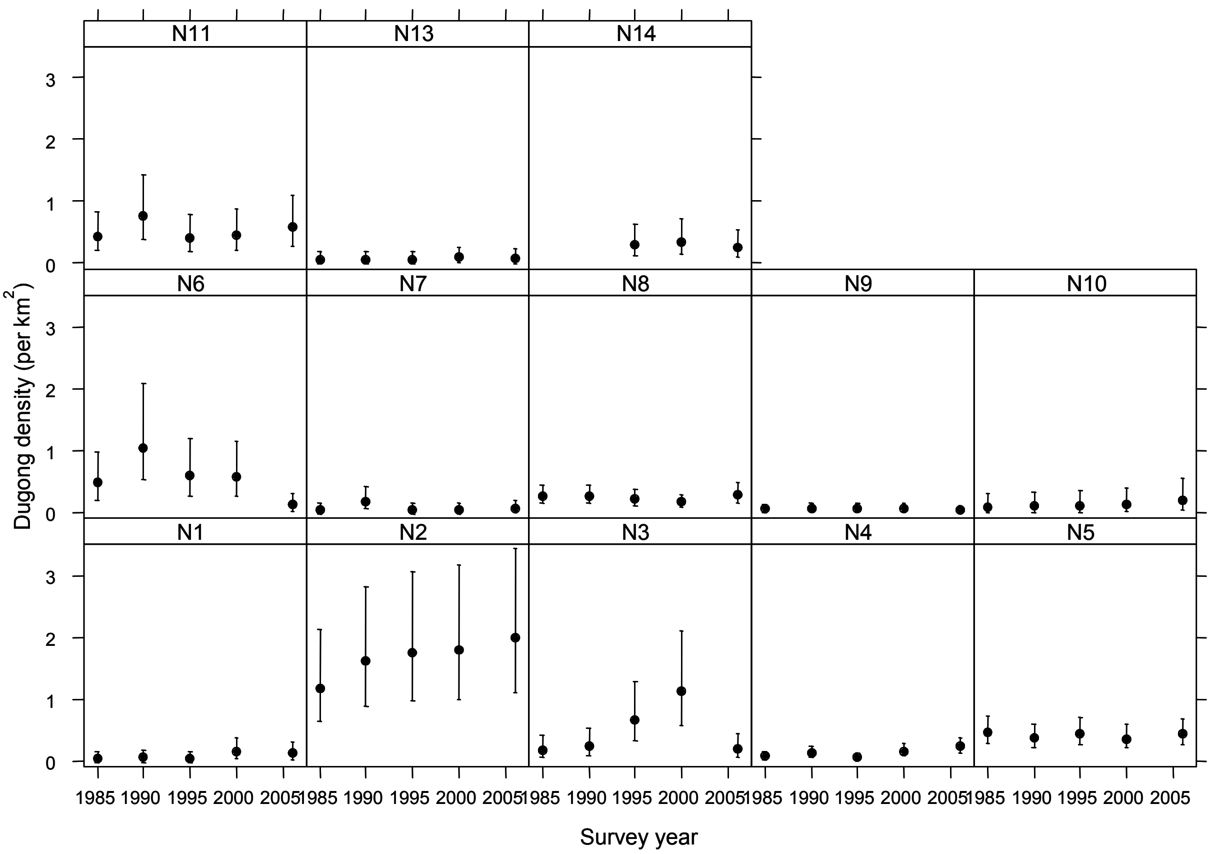


Figure 3: Estimated dugong density (per km^2) in the Northern GBR calculated using the Marsh & Sinclair (1989) method across years in each survey block. Error bars represent 95% credible intervals. See Figure 2 for block locations.

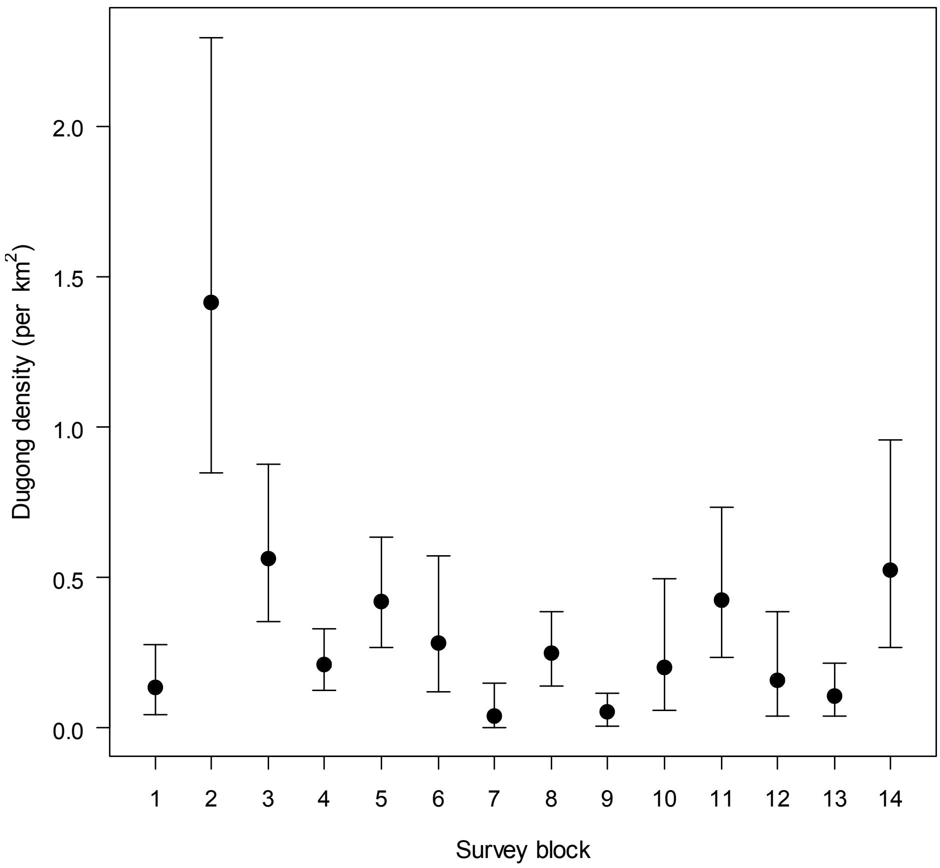


Figure 4: Estimated dugong density (per km^2) in the Northern GBR (Pollock *et al.* 2006 estimates) in each survey block. Error bars represent 95% credible intervals. See Figure 2 for block locations.

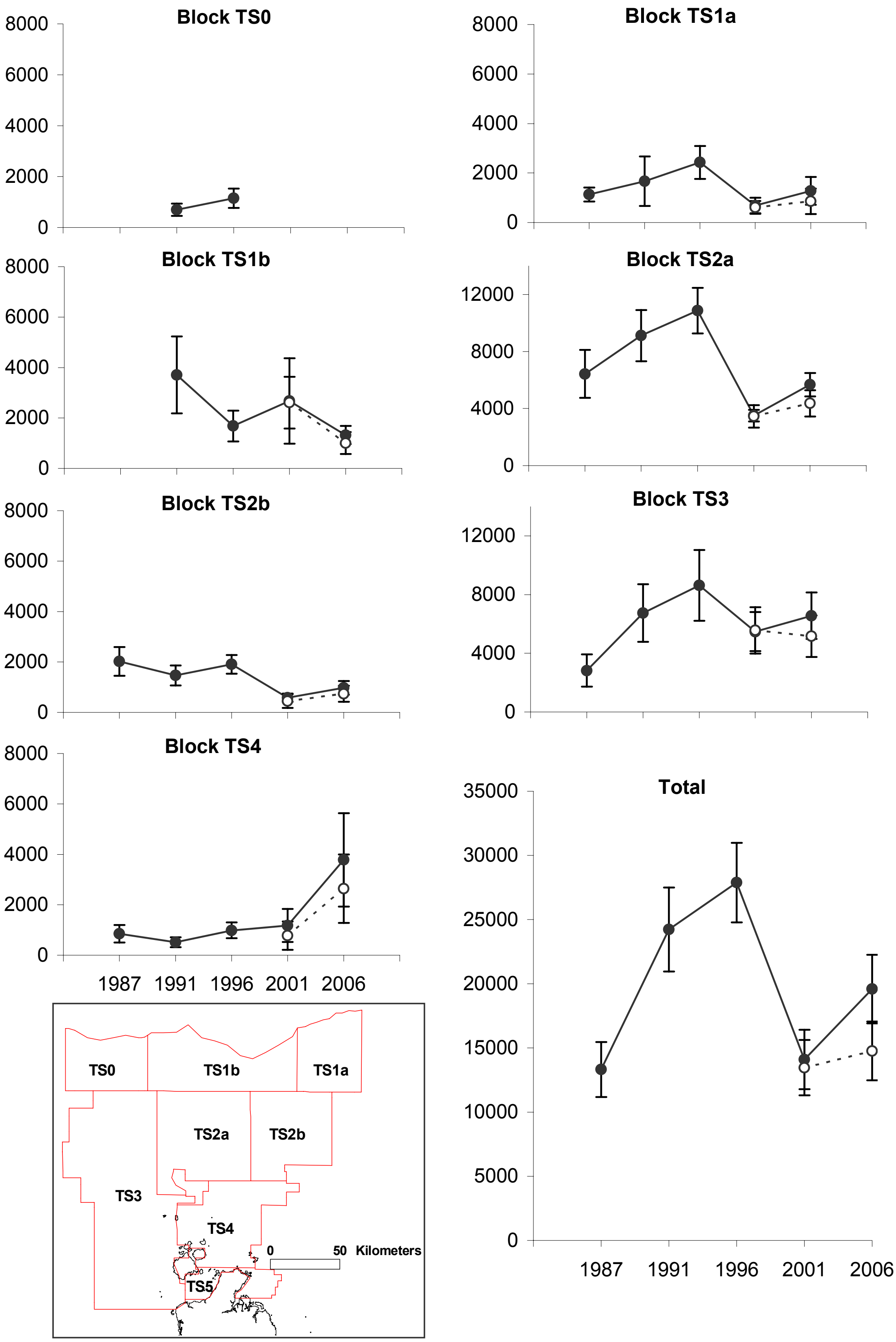


Figure 5: Temporal changes in the estimated number of dugongs (± standard error) in each of the Torres Strait survey blocks (Blocks 0, 1A, 1B, 2A, 2B, 3,4) that supported an estimated 500 dugongs or more on at least one of the aerial surveys. The estimates were obtained using the technique of Marsh & Sinclair (1989) (unbroken line all surveys) and Pollock *et al.* (2006) (dotted line 2001 and 2006 only).

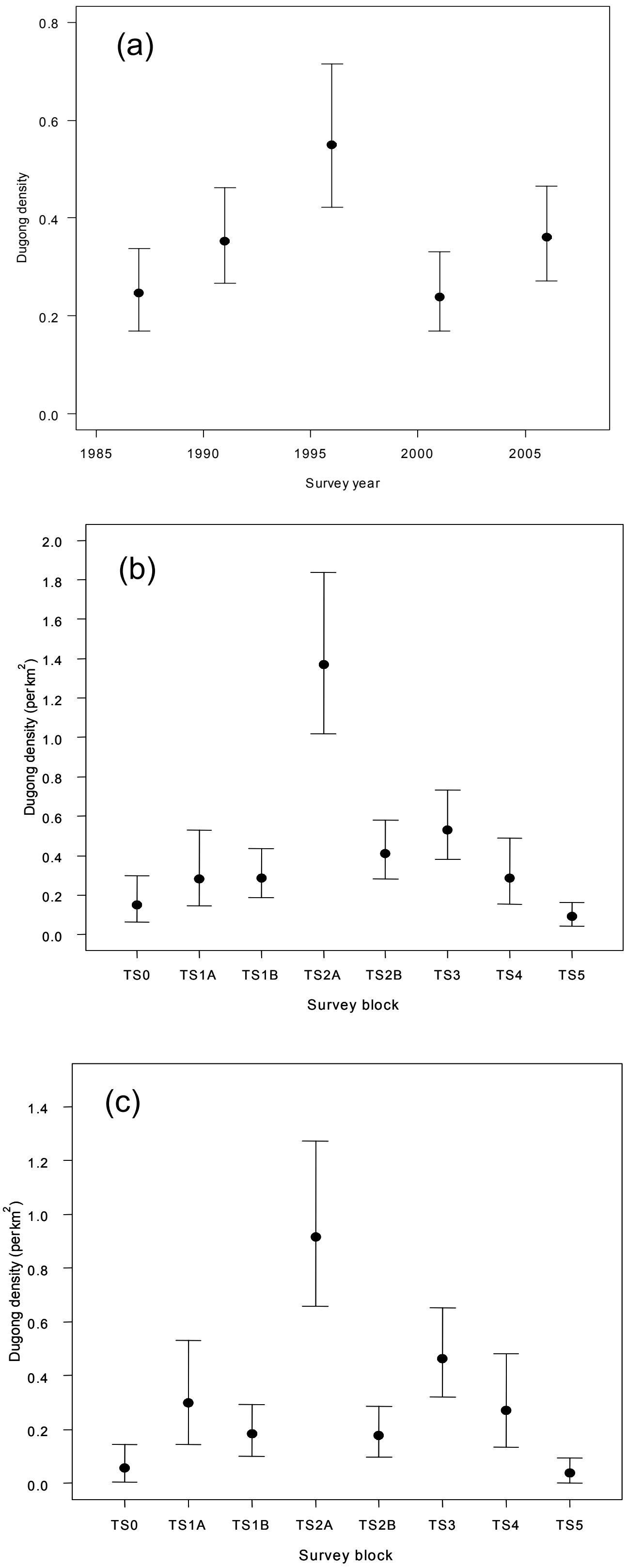


Figure 6: Estimated dugong density (per km^2) in the Torres Strait: (a) in each survey year based on the Marsh & Sinclair(1989) method; in each survey block across years (b) based on the Marsh & Sinclair(1989) method for 1987, 19991, 1996, 2001 and 2006 and (c) based on the Pollock et al (2006) method for 2001 and 2006 only . Error bars represent 95% credible intervals. See Figure 5 for block locations.

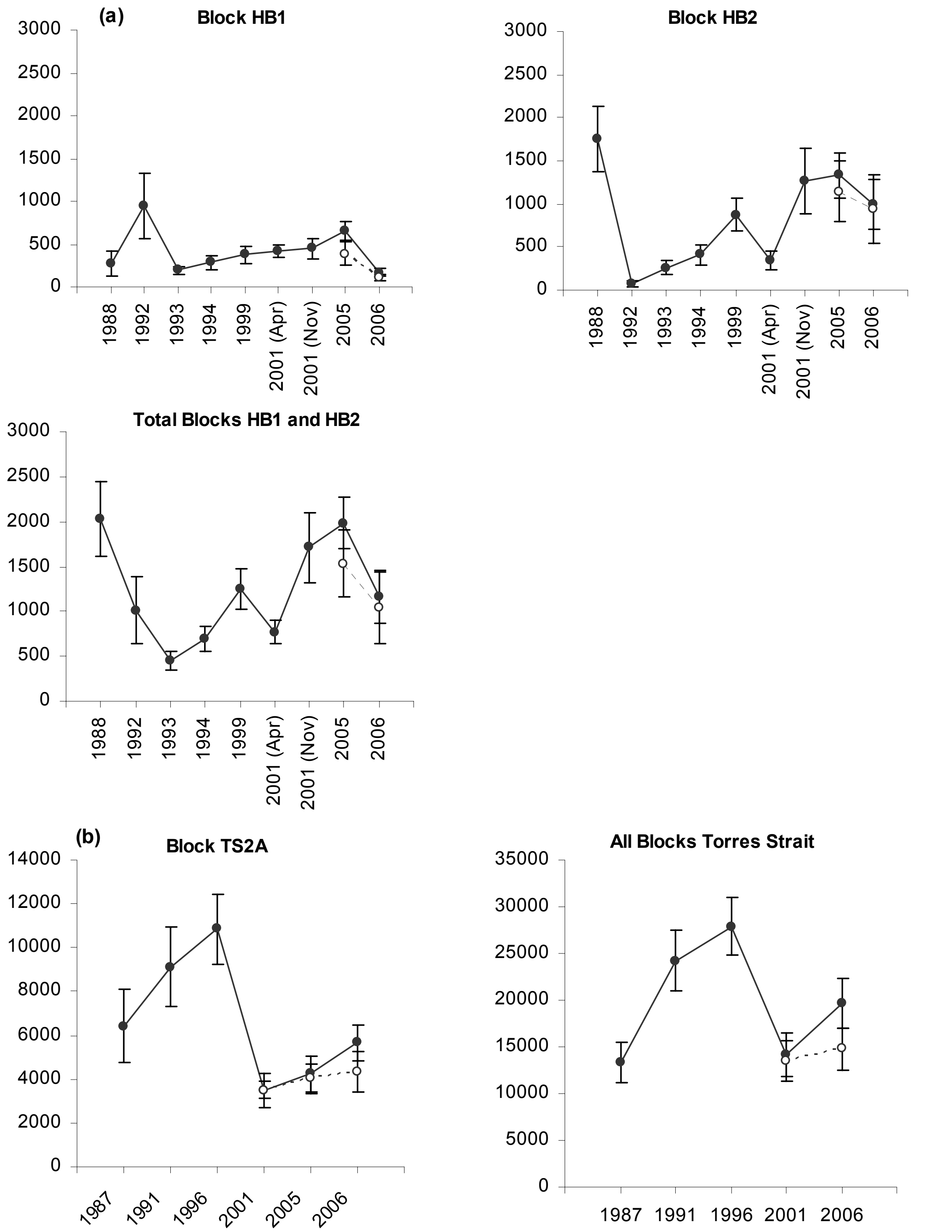


Figure 7: The estimates of dugong numbers for: (a) the combined Hervey Bay Index Blocks and the total Hervey Bay survey for various surveys conducted between 1988-1925 inclusive and (b) the Torre Strait Index Block 2A and the total survey for various surveys conducted between 1978-2006 inclusive. The estimates were obtained using the technique of Marsh & Sinclair (1989) (unbroken line all surveys) and Pollock *et al.* (2006) (dotted line 2001 and 2006 only. Note: Hervey Bay Block 1 was slightly smaller in 20O6 than in previous years because the survey was terminated at transect 1067 in Great Sandy Strait for logistical reasons. See Figure 1a for block locations.

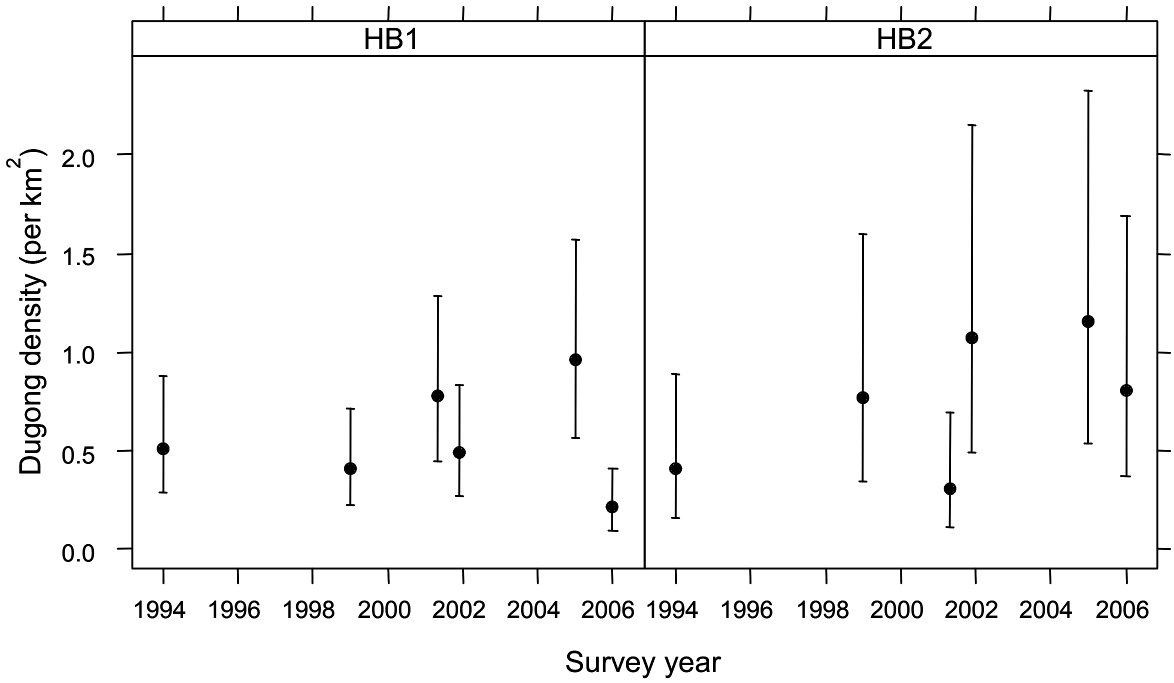


Figure 8: Estimated dugong density (per km^2) based on the Marsh & Sinclair method in Hervey Bay across years in survey Blocks 1 and 2. Error bars represent 95% credible intervals. See Figure 1a for block locations.

Table 1: Details of the aerial surveys of the Northern GBR, Torres Strait and the Hervey Bay Index Blocks conducted prior to 2006.

Date of Survey	Reference
Northern Great Barrier Reef	
November 1985	Marsh & Saalfeld 1989
November 1990	Marsh & Corkeron 1996
November 1995	Marsh &Corkeron 1996
November 2000	Marsh &Lawler 2002
Torres Strait	
November1987	Marsh *et al.* 1997
November 1991	Marsh *et al.* 1997
November 1996	Marsh *et al.* 1997
November 2001	Marsh *et al.* 2004
November 2005 (Index Bock 2 A only)	Marsh et al. 2007
Hervey Bay Index Blocks 1 and 2	
August 1988	Marsh & Saalfeld 1990
November1992	Marsh & Saalfeld 1990
November 1993	Marsh *et al.* 1994
November 1994	Marsh *et al.* 1994
November 1999	Marsh & Lawler 2001
April 2001	Lawler (unpublished)
November 2001	Lawler (unpublished)
November 2005	Marsh *et al.* 2007

Table 2: Results of linear mixed effect analyses examining dugong density among surveys.

Source of variation	Num. DF	Denom. DF	F	MCMC P-value	Variance component
Northern GBR 1985, 1990, 1995, 2000 and 2006 (Marsh & Sinclair method)					
Block	11	159	20.11	<0.0001	
Among transects within block					0.208
Year	4	636	1.49	0.248	
Block x Year	44	636	1.63	0.006	
Residual (among transect within block variation among years)					0.712
Northern GBR (Pollock *et al.* method) 2000 and 2006					
Block	13	196	7.96	<0.0001	
Among transects within block					0.320
Year	1	196	1.67	0.959	
Block x Year	13	196	1.71	0.066	
Residual (among transect within block variation among years)					0.836
Torres Strait 1987, 1991, 1996, 2001 and 2006 (Marsh & Sinclair method)					
Block	7	78	16.31	<0.0001	
Among transect within block					0.144
Year	4	312	6.75	0.025	
Block x Year	28	312	1.23	0.212	
Residual (among transect within block variation among years)					0.788
Torres Strait (Pollocket *al.* method) 2001 and 2006					
Block	7	82	14.33	<0.0001	
Among transect within block					0.089
Year	1	81	1.23	0.529	
Block x Year	7	81	0.72	0.719	
Residual (among transect within block variation among years)					0.566
Hervey Bay Block 1 and 2 1994, 1999, April 2001, November 2001, 2005 and 2006 (Marsh & Sinclair method)					
Block	1	35	0.988	0.654	
Among transects within block					0.311
Year	5	175	3.30	0.001	
Block x Year	5	175	3.26	0.008	
Residual (among transect within block variation among years)					1.057

Table 3: Comparison of the population estimates (standard errors) for dugongs for various regions of the survey conducted in November 2006 obtained using the methods of Marsh & Sinclair (1989) and Pollock *et al.* (2006).

	Population estimate (SE) Marsh & Sinclair (1989) method	**Population estimate (SE) Pollock *et al.* (2006) method**	**Pollock estimate as percentage of Marsh & Sinclair estimate**
Northern GBR Blocks 1-14			
2000	9193 (917)	9730 (1485)	105.8
2006	8239 (992)	8812 (1769)	107.0
Torres Strait			
2001	14106 (2314)	13465 (2152)	95.5
2006	19587 (2669)	14767 (2292)	75.4
Torres Strait Index Block 2A			
2001	3504 (403)	3454 (782)	98.6
2005	4251 (819)	4042 (671)	95.1
2006	5675 (819)	4362 (919)	76.9
Hervey Bay Index Blocks 1 and 2 combined			
2005	1980 (283)	1532 (376)	77.3
2006*	1169 (294)	1044 (399)	89.3

*Hervey Bay block 1 was slightly smaller in 2006 than in previous years because survey was terminated at transect 1067 for logistical reasons.

Table 4: Power of two time series of hypothetical aerial surveys (five years apart over 20 years from first survey; eight surveys three years apart over 21 years from first survey) to detect declines in dugong abundance (annual declines of 0.05, 0.03 and 0.01). The coefficients of variation were based on the dugong data from the 2006 surveys based on the Pollock *et al.* (2006) method for the Northern GBR only (0.2); Torres Strait (0.16) and the entire survey region (0.127).

Initial coefficient of variation	Number of surveys	Interval between surveys (years)	Annual rate of decline of population	Population decline per survey interval	Power of surveys to detect declining trend	Percentage initial population remaining after survey period ended
0.127[1]	8	3	0.05	0.1426	1	34.0
0.127[1]	5	5	0.05	0.2262	0.99	35.8
0.16[2]	8	3	0.05	0.1426	0.99	34.0
0.16[2]	5	5	0.05	0.2262	0.986	35.8
0.2[3]	8	3	0.05	0.1426	0.983	34.0
0.2[3]	5	5	0.05	0.2262	0.927	35.8
0.127[1]	8	3	0.03	0.0873	0.989	52.7
0.127[1]	5	5	0.03	0.1413	0.944	54.4
0.16[2]	8	3	0.03	0.0873	0.932	52.7
0.16[2]	5	5	0.03	0.1413	0.825	54.4
0.2[3]	8	3	0.03	0.0873	0.81	52.7
0.2[3]	5	5	0.03	0.1413	0.664	54.4
0.127[1]	8	3	0.01	0.0297	0.428	81.0
0.127[1]	5	5	0.01	0.0490	0.326	81.7
0.16[2]	8	3	0.01	0.0297	0.316	81.0
0.16[2]	5	5	0.01	0.0490	0.243	81.7
0.2[3]	8	3	0.01	0.0297	0.233	81.0
0.2[3]	5	5	0.01	0.0490	0.189	81.7

[1] Based on entire survey region; [2] Based on Torres Strait only; [3] Based on Northern GBR only.

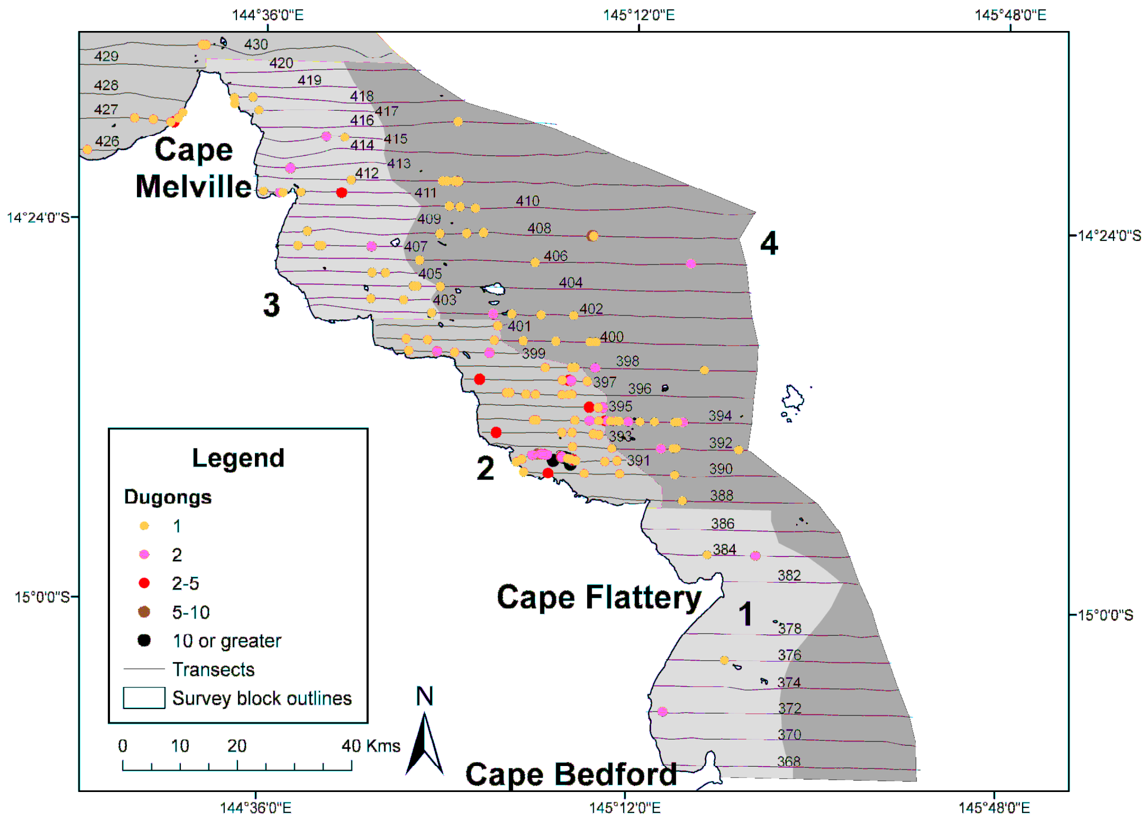
Table 5: Estimates of the total sustainable anthropogenic mortality (Potential Biological Removal sensu Wade, 1998) for the Northern Great Barrier Reef region and Torres Strait for a range of estimates of R_{max} and assuming value for the Recovery Factor of 0.1 and 0.5. The values for the PBR are based on the population estimate derived using Pollock *et al.* (2006) because this method should provide more accurate population estimates than the Marsh & Sinclair (1989) method.

Recovery Factor	Population estimate (SE)	SE	C.V	N min	Potential Biological Removal [2]		
					R_{max}=0.01	R_{max}=0.03	R_{max}=0.05
Northern GBR							
0.5	8812	1769	0.2008	7454	19	56	93
1.0					37	112	186
Torres Strait							
0.5	14767	2292	0.1552	12968	32	97	162
1.0					65	195	324

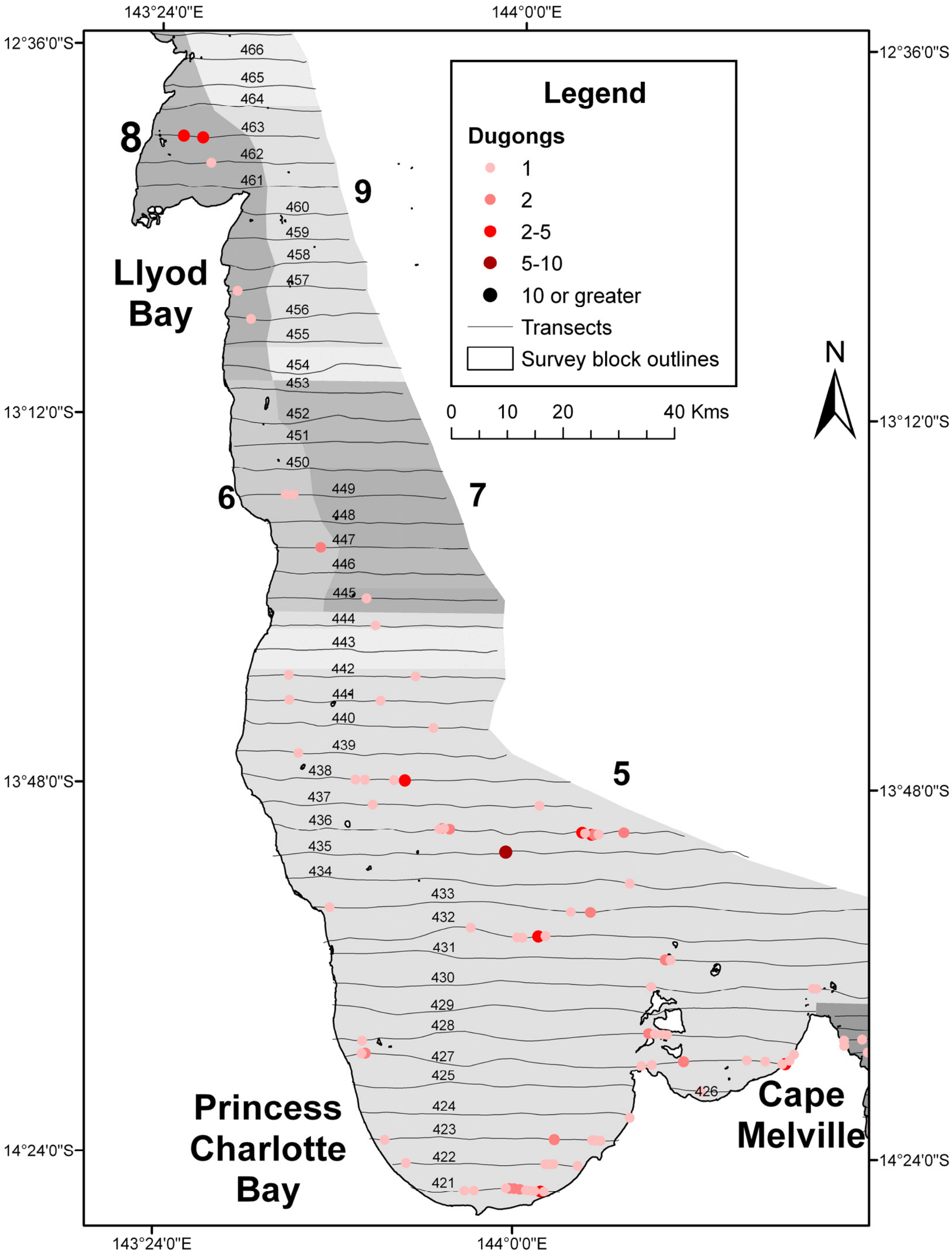
Appendix

Appendix figures showing the GPS tracks of transects flown in during the aerial survey in November 2006 showing the positions and sizes of the dugong groups sighted and the transect numbers.

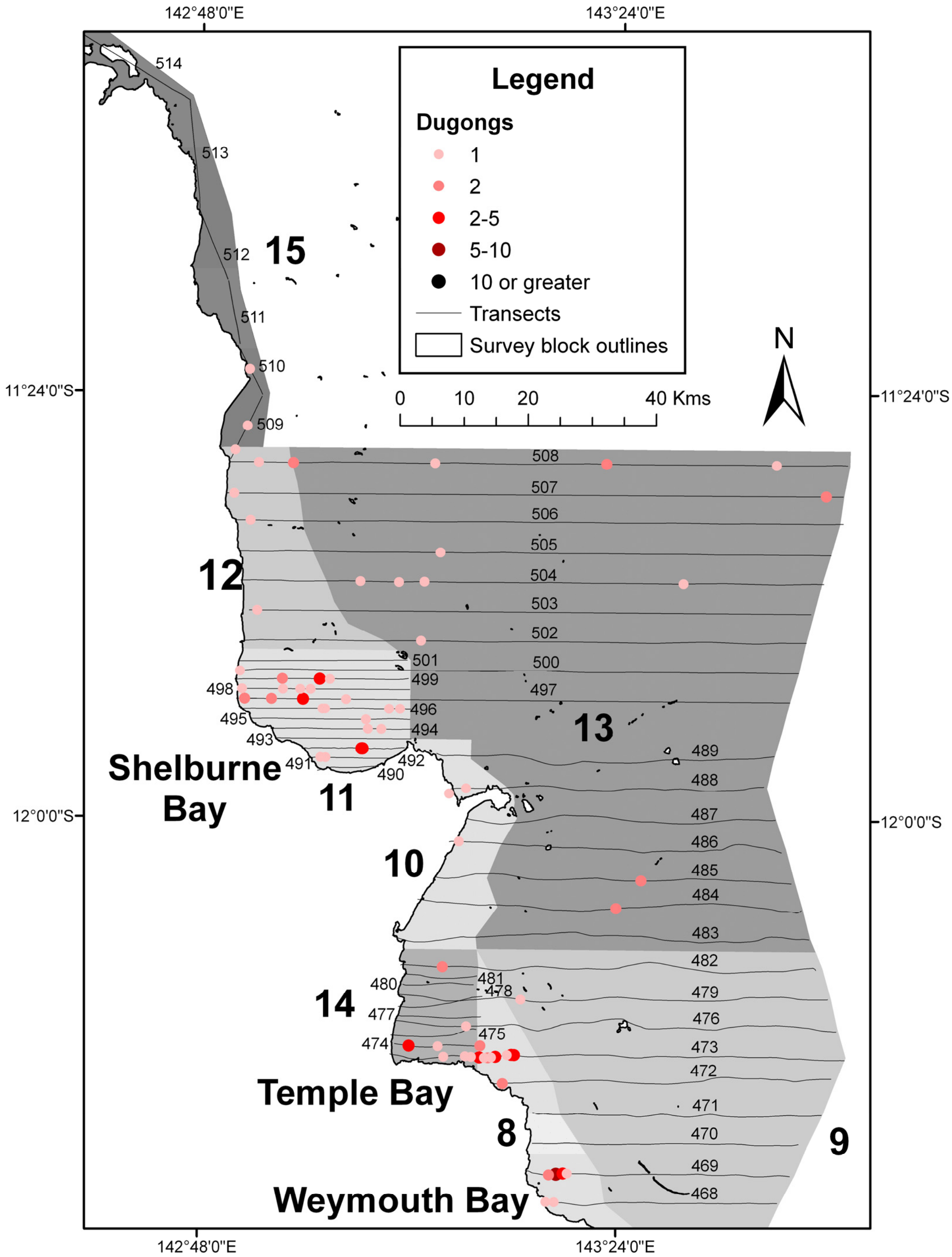
Appendix Figure 1: GPS tracks of transects flown in Blocks 1-4 in the Northern GBR during the aerial survey in November 2006 showing the positions and sizes of the dugong groups sighted and the transect numbers.



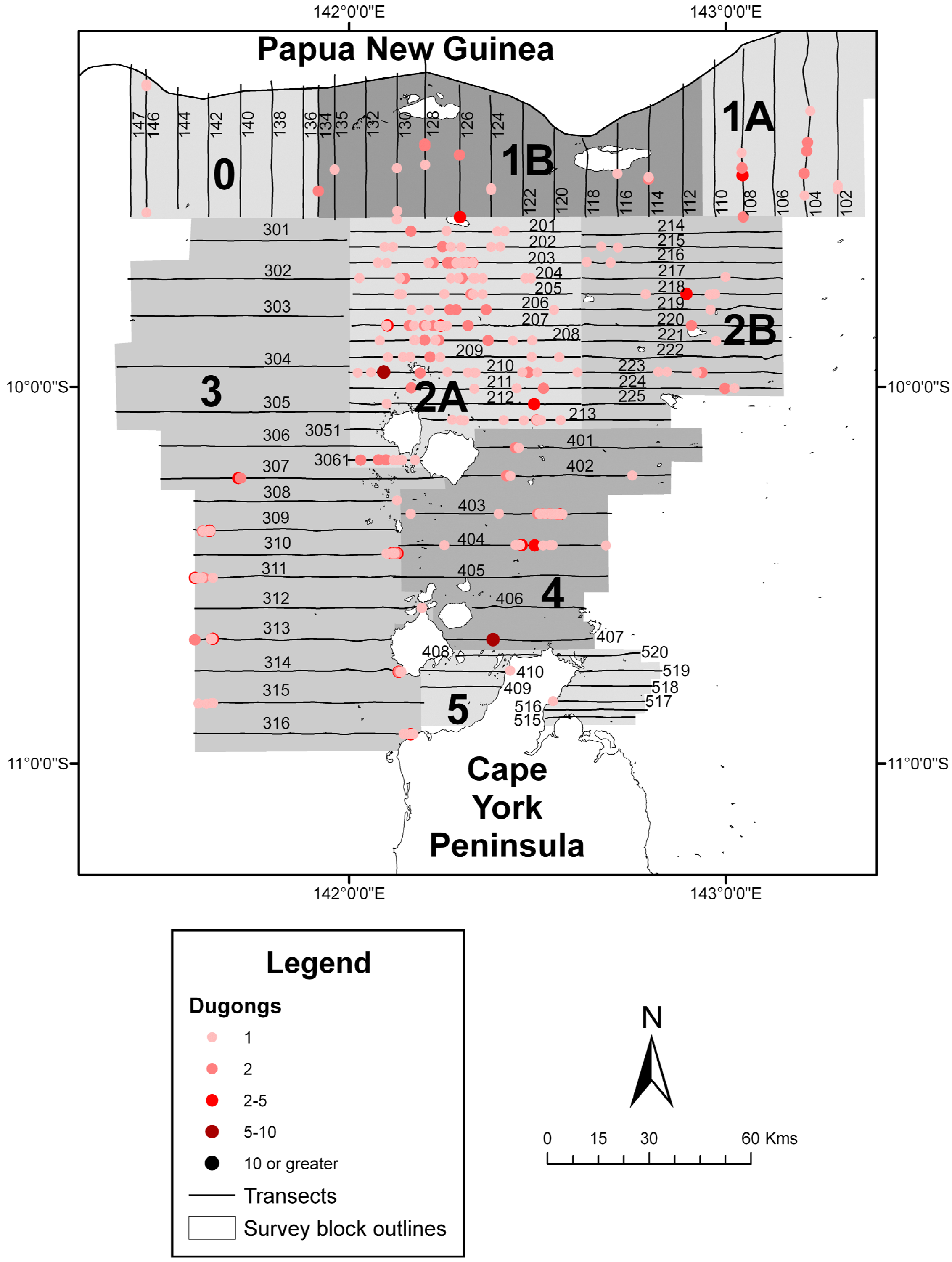
Appendix Figure 2: GPS tracks of transects flown during the aerial survey in November 2006 of Blocks 5-9 in the Northern GBR showing the positions and sizes of the dugong groups sighted and the transect numbers.



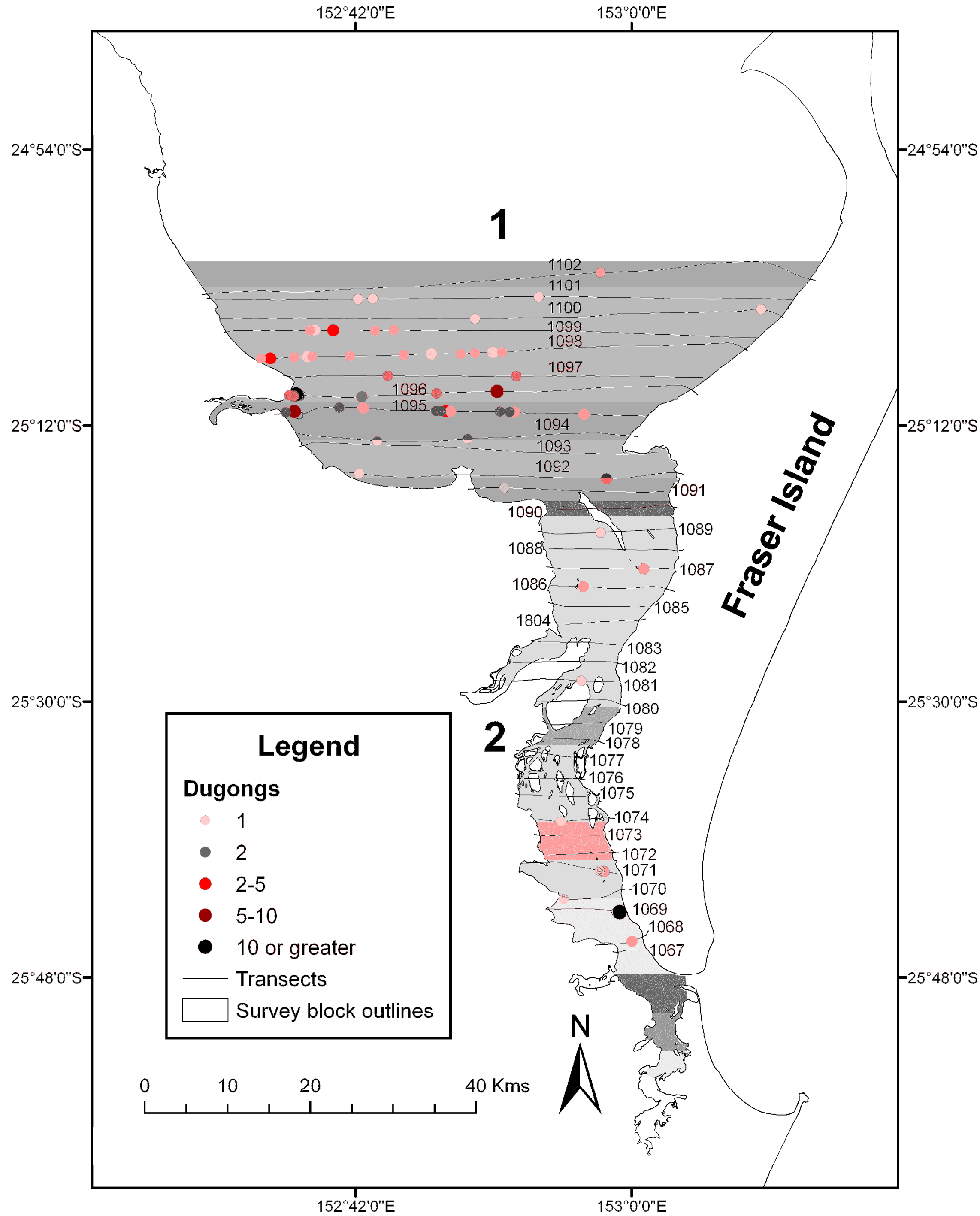
Appendix Figure 3: GPS tracks of transects flown in Blocks 10-15 in the Northern GBR during the aerial survey in November 2006 showing the positions and sizes of the dugong groups sighted and the transect numbers. Hunter Point is at the landward boundary of Blocks12 and Block 15.



Appendix Figure 4: GPS tracks of transects flown in Blocks 0-5 in Torres Strait during the aerial survey in November 2006 showing the positions and sizes of the dugong groups sighted and the transect numbers.



Appendix Figure 5: GPS tracks of transects flown in Hervey Bay Index Blocks 1 and 2 during the aerial survey in November 2006 showing the positions and sizes of the dugong groups sighted and the transect numbers. Hervey Bay Block 1 was slightly smaller in 20O6 than in previous years because survey was terminated after transect 1067 for logistical reasons.



Appendix Tables

Appendix Table 1: Areas of survey blocks and sampling intensities for the aerial survey conducted in 2006. For locations of blocks see Appendix Figures 1-5.

Block	Area (km^2)	Sampling Intensity (%)
Northern GBR		
1	1041	9.0
2	674	16.7
3	1049	17.2
4	3598	8.9
5	7281	8.8
6	464	8.7
7	1064	8.8
8	982	8.5
9	2905	8.6
10	278	9.0
11	430	25.3
12	415	9.1
13	4838	8.4
14	225	22.5
15	260	12.3
Torres Strait		
0	2339	5.6
1A	2452	4.5
1B	3848	4.6
2A	4420	8.4
2B	3363	8.6
3	9666	4.3
4	3436	4.7
5	1022	10.9
Hervey Bay Index Blocks		
1	481	19.1
2	1307	17.5

Appendix Table 2a: Weather conditions encountered during the 2006 survey of the Northern GBR in comparison with the following previous surveys of the same areas. Historical data from Marsh and Lawler (2002).

	1985	1990	1995	2000	2006
Wind speed (km.h^{-1})	<28	<15	<15	<18	<15
Cloud cover (oktas)*	0-5	0-7	2-7	2-8	0-8
Minimum cloud height*	305-1525	1500-35000	305-1220	300-10000	1500-2000
Beaufort sea state$^{\#}$ (range)	1.5 (0-4)	1.5 (0-2.5)	3 (1-4)	1.65	1.9 (0-4)
Glare$^{\bullet\#}$ **North** **South** **Overall$^{\sim}$**	 1 (0-2.5)	 2.2 (1-3)	 1.5 (0-3)	 1.44 (0-3) 1.69 (0-3) 1.9 (0-3)	 1.95 (0-4) 1.16 (0-3) 2.21
Visibility (km)*	8->50	N/A	10-30	>10	10-20

* Range; $^{\#}$ Means of modes for each transect; $^{\bullet}$ 0-none, 1 <25% of field of view affected, 2 <25-50%, 3 >50%; $^{\sim}$ taken from the side of the aircraft with the highest glare.

Appendix Table 2b: Weather conditions encountered during the 2006 surveys of Torres Strait in comparison with the prior surveys of the same areas: historical data from; Marsh et al, 1997, 2004 and 2005.

	1987	1991	1996	2001	2005	2006
Wind speed (km.h^{-1})	<15	<15	<10	<15	<10	<15
Cloud cover (oktas)*	1-8	0-5	0-7	0-7	0-3	1-6
Minimum cloud height*	270-4000	460-750	1000-5000	2000-5000	2500-4000	1000-2000
Beaufort sea state$^{\#}$ (range)	1.3 (0-4)	1.9 (0-4)	1.1 (0-3)	1.4 (0-3)	0.92 (0-2.5)	2.2 (0-3)
Glare$^{\bullet\#}$ **North** **South** **Overall$^{\sim}$**	1.4 (0-3) 0.75 (0-3)	1.7 (0-3) 2.3 (0-3)		0.9 (0-3) 1.3 (0-3)	0.79 (0-2) 1.59(0-3)	1.91 (0-3) 1.32 (0-3) 2.25
Visibility (km)*	N/A	>20	>10	>20	>10	10-20

* Range; $^{\#}$ Means of modes for each transect; $^{\bullet}$ 0-none, 1 <25% of field of view affected, 2 <25-50%, 3 >50%; $^{\sim}$ taken from the side of the aircraft with the highest glare.

Appendix Table 2c: Weather conditions encountered during the 2006 surveys of the Index Bocks of Hervey Bay in comparison with the prior surveys of the same areas: historical data from Marsh *et al.* (2005).

	1988	1993	1994	1999	2005	2006
Wind speed (km.h^{-1})	<28	<20	<10	<10	<10	0
Cloud cover (oktas)*	1-6	1-4	1-3	0	1-7	0-7
Minimum cloud height*	610-2400	460-1800	2000-5000	N/A	2000	
Beaufort sea state$^{\#}$ (range)	2.1 (0-4)	1.2 (0-3)	1.94 (1-3)	1.67 (0-4)	2.2 (1-3)	1.6 (0-3)
Glare$^{\bullet\#}$ **North** **South** **Overall$^{\sim}$**	0.9 (0-3)	1.4	0.92 1.08	1.92 1.86 1.89	1.44 1.27 1.35	0.85 (0-3) 1.40 (0-3) 1.65
Visibility (km)*	N/A	N/A	>20	>30		10

* Range; $^{\#}$ Means of modes for each transect; $^{\bullet}$ 0-none, 1 <25% of field of view affected, 2 <25-50%, 3 >50%; $^{\sim}$ taken from the side of the aircraft with the highest glare.

Appendix Table 3: Beaufort sea state and glare for each transect of the 2006 aerial survey for dugongs. See Appendix Figures 1-5 for transect locations.

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**
Northern Great Barrier Reef									
N1									
368	2	3	3	2	2	2	3	3	3
370	2	3	3	2	2		3	3	
372	3	4	3	0	3		0	3	
374	2	3	3						
376	3	4	3	2	3		2	2	2
378	2	4	2	2	2		2	2	
380	3	3	3	0	2	2	1	3	
382	2	3	2	2	2		3	3	
384	0	2	0	1	3	3	0	2	0
386	0	1	1	0	3	3	0	3	2
388	0	1	1	0	3	0	0	2	1
N2									
390	0	1	1						
391	2	2	2	3	3	3	2	2	2
392	0	1	0	0	2	2	0	3	0
393	2	2	2	2	3	3	1	3	
394	0	1	1	2	2		2	2	
395	2	2	2	3	3	3	1	2	
396	1	1	1	1	2		1	2	
397	2	2	2	1	2	2	1	2	2
398	1	2	2	1	2		0	3	
399	2	2	2	2	2	2	3	3	3
400	2	3	3	3	3		3	3	
401	2	4	3	3	3	3	3	3	3
402	2	3	3	3	3		3	3	
N3									
403	3	4	4	3	3		3	3	
404	3	3	3						
405	3	4	3	3	3	3	3	3	3
406	2	3	2	3	3		3	3	
407	1	4	3	3	3	3	3	3	3
408	2	3	3	3	3		3	3	
409	3	3	3	3	3	3	3	3	3
410	2	3	2						
411	2	3	3	3	3	3	3	3	3
412	2	4	3	3	3		3	3	

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
413	1	2	1	2	3		1	1	1
414	1	3	3	1	1		0	0	
415	1	3	1	1	1		0	0	
416	1	2	1						
417	1	2	1	2	3	3	0	1	0
418	1	3	3	1	1		0	0	
419	1	3	3	1	1		0	0	
420	3	3	3	2	3		0	1	
N4									
368	3	3	3	2	2		3	3	
370	2	3	2	2	3	3	0	3	3
372	2	4	3	0	2	2	0	3	
374	2	2	2	2	2	2	3	3	3
376	3	3							
378	2	3		2	2		3	3	
380	3	3	3						
382	3	3		0	2		2	3	
384	1	1	1	0	0		1	1	
386	1	1	1	0	2	0	0	2	1
388	0	0	0	3	3		2	2	
390	0	1	1	1	3		0	3	
392	0	1	1	3	3		2	2	
394	0	1	0	0	1	1	1	2	1
396	0	1	0	2	2		2	2	
398	2	2	2	2	3		3	3	3
400	1	2	2	0	3	3	0	3	2
402	2	3	2	2	3	2	3	3	3
404	1	3	2	2	3	3	0	2	1
406	1	3	2	2	3	3	2	3	3
408	1	3	2	3	3	3	3	3	3
410	1	2	2	0	3	3	0	3	2
412	2	4	2	0	3		0	3	
414	1	3	3						
416	1	3	3	1	3		1	1	1
418	1	3	1						
420	1	1	1	1	1		1	1	
N5									
421	1	2	1	1	1		0	0	
422	1	3	1	0	2		0	1	
423	1	3	2	1	1		0	0	
424	2	3	2	1	1		0	0	

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
425	1	3	2	1	1		0	0	
426	1	1	1	0	1		0	0	0
427	1	3	3	0	2		1	2	
428	1	3	3	2	2		0	0	
429	1	3	3	1	3	3	1	2	2
430	1	3	3	2	2	2	0	1	
431	1	3	2	2	2	2	0	1	1
432	1	3	3	2	3	2	0	0	0
433	1	3	3	1	3	2	0	1	0
434	1	3	1	0	3	2	0	0	0
435	1	3	3	1	3		0	2	0
436	1	3	3	2	3	2	0	1	1
437	1	3	3	3	3		2	2	
438	1	3	3	2	3		0	1	
439	1	3	2	1	4	1	0	2	2
440	1	3	3	2	2		0	0	
441	1	3	2	3	3		1	1	
442	2	3	3	2	2		0	0	
443	1	3	3	3	3		1	1	
444	1	3	3	2	3	2	0	0	0
N6									
445	2	2							
446	1	3	2	2	2		0	0	
447	2	2		1	1		2	2	
448	2	3		2	2		0	0	
449	3	3							
450	2	3	2	0	0	0	0	0	0
N7									
445	2	3	3	1	3		0	1	1
446	3	3	3	3	3		0	0	
447	1	3	2	2	2		1	1	
448	3	3	3	1	1		0	0	
449	2	3	2	0	2		0	1	1
450	2	3	3	2	2		0	0	
N8									
452	3	3		2	2		1	1	
453	3	3							
454	3	3		1	1		0	0	
455	3	3							
456	2	2	2	1	1		1	1	
457	3	3							

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
458	3	3	3	1	1		0	0	
459	2	2							
460	1	1		2	2		1	1	
461	1	2	1	1	1	1	1	1	1
462	2	2	2	2	2		1	1	
463	1	2		2	2		2	2	
464	2	2							
465	1	1		2	2		0	0	
466	1	1							
467	1	1		0	0		0	0	
468	2	2							
469	2	2	2	1	1		0	0	
470	2	2							
471	1	1		1	1		0	0	
472	3	3							
473	3	3							
N9									
451	3	3	3	2	2		1	1	
452	3	3	3						
453	3	3	3	2	2		2	2	
454	3	3							
455	3	3	3	2	2		2	2	
456	3	3	3						
457	3	3	3	0	0		0	0	
458	3	3		0	1		0	0	0
459	2	2		2	2		1	1	
460	2	2							
461	2	2		3	3		1	1	
462	2	2	2						
463	2	2		3	3		2	2	
464	2	2		3	3		2	2	
465	2	2	2						
466	1	2		2	2		1	1	
467	1	2							
468	1	2	1	3	3		0	0	
469	1	2	2						
470	1	2	2	2	2		1	1	
471	1	2	1						
472	2	2	2	1	1		1	1	
473	2	2	2						
476	2	3	2	2	2		1	1	

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
479	2	2	2	1	1		2	2	
482	2	2	2	1	1		1	1	
N10									
483	1	1	1	0	1		0	0	0
484	1	1	1						
485	1	1		1	3		0	0	0
487	1	1		1	1		0	0	
489	1	1		1	1		1	1	
N11									
490				0	2		0	1	1
491	1	1	1	0	2	2	0	2	0
492	1	1	1	0	2	2	0	2	1
493	0	1	1	0	2	0	0	1	0
494	1	1	1	1	2	2	1	1	1
495	0	1	0	0	2	1	0	1	0
496	0	0	0	0	1	0	0	1	1
497	0	0		0	0		1	1	
498	0	0	0	0	1	1	0	3	0
499	0	1	0	0	0	0	0	1	0
500	0	1	0	0	2	2	0	0	0
501	0	1	0	1	1	1	0	0	0
N12									
502	1	2	2	0	3	2	0	2	0
503	2	3		1	2	1	2	2	2
504	2	2	2	2	3	2	0	2	
505	2	2	2	2	3		0	0	0
506	1	1		2	2		1	1	
N13									
483	0	1	1	1	1		0	0	
484	0	1	1	0	2		0	1	
485	1	1	1						
486	1	1	1	1	2		1	1	1
487	1	1	1	2	2		1	1	
488	1	2	1	3	3		1	1	
489	1	1	1	1	1		1	1	
497	0	1	0	0	0	0	0	1	1
500	0	1	1	2	2	2	0	0	0
502	1	3	2	0	2	2	0	1	0
503	1	1	1	1	3.5	2	0	2	1
504	1	2	1	1	2	2	0	3	1
505	2	3	2	2	2	2	0	3	2

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**
506	1	3	2	1	3	2	1	1	1
N14									
473	2	2	2	1	1		0	0	
474	2	3	2	0	1		0	0	0
475	2	2		0	0		1	1	
476	3	3							
477	2	2		0	0		0	0	
478	2	2		0	0		1	1	
479	2	2	2	1	2		0	1	
480	2	2		0	0		0	0	
481	2	2		0	0		1	1	
482	2	2							
Torres Strait									
TS0									
135	1	3	2	0	2	0	0	3	3
136	2	2	2	0	0	0	2	3	3
138	1	3	2	0	1	0	1	3	3
140	2	3	2	0	0	0	2	3	2
142	2	3	2	0	0	0	2	3	3
144	2	2	2	0	0	0	0	3	3
146	1	3	3	0	0	0	2	3	3
147	1	3	3	0	0	0	2	3	2
TS1A									
102	1	3	2	3	4	4	2	3	2
104	1	3	2	3	3	3	1	2	
106	1	3	2	3	3	3	1	1	1
108	1	3	3	3	3	3	1	1	1
110	3	3	3	3	3	3	1	1	1
TS1B									
112	2	2	2	3	3	3	2	3	2
114	2	3	3	0	3		2	3	3
116	2	3	2	3	3	3	3	3	3
118	2	3	2	3	3	3	3	3	3
120	2	4	2	0	3	3	0	1	
122	2	3	3	3	3	3	1	1	1
124	2	4	3	3	3	3	0	1	0
126	1	4	2	0	3	3	1	1	1
128	2	4	2	0	3	3	1	2	1
130	1	3	2	0	3	3	0	1	1
132	1	4	3	0	3	0	0	1	0
134	1	2	2	1	3	3	1	2	2

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
TS2A									
201	0	1	0	0	2	0	0	0	0
202	0	0	0	0	0	0	0	1	0
203	0	1	1	0	1	1	0	0	0
204	0	1	1	0	1	0	0	1	0
205	0	1	1	0	1	0	0	1	0
206	1	1		0	2	0	0	2	0
207	2	3	2	0	2	2	1	3	2
208	1	2	2	0	3	3	0	2	1
209	1	3	2	0	2	2	1	3	2
210	1	3	2	0	3	2	0	2	2
211	2	4	2	3	3	3	2	3	2
212	1	3	3	2	3	3	1	1	1
213	2	2	2	2	2	2	2	2	2
3051	2	2	2	3	3	3	1	3	
3061	1	3		0	2	2	1	1	1
TS2B									
213	2	2	2	2	2	2	0	3	
214	2	3	2	1	1	1	0	1	0
215	1	3	3	1	3	2	0	1	0
216	2	3	3	0	3	3	0	1	0
217	1	4	3	1	3	3	0	1	1
218	1	3	3	0	2	2	0	3	3
219	1	4	3	0	2	0	0	3	3
220	2	3	2	1	2	2	0	2	1
221	1	3	2	2	2	2	1	1	1
222	1	3	2	2	3	2	1	1	1
223	0	3	3	1	3	1	0	1	1
224	2	3	2	2	3		1	1	1
225	1	3	3	0	3	3	1	2	1
TS3									
301	2	3	3	0	1	0	1	3	1
302	2	3	2	2	2	2	0	1	1
303	2	3	2	0	3	2	1	3	1
304	2	3	3	2	3	2	0	1	1
305	2	3	3	0	2	0	0	3	2
306	2	3	3	0	3	2	0	2	1
307	2	3	2	0	2	2	0	3	1
308	2	3	3	0	3	1	0	2	0
309	2	3	3	2	3	2	2	2	2
310	0	4	3	1	2	1	0	1	0

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**
311	2	4	3	1	1	1	2	2	2
312	1	4	3	0	1		0	1	
313	2	3	2	2	3	3	1	3	3
314	1	3	3	1	3	2	1	2	2
315	1	3	2	0	3	3	1	3	3
316	1	3	1	1	2	2	0	2	1
TS4									
401	1	2	2	0	3	3	0	2	1
402	2	2	2	1	2		1	2	
403	2	2	2	2	3	2	1	2	2
404	2	2	2	0	3	2	0	3	2
405	2	3	2	0	3	3	0	3	2
406	2	3	3	2	2		2	2	
407	2	3	3	2	3	3	0	3	3
TS5									
408	2	4	2	0	2	0	0	2	0
409	2	3	3	1	2		1	2	
410	2	3	3	0	2	1	0	2	1
411	0	1	0	0	1	1	0	1	1
412	0	1	1	1	1	1	0	1	0
515	1	4	2	1	3	3	1	3	1
516	2	4	3	0	3	3	3	3	3
517	1	3	3	2	3	3	0	3	1
518	2	3	3	3	3	3	3	3	3
519	2	3	2	3	3	3	0	2	
520	0	3	2	0	3	0	0	3	1
TS6									
507	0	2	2	1	2	2	0	2	1
508	0	2	1	0	2	1	0	2	1
509	1	1	1	3	3	3	0	0	0
510	1	1		1	2	1	1	2	2
511	1	2	1	3	3	3	0	0	0
512	1	2	1	0	0	0	3	3	3
513	1	2	1	3	3	3	0	1	0
514	1	2	2	0	1	0	0	3	2
Hervey Bay									
HB1									
1091	2	2		2	3		2	3	
1092	1	3	2	0	2	1	0	3	3
1093	2	2	2	2	2		3	3	
1094	1	2	2	0	1	1	2	3	3

	Beaufort Sea State			Glare[1] South/West			Glare[1] North/East		
Block, Transect	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**
1095	0	1	0	0	1	0	0	0	0
1096	0	2	0	0	3	0	0	1	0
1097	0	1	1	1	2	1	0	1	0
1098	0	1	0	0	2	0	0	2	1
1099	0	2	2	0	2	2	0	2	1
1100	0	3	2	0	2	0	0	1	1
1101	0	3	2	0	3	1	0	2	1
1102	1	3	3	0	3	0	0	1	0
HB2									
1067	1	2		2	2		3	3	
1068	1	2		3	3		1	1	
1069	1	2		0	2		1	3	
1070	1	2		0	2		0	3	
1071	1	2		0	1		0	2	
1072	1	2		1	1		2	2	
1073	1	2		1	1		2	2	
1074	2	2							
1075	1	2	1	2	2		1	1	
1076	1	1		2	2		2	2	
1077	0	0		0	1	0	0	0	0
1078	0	1		2	2		3	3	
1079	0	1		0	0		0	0	
1080	1	1		0	3		0	3	
1081	1	1		0	0		3	3	
1082	1	2	2	2	3		3	3	3
1083	2	2		1	1		2	2	
1084	2	2		2	2		3	3	
1085	2	2	2	1	3		0	2	
1086	2	2		1	3		3	3	3
1087	2	2	2	0	2	2	2	3	2
1088	1	2	2	3	3	3	3	3	3
1089	1	2	2	0	3		2	3	
1090	1	2	2	2	2		3	3	

[1] Glare scale: 0 = no glare; 1 = 0 - 25%; 2 = 25 - 50%; 3 = >50%.

Appendix Table 4: Raw data for sightings of dugong groups for each transect in each block surveyed in 2006 as used to estimate population size. See Appendix Figures 1-5 for transect locations.

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
Northern Great Barrier Reef					
N1	470				
368		22.7	9.1	0	0
370		22.7	9.1	0	0
372		23.1	9.2	1	0
374		22.4	9.0	0	0
376		21.4	8.5	1	0
378		21.6	8.6	0	0
380		20.9	8.4	0	0
382		21.1	8.5	0	0
384		25.7	10.3	1	1
386		23.3	9.3	0	0
N2	453				
388		13.1	5.2	0	0
390		22.2	8.9	2	2
391		21.1	8.4	14	7
392		21.2	8.5	2	0
393		22.2	8.9	3	2
394		22.3	8.9	2	3
395		22.3	8.9	0	4
396		23.4	9.4	1	6
397		22.3	8.9	0	5
398		22.3	8.9	3	0
399		22.2	8.9	0	4
400		22.3	8.9	1	2
401		22.3	8.9	0	1
N3	456				
402		22.8	9.1	1	0
403		22.0	8.8	2	0
404		26.1	10.4	0	2
405		24.1	9.6	1	1
406		22.6	9.0	0	0
407		22.0	8.8	2	2
408		22.3	8.9	1	0
409		22.6	9.1	0	0
410		22.2	8.9	0	0
411		26.9	10.8	5	0
412		23.7	9.5	0	1
413		23.3	9.3	1	1
414		22.4	8.9	0	0
415		21.6	8.6	1	1
416		23.2	9.3	0	0

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
417		24.0	9.6	0	1
418		24.3	9.7	1	2
419		23.0	9.2	0	0
420		25.2	10.1	0	0
N4	459				
368		21.4	8.6	0	0
370		23.3	9.3	0	0
372		22.4	9.0	0	0
374		20.5	8.2	0	0
376		17.3	6.9	0	0
378		12.4	5.0	0	0
380		7.3	2.9	0	0
382		2.8	1.1	0	0
384		7.5	3.0	0	0
386		11.4	4.6	0	0
388		27.0	10.8	1	0
390		23.5	9.4	0	1
392		23.6	9.4	1	3
394		25.7	10.3	8	5
396		25.7	10.3	0	0
398		30.5	12.2	2	0
400		45.0	18.0	2	2
402		54.4	21.7	1	3
404		54.1	21.6	0	1
406		59.3	23.7	3	0
408		57.7	23.1	4	1
410		58.2	23.3	2	1
412		51.9	20.7	4	1
414		41.0	16.4	0	0
416		29.9	12.0	1	0
418		16.8	6.7	0	0
420		12.6	5.0	0	0
N5	456				
421		25.7	10.3	3	12
422		35.5	14.2	4	1
423		43.9	17.6	3	2
424		48.5	19.4	1	0
425		50.0	20.0	0	0
426		12.7	5.1	0	1
427		78.9	31.5	4	7
428		83.5	33.4	4	1
429		86.5	34.6	0	0
430		118.7	47.5	2	1
431		114.8	45.9	0	4
432		116.0	46.4	5	3

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
433		111.0	44.4	2	1
434		98.1	39.2	1	0
435		84.5	33.8	0	2
436		74.2	29.7	6	6
437		65.2	26.1	1	1
438		58.6	23.5	1	3
439		49.6	19.8	0	1
440		44.2	17.7	1	0
441		44.7	17.9	1	1
442		46.3	18.5	1	1
443		44.6	17.9	0	0
444		41.9	16.7	0	1
N6	454				
445		10.4	4.2	0	0
446		10.9	4.3	0	0
447		11.3	4.5	1	0
448		9.8	3.9	0	0
449		13.7	5.5	0	2
450		13.8	5.5	0	0
451		13.0	5.2	0	0
452		8.5	3.4	0	0
453		8.4	3.3	0	0
N7	454				
445		32.4	13.0	1	0
446		27.2	10.9	0	0
447		24.3	9.7	0	0
448		25.5	10.2	0	0
449		25.3	10.1	0	0
450		23.6	9.5	0	0
451		23.4	9.4	0	0
452		25.5	10.2	0	0
453		24.2	9.7	0	0
N8	452				
454		8.6	3.4	0	0
455		7.7	3.1	0	0
456		8.4	3.4	0	1
457		7.0	2.8	0	1
458		9.8	3.9	0	0
459		7.2	2.9	0	0
460		4.6	1.8	0	0
461		23.5	9.4	0	0
462		22.2	8.9	1	0
463		17.6	7.0	1	2
464		9.9	3.9	0	0
465		7.2	2.9	0	0

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
466		1.7	0.7	0	0
467		6.3	2.5	0	0
468		9.5	3.8	0	2
469		11.7	4.7	2	6
470		8.0	3.2	0	0
471		5.4	2.1	0	0
472		9.9	4.0	1	1
473		9.3	3.7	5	6
476		6.7	2.7	0	0
479		4.2	1.7	0	0
482		1.2	0.5	0	0
N9	452				
454		23.3	9.3	0	0
455		21.8	8.7	0	0
456		19.1	7.6	0	0
457		18.1	7.3	0	0
458		16.3	6.5	0	0
459		15.7	6.3	0	0
460		14.7	5.9	0	0
461		13.0	5.2	0	0
462		13.3	5.3	0	0
463		13.8	5.5	0	0
464		19.0	7.6	0	0
465		19.6	7.9	0	0
466		20.4	8.2	0	0
467		19.3	7.7	0	0
468		27.1	10.8	0	0
469		30.3	12.1	0	0
470		35.4	14.1	0	0
471		40.7	16.3	0	0
472		43.6	17.4	0	0
473		48.1	19.2	0	0
476		49.4	19.8	0	0
479		51.0	20.4	1	0
482		52.4	21.0	0	0
N10	450				
483		12.8	5.1	0	0
484		12.6	5.1	0	0
485		8.2	3.3	0	0
486		7.2	2.9	1	0
487		7.8	3.1	0	0
488		8.5	3.4	2	0
489		5.5	2.2	0	0
N11	457				
490		9.1	3.6	0	0

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
491		12.7	5.1	0	2
492		16.2	6.5	2	0
493		21.1	8.4	0	0
494		21.8	8.7	0	2
495		25.0	10.0	0	1
496		26.5	10.6	2	2
497		27.0	10.8	4	1
498		27.0	10.8	1	2
499		27.3	10.9	0	3
500		27.1	10.8	1	0
501		26.7	10.7	0	0
N12	454				
502		21.9	8.8	0	0
503		15.1	6.1	1	0
504		13.2	5.3	0	0
505		11.7	4.7	0	0
506		10.6	4.2	0	1
507		11.4	4.5	0	1
508		9.8	3.9	0	1
N13	458				
483		52.2	20.9	0	0
484		47.6	19.0	0	1
485		47.9	19.2	0	1
486		44.7	17.9	0	0
487		40.5	16.2	0	0
488		40.7	16.3	0	0
489		47.1	18.9	0	0
494		58.0	23.2	0	0
497		59.3	23.7	0	0
500		60.6	24.2	0	0
502		65.8	26.3	0	1
503		74.0	29.6	0	0
504		77.3	30.9	2	2
505		80.8	32.3	0	1
506		83.8	33.5	0	0
507		85.1	34.0	0	1
508		87.1	34.8	1	3
N14	453				
473		13.5	5.4	0	3
474		13.6	5.4	2	2
475		13.3	5.3	0	0
476		13.0	5.2	0	1
477		12.5	5.0	0	0
478		11.9	4.8	0	0
479		12.3	4.9	0	0

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
480		12.2	4.9	0	0
481		11.5	4.6	0	0
482		11.8	4.7	0	1
Torres Strait					
TS0	460				
135		38.6	15.4	0	1
136		38.1	15.2	0	0
138		40.0	16.0	0	0
140		38.3	15.3	0	0
142		36.3	14.5	0	0
144		38.2	15.3	0	0
146		43.5	17.4	1	2
147		44.8	17.9	0	0
TS1A	468				
102		58.0	23.2	2	0
104		56.4	22.5	1	4
106		52.5	21.0	0	0
108		49.9	20.0	1	3
110		46.6	18.6	0	0
TS1B	460				
112		39.4	15.8	0	0
114		33.4	13.4	1	1
116		27.9	11.1	0	0
118		23.3	9.3	1	0
120		25.5	10.2	0	0
122		33.3	13.3	0	0
124		36.2	14.5	1	1
126		38.4	15.3	2	1
128		47.7	19.1	3	0
130		42.0	16.8	1	2
132		41.6	16.6	0	0
134		41.7	16.7	1	0
TS2A	462				
201		67.2	26.9	3	1
202		67.2	26.9	3	4
203		67.3	26.9	10	8
204		67.3	26.9	8	4
205		67.4	26.9	4	2
206		67.4	27.0	2	4
207		67.4	27.0	11	7
208		67.5	27.0	6	3
209		67.5	27.0	4	3
210		67.6	27.0	8	5
213		47.2	18.9	8	2
305		10.7	4.3	0	0

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
306		20.9	8.4	8	0
306		13.7	5.5	0	0
211		67.6	27.0	2	2
212		67.7	27.1	1	1
TS2B	468				
213		25.6	10.2	0	0
214		58.5	23.4	0	0
215		58.5	23.4	1	1
216		58.5	23.4	2	0
217		58.5	23.4	1	0
218		58.5	23.4	4	1
219		58.5	23.4	1	0
220		58.5	23.4	1	0
221		58.5	23.4	1	0
222		58.5	23.4	0	0
223		58.5	23.4	3	1
224		58.5	23.4	2	0
225		24.4	9.8	0	0
TS3	462				
301		45.7	18.3	0	0
302		63.1	25.2	0	0
303		63.1	25.2	0	0
304		67.7	27.1	0	1
305		79.5	31.8	1	1
306		54.9	22.0	1	2
307		82.2	32.9	0	2
308		59.6	23.9	0	1
309		58.8	23.5	2	3
310		59.7	23.9	4	7
311		59.7	23.9	2	5
312		67.9	27.2	1	1
313		57.4	23.0	4	3
314		61.1	24.5	1	5
315		65.2	26.1	2	2
316		65.3	26.1	4	4
TS4	462				
401		65.3	26.1	1	2
402		60.1	24.0	3	1
403		60.3	24.1	16	4
404		60.3	24.1	7	3
405		60.3	24.1	0	0
406		42.1	16.8	0	0
407		42.9	17.1	0	1
TS5	469				
408		25.7	10.3	0	0

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
409		25.8	10.3	1	0
410		24.5	9.8	0	0
411		22.0	8.8	0	0
412		19.2	7.7	0	0
515		25.9	10.4	0	0
516		28.4	11.4	0	0
517		24.5	9.8	1	0
518		23.1	9.2	0	0
519		22.8	9.1	0	0
520		24.6	9.8	0	0
Hervey Bay*					
HB1	460				
1066		5.1	2.0	0	0
1067		3.4	1.4	0	0
1068		6.8	2.7	1	0
1069		8.5	3.4	0	0
1070		7.5	3.0	0	1
1071		10.5	4.2	1	1
1072		7.2	2.9	0	0
1073		7.1	2.8	0	0
1074		8.2	3.3	1	0
1075		8.1	3.3	0	0
1076		6.2	2.5	0	0
1077		7.7	3.1	0	0
1078		6.2	2.5	0	0
1079		7.5	3.0	0	0
1080		9.4	3.8	0	0
1081		12.6	5.1	1	0
1082		11.7	4.7	0	0
1083		10.2	4.1	0	0
1084		9.0	3.6	0	0
1085		11.0	4.4	0	0
1086		13.2	5.3	0	1
1087		13.4	5.4	1	0
1088		14.7	5.9	0	0
1089		14.7	5.9	0	1
1090		14.4	5.8	0	0
HB2	453				
1091		21.6	8.6	0	1
1092		36.0	14.4	2	0
1093		38.9	15.5	0	0
1094		36.8	14.7	0	2
1095		40.8	16.3	9	6
1096		43.2	17.3	1	5
1097		46.6	18.7	1	1

Block, Transect #	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
1098		53.5	21.4	8	6
1099		57.8	23.1	4	3
1100		61.5	24.6	0	2
1101		64.4	25.8	1	2
1102		67.3	26.9	0	1

* Hervey Bay Block 1 was slightly smaller in 2006 than in previous years because survey was terminated at transect 1067 for logistical reasons.

Appendix Table 5: Details of group size estimates and correction factors used in the population estimates for dugongs in the 2006 survey of the Northern Great Barrier Reef Region, Torres and Hervey Bay using the Method of Marsh & Sinclair (1989).

Blocks: Transects	Groups size (C.V)	Number of observers		Perception correction factor estimate (C.V)		Availability correction factor estimate (C.V)
		Port	Starboard	Port	Starboard	
Northern Great Barrier Reef						
N2: all	1.672 (0.101)	2	2	1.285 (0.044)	1.062 (0.010)	2.780 (0.116)
N3: 402-412	1.192 (0.081)	2	2	1.285 (0.044)	1.062 (0.010)	2.780 (0.116)
N3: 413-420	1.192 (0.081)	2	2	1.206 (0.043)	1.084 (0.015)	2.780 (0.116)
N4: 368-412	1.404 (0.140)	2	2	1.285 (0.044)	1.062 (0.010)	2.780 (0.116)
N4: 414-420	1.404 (0.140)	2	2	1.206 (0.043)	1.084 (0.015)	2.780 (0.116)
N5: all	1.258 (0.055)	2	2	1.206 (0.043)	1.084 (0.015)	2.780 (0.116)
N8: all	1.517 (0.078)	2	2	1.206 (0.043)	1.084 (0.015)	2.780 (0.116)
N11: all	1.522 (0.142)	2	2	1.051 (0.009)	1.069 (0.014)	2.780 (0.116)
N13: 483-489	1.538 (0.119)	2	2	1.206 (0.043)	1.084 (0.015)	2.780 (0.116)
N13: 497-508	1.538 (0.119)	2	2	1.051 (0.009)	1.069 (0.014)	2.780 (0.116)
N14: all	1.333 (0.177)	2	2	1.206 (0.043)	1.084 (0.015)	2.780 (0.116)
Torres Strait						
TS1A: all	1.636 (0.124)	2	2	1.285 (0.044)	1.062 (0.010)	1.883 (0.124)
TS1B: 112-118	1.333 (0.094)	2	2	1.285 (0.044)	1.062 (0.010)	1.883 (0.124)
TS1B: 120-134	1.333 (0.094)	2	2	1.051 (0.009)	1.069 (0.014)	1.883 (0.124)
TS2A: 201-210, 213, 3051, 305, 3061	1.298 (0.039)	2	2	1.051 (0.009)	1.069 (0.014)	1.883 (0.124)
TS2A: 211,212	1.298 (0.039)	2	2	1.285 (0.044)	1.062 (0.010)	1.883 (0.124)
TS2B: all	1.263 (0.102)	2	2	1.051 (0.009)	1.069 (0.014)	1.883 (0.124)
TS3: 301-307	1.508 0.067)	2	2	1.051 (0.009)	1.069 (0.014)	1.883 (0.124)
TS3: 308-316	1.508 (0.067)	2	2	1.285 (0.044)	1.062 (0.010)	1.883 (0.124)
TS4: all	1.579 0.154)	2	2	1.051 (0.009)	1.069 (0.014)	1.883 (0.124)

Blocks: Transects	Groups size (C.V)	Number of observers		Perception correction factor estimate (C.V)		Availability correction factor estimate (C.V)
		Port	Starboard	Port	Starboard	
Hervey Bay						
HB1: 1091-1102	1.4 (0.106)	2	2	1.010 (0.004)	1.004 (0.002)	2.2 (0.172)
HB2: 1066-1090	1.4 (0.122)	2	2	1.010 (0.004)	1.004 (0.002)	2.2 (0.172)

Appendix Table 6a: Estimates of dugong numbers for each survey block in the Northern GBR for various surveys conducted between 1985 and 2005 inclusive. All surveys were in November-December unless otherwise indicated. The block locations are in Appendix Figures 1-3. No population estimate was obtained for blocks where less than five groups of dugongs were sighted.

	Marsh & Sinclair Method										**Pollock *et al.* Method**			
Block	**1985**		**1990**		**1995**		**2000**		**2006**		**2000**		**2006**	
	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.
1	0#		*		*		112	47			73	52		
2	1644	570	1564	488	910	157	2265	562	1484	395	1617	623	1293	466
3	272	110	903	650	832	213	1985	488	403	95	1742	600	498	249
4	626	256	768	202	235	101	1074	242	1676	463	1060	380	1629	693
5	3630	714	3782	767	4396	1052	2233	407	2735	593	2832	1019	3061	1333
6	792	423	1673	1037	676	312	540	164	*		472	221	*	
7	0#		182	97	0#		0#		*				*	
8	611	192	829	305	305	181	389	132	1098	466	632	313	1407	725
9	*		*		*		*		*				*	
10	*		*		*		*		*				*	
11	222	81	268	66	309	109	214	79	277	56	287	191	293	116
12	*		*		*		*		*				*	
13	128	83	207	99	82	69	242	83	453	169	468	256	492	211
14					98	26	139	56	112	55	547	152	139	106
Total	**7925**	**1068**	**10176**	**1575**	**7843**	**1155**	**9193**	**917**	**8239**	**992**	**9730**	**1485**	**8812**	**1769**

* too few sightings to estimate population.
0# no dugongs seen.

Appendix Table 6b: Estimates of dugong numbers for each survey block in Torres Strait for various surveys conducted between 1987-2006 inclusive. No population estimate was obtained for blocks where less than five groups of dugongs were sighted.

	Marsh & Sinclair Method										Pollock *et al.* Method			
Block	**1987**		**1991**		**1996**		**2001**		**2006**		**2001**		**2006**	
	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.
0	0#		696	238	1152	381	0	0			0	0		
1a	1131	278	1669	999	2427	663	685	317	1280	561	612	258	858	516
1b			3705	1529	1681	615	2678	1695	1323	358	2607	1022	1005	435
2a	6424	1679	9113	1798	10869	1600	3504	403	5675	819	3454	782	4362	919
2b	2019	573	1467	399	1905	370	583	166	972	268	451	274	736	318
3	2822	1102	6740	1958	8623	2411	5473	1327	6556	1586	5565	1585	5166	1418
4	848	347	518	197	984	313	1183	655	3781	1850	776	565	2640	1356
5	76	55	320	277	240	70	0	0	0	0	0	0	0	0
Total	**13319**	**2136**	**24225**	**3276**	**27881**	**3095**	**14106**	**2314**	**19587**	**2669**	**13465**	**2152**	**14767**	**2292**

0# no dugongs seen.

Appendix Table 6c: Estimates of dugong numbers for the Torres Strait Index Block and the total survey for various surveys conducted between 1988-2006 inclusive.

	Block 2A Torres Strait		**Total Torres Strait**	
	Nhat	s.e.	Nhat	s.e.
Marsh & Sinclair Method				
1987	6424	1679	13319	2136
1991	9113	1798	24225	3276
1996	10869	1600	27881	3095
2001	3504	403	14106	2314
2005	4251	819	n/a	
2006	5675	819	19587	2669
Pollock *et al.* Method				
2001	3454	782	**13465**	**2152**
2005	4042	671	n/a	
2006	4362	919	14767	2292

Appendix Table 6d: Estimates of dugong numbers for each of the Hervey Bay Index Blocks and the total Hervey Bay survey for various surveys conducted between 1988-2006 inclusive. Note: Hervey Bay Block 1 was slightly smaller in 2006 than in previous years because survey was terminated at transect 1066 for logistical reasons.

	Block 1		**Block 2**		**Total Blocks 1 and 2**		**Total for all Blocks**	
	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.	Nhat	s.e.
Marsh & Sinclair Method								
1988	269	147	1753	388	2022	415	2175	419
1992	943	377	71	40	1014	379	1088	382
1993	193	52	257	85	450	100	524	124
1994	287	79	408	115	695	140	695	140
1999	373	96	875	196	1248	218	1653	248
2001 (Apr)	416	68	348	110	764	129	919	146
2001 (Nov)	446	112	1263	375	1709	392	1709	392
2005	649	110	1331	261	19`80	283	4251	819
2006	1002	290	167	46	1169	294	n/a	n/a
Pollock *et al.* Method								
2005	389	130	1143	353	1532	376	4042	671
2006	936	397	108	37	1044	399	n/a	n/a

Further information

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