Report to the Australian Marine Mammal Centre and the Torres Strait Regional Authority

Aerial survey of Torres Strait to evaluate the efficacy of an enforced and possibly extended Dugong Sanctuary as one of the tools for managing the dugong fishery

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Executive Summary

(1) Torres Strait is the most important dugong habitat in Queensland, Australia and probably the world. Torres Strait, with an estimated dugong population of > 12,000 animals, contains a remarkable 54% of the high and very high density dugong habitat in North-East Australia and 58% of the corresponding habitat in Queensland, dwarfing the Great Barrier Reef region (15%) and Hervey Bay (14%).

(2) Within Torres Strait, the spatial model of dugong distribution based on the results of all aerial surveys (1987 - 2011) indicated that by far the most important dugong habitat is the ~10,500km^2 area extending from Badu to Boigu Islands, east to Gerber (Gabba) Island and west to the Warul Kawa Island Indigenous Protected Area (Deliverance Island). This region contains 56% of the high and very high density dugong habitat in Torres Strait and 30% of the high and very high density dugong habitat in eastern Queensland. Most (89 %) of this habitat is outside the major hunting grounds of the communities in the area.

(3) Almost one quarter (~22%) of the area of high and very high dugong density in Torres Strait occurs in the Dugong Sanctuary, illustrating the potentially significant value of the spatial closure of this region if it were enforced. All of this region is outside the major hunting grounds of the communities in the area, although some hunting occurs in the eastern parts of the Sanctuary.

(4) The dugong population estimates for the Torres Strait blocks surveyed since 1987 vary from 12,600-28,000. This variation is likely the result of: (1) the region to the west of Torres Strait being surveyed for the first time in 2011, thus the proportion of the dugong population surveyed has not been constant across surveys; and (2) the noise in the data resulting from uncorrected fluctuations in the availability of dugongs to observers resulting from local scale movements of dugongs between areas of different bathymetry.

(5) The time series of aerial surveys of Torres Strait since the mid 1980s 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 and the limited management interventions to regulate this harvest to date.

(6) This failure to detect a decline in dugong numbers should not be used as a reason for reducing the commitment to implementing the community-based Dugong and Marine Turtle Management Plans, because of: (a) the uncertainties in the estimates of both the size of the dugong population and anthropogenic mortality; (b) the difficulty of detecting trends in the abundance of marine mammals; (c) the uncertainty surrounding the impact of climate change on the frequency of seagrass diebacks in Torres Strait; (d) the evidence that the life history and reproductive rate of female dugongs are adversely affected by seagrass loss; (e) the evidence that dugongs in Torres Strait are breeding at exceptionally small sizes/young ages which may be a sign that the population is declining; and, (f) the escalating political and public concerns about dugong hunting.

(7) Irrespective of whether the current anthropogenic impacts on the dugong population of Torres Strait are sustainable, the dugong population size in the region is substantial (>12,000 individuals) and is genetically healthy.

(8) We consider that there is time to work with local Traditional Owners to develop appropriate management arrangements without dugongs becoming locally extinct within this region or parts thereof.

Recommendations

Management

(1) That the major priority for dugong management in Torres Strait be continued support for the implementation of the community-based Dugong and Marine Turtle Management Plans.

(2) That the Torres Strait Regional Authority (TSRA) give high priority to facilitating complementary management between Torres Strait Traditional Owners, PNG villagers and the peoples of the Northern Peninsula Area (Cape York Land Council and the Great Barrier Reef Maine Park Authority). In particular, it will be important to decide whether the regional objective for dugong management in Torres Strait is to maintain the population at its present level or to facilitate its increase. Clarification of this objective is a fundamental pre-requisite to setting a total allowable catch for the Torres Strait dugong fishery.

(3) That the community ranger program give high priority to obtaining robust estimates of the current dugong harvest from all the major hunting communities.

(4) That the TSRA Land and Sea Management Group give high priority to discussions with the Prescribed Bodies Corporate of the Top Western and Near Western Islands and the Protected Zone Joint Authority about the desirability of the following suggestions:

    a. declaring some or all of the high density dugong area extending from Badu to Boigu Islands, east to Gerber (Gabba) Island and west to the Warul Kawa Island Indigenous Protected Area (Deliverance Island) as a no-hunting area for an agreed period;
    b. negotiating with the Australian government for consequential payments for eco-system services in order to secure some long-term funding for community based natural resource management in Torres Strait[1].
    c. asking the Australian government for assistance to enforce the Dugong Sanctuary, perhaps using money raised from private enterprise e.g. through Indigenous Impact Bonds[2].

Research and Monitoring

(1) That the dugong aerial surveys be continued at regular (typically 5-year) intervals for the combined region of the northern GBR and Torres Strait with the next survey occurring in November 2013 to enable a seasonal comparison of the dugong's use of the Dugong Sanctuary;

(2) That the correction for availability bias in the Pollock *et al*.(2006) method be improved using the data on dugong diving behaviour;

(3) That the data on turtle distribution in Torres Strait collected during the times series of aerial surveys be analysed with a view to developing a predictive and spatial model that parallels that for dugongs to inform spatial planning in Torres Strait;

(4) That when the technology is available, consideration be given to the feasibility of using Unmanned Aerial Vehicles rather than manned aircraft to conduct the surveys for reasons of human safety and logistics.

[1] Cape York Land Council is considering declaring no-hunting areas off Cape York and asking the Australian Government for consequential funding for ecosystem services (Noel Pearson *pers comm*.). This approach is potentially compatible with the 'Biodiversity Banking Scheme' announced by the Australian Government in August 2011 http://www.environment.gov.au/epbc/publications/pubs/epbc-reform-overview.pdf.

[2] As proposed by Patrick Dobson and Ian Gill
http://www.smh.com.au/opinion/politics/a-bran-nue-way-ahead-20110816-1iw7j.html#ixzz1VXzvoJlM

Introduction

Torres Strait supports the largest population of dugongs in the world (Marsh *et al.* 2011). Archaeological evidence indicates that dugongs have been hunted for 4,000 years in this region (Crouch *et al.* 2007) and that the harvest has been substantial for at least 300 years (McNiven and Bedingfield 2008). Dugong hunting is now a Traditional fishery sanctioned by the *Torres Strait Treaty* 1982 between Australian and Papua New Guinea (PNG) and in Australia by the *Torres Strait Fisheries Act* C'wlth 1993 and the *Native Title Act* C'wlth 1993. Recent modelling suggests that this fishery may not be sustainable (Heinsohn *et al.* 2004, Marsh *et al.* 2004); a conclusion supported by some Islander leaders. Non-hunting impacts (e.g. fishing activities, boating and habitat loss) on the dugong population in the Australian waters of Torres Strait are generally relatively low (Marsh *et al.* 2002, Halpern *et al.* 2008); fishing impacts are much more of a concern in PNG waters (*pers.comm.* Daru Dugong Workshop 2009). The Torres Strait dugong fishery targets mainly adults (Kwan 2002) and like other marine mammals, dugongs are large, long-lived animals that are dependent on high adult survivorship for population maintenance (Heinsohn *et al.* 2004; Marsh *et al.* 2004; Marsh & Kwan 2008). Thus the management of hunting is the most important component of the management of anthropogenic impacts on dugongs in the Australian waters of Torres Strait.

Australia has obligations and responsibilities for the conservation and management of dugongs as signatory to the *Convention on Biological Diversity,* the *Convention on International Trade in Endangered Species of Wild Fauna and Flora*, and the *Convention on the Conservation of Migratory Species of Wild Animals*. As a signatory to the *Convention on Biological Diversity,* Australia also has responsibilities for the conservation of the customary use of biological resources in accordance with traditional cultural practices that are compatible with conservation or sustainable use requirements. All these responsibilities and obligations are recognized in legislation by the *Environment Protection and Biodiversity Conservation Act* C'wlth 1999 (EPBC Act) and the Commonwealth government has made considerable investment in the development of community-based Dugong and Marine Turtle Management Plans (Marsh *et al.* 2011), which are being developed for the Sea Countries of individual communities.

Grayson (2011) compared a spatial model of dugong distribution based on 20 years of aerial surveys (partial funding from Australian Marine Mammal Centre; Grech *et al.* 2011) with the spatial distribution of dugong hunting using information from Indigenous hunters and Hudson (1986), Kwan (2002) and Grayson (2011). The research indicates that dugong hunting mainly occurs within 30 km of inhabited islands or on reef tops and most of the high and very high density dugong habitat in the region covered by the 1987-2006 aerial surveys occurred outside these core hunting areas.

The appropriateness of using spatial closures as one of the tools for dugong management in Torres Strait was discussed with key Australian government and community stakeholders including Traditional Owners at a workshop in October 2008 (Marsh *et al.* 2009). The Torres Strait Islander attendees at the workshop strongly supported more active enforcement of the gazetted Dugong Sanctuary in western Torres Strait and the development of spatial closures in PNG waters. Representatives of PNG communities at a dugong workshop in Daru in February 2009 also endorsed this approach. The draft *Strategic Assessment of the Torres Strait Turtle and Dugong Fisheries* also suggested spatial closures as one of the potential management tools (Australian Fisheries Management Authority 2006). Spatial and/or spatio-temporal closures of parts of the Sea Country of individual communities have been included in many of the Dugong and Marine Turtle Management Plans.

Prior to this survey, the proportion of the high density dugong habitat in the Torres Strait region that is in western Torres Strait could not be determined because: (1) seagrass beds in the area had not been mapped, and (2) the 1987-2006 aerial surveys did not cover most of this region because the design of the aerial surveys was developed in the 1980s before GPS technology enabled safe low level surveys of featureless seascapes. The Torres Strait Regional Authority (TSRA) demonstrated its commitment to evaluating the potential of an actively enforced and possibly extended Dugong Sanctuary as one of the tools for managing dugongs in Torres Strait by partnering with scientists at Fisheries Queensland to conduct a vessel-based seagrass survey in March 2010. This survey demonstrated that the region supported the largest continuous seagrass bed recorded in Australia (Taylor & Rasheed 2010).

Our project, which was also co-funded by the TSRA in conjunction with the Australian Marine Mammal Centre, aimed to: (a) inform dugong management in Torres Strait by conducting an aerial survey of all potential dugong habitats in the region including the previously unsurveyed regions to the west; and (b) quantify the potential of existing and extended spatial closures in Torres Strait as management tools for the dugong fishery.

Methods

Timing of survey

The weather conditions in November 2010 (pre-Wet Season) were unsuitable for aerial survey and the survey was rescheduled to March 2011 (post-Wet Season). Members of the survey crew were trained in Townsville in a workshop from March 1-3 2011. The survey was conducted from March 4-23, 2011. The survey crew included one Torres Strait Islander.

Survey design

The aerial survey design was based on that used in previous surveys of Torres Strait with three important differences:

(1) In order to cover the previously unsurveyed waters of western Torres Strait, especially the Dugong Sanctuary, we extended the north-south transects (Block 6) and the east-west transects (Blocks 7, 8, 9; Figure 1; Appendix Table 1). The western boundary of the survey was determined by the border of Papua Burat, the results of the seagrass survey of the Dugong Sanctuary conducted by TSRA and Fisheries Queensland in March 2010 (Taylor & Rasheed 2010) and the dugong spatial model developed on the basis of the previous surveys (Grech *et al.* 2011).

(2) The bureaucratic challenges associated with obtaining a permit for an Australian aircraft to fly in PNG airspace precluded our surveying within 5 nm of the PNG coast and necessitated truncating the north-south transects in Blocks 6, 0, 1B, 1A (Figure 1).

(3) The survey intensity was increased in Block 1A with the aim of increasing the precision of the population estimates for that block.

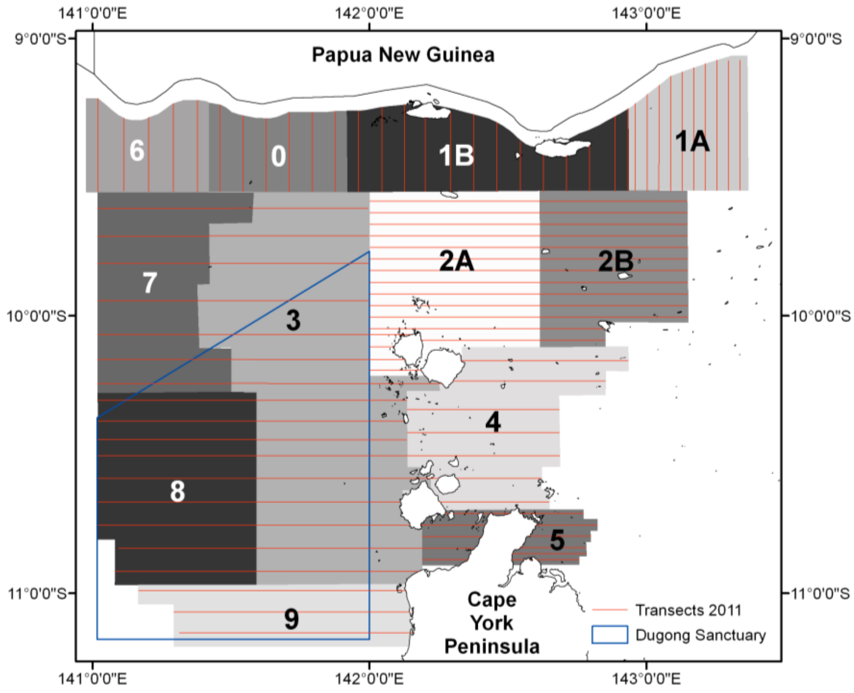

Figure 1. Torres Strait showing the aerial survey transects flown in the 1987-2006 surveys (Blocks 0, 1A, 1B, 2A, 2B, 3, 4, 5) and the additional transects to the west (Blocks 6,7,8, 9) flown in 2011 and the boundary of the Dugong Sanctuary (blue). The truncation of the transects along the PNG coast was necessitated by the restrictions on obtaining a permit for an Australian aircraft to fly in PNG airspace

Survey Methodology

The survey was conducted using a 6-seater high-wing Patenavia 68B aircraft using the strip transect aerial survey technique detailed in Marsh & Sinclair (1989a) and used in previous dugong surveys in Torres Strait. This technique has been shown to be more suitable than line transect methodology for dugongs (Pollock *et al.* 2006). The aircraft was fitted with a GPS and flown as close as possible to a ground speed of 100 knots. Given the remoteness of western Torres Strait, the survey was conducted for safety reasons at a height of 152 m (500') above sea level, rather than the survey height of 137m (450') used in previous surveys. The experimental work of Marsh & Sinclair (1989b) suggests that this relatively small change in survey height (11% increase) should not make a substantive difference to the results especially as the transect width was kept constant at 200m.

Transects 200m wide on the water surface were demarcated using fibreglass rods attached to artificial wing struts on each side of the aircraft. Tandem teams, each of two observers on each side of each aircraft, recorded their sightings independently onto separate tracks of an audio-recorder. For training purposes, one unexperienced observer on the port side was linked to the front intercom for four transects at the beginning of the survey. The independent sightings of the tandem observers were used to develop survey specific correction factors for perception bias for each side of the aircraft as outlined below. The transect on each side of the aircraft was divided into four horizontal strips using markers on the wing struts. Each sighting was designated as being made in one of these sub-strips, which enabled us to decide if simultaneous sightings by members of the same group of tandem observers were of the same group of animals.

Estimating the Size of the Dugong Population

Two methods were used to estimate dugong abundance: (1) Marsh & Sinclair (1989a), which has been used to calculate standardised estimates of relative abundance from all surveys since 1987; and (2) Pollock *et al.* (2006), which has been used as well since 2001. 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, 1989a). We believe the methodology of Pollock *et al.* (2006) is superior because the correction for availability bias addresses the spatial heterogeneity in sighting conditions within each survey whereas the Marsh & Sinclair (1989a) method averages these conditions within surveys and only corrects for differences in availability bias between surveys. Estimates from both techniques were calculated as the additional data required for the Pollock *et al.* (2006) methodology have been collected only from 2001.

Dugong abundance was estimated separately for each of the blocks surveyed. Fewer than five dugongs were sighted in both Blocks 4 and 5 in 2011, thus we combined the two blocks to estimate dugong density using both methodologies. The standard error estimates were incorporated the errors associated with the correction factors. Any dugongs in groups of $\geq$ 10 were added to the estimates of population size at the end as outlined in Norton-Griffiths (1978). All results are presented $\pm$ standard errors unless otherwise indicated.

Statistical Analysis

Differences in dugong density among all survey years from 1987 and blocks (0, 1A, 1B, 2A, 2B, 3, 4 and 5) were examined by linear mixed-effects models using data generated by the methodologies of Marsh & Sinclair (1989a). The methodology of Pollock *et al.* (2006) was used to analyse the significance of the variation in dugong density for the surveys from 2001.

Statistical analyses followed Marsh *et al.* (2007). Years and blocks were treated as fixed effects; transects within blocks as random effects as there was a large variation in animal density within blocks. Mixed effects models were employed to indicate appropriate tests for differences between three explanatory variables (years, blocks and the block-year interaction) and to estimate the random components of variance. The variance of the mixed effects models were estimated by the restricted maximum likelihood method. We transformed dugong density (ln (y + 0.1)) to ensure homogeneous mean-variance components and used the transformed density as a response variable.

Appropriate F-ratios were calculated from the fixed effects model. The statistical significance of the fixed effects was determined by simulation using Monte Carlo Markov Chains based on the parameters estimated from mixed-effects model 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 dugong density.

Differences in dugong density among all 12 blocks surveyed in 2011 were examined by ANOVA with post-hoc comparisons. The dugong density was transformed with $\ln(y+0.1)$.

Spatial Modeling

Spatial data from the 2011 aerial survey were integrated with dugong sightings from aerial surveys conducted in 1987, 1991, 1996, 2001, 2005 and 2006 (Marsh *et al.* 1997, 2004, 2007) to form a common GIS database. We used the uncorrected data on dugong distribution and abundance and the method of Grech and Marsh (2007) and Grech *et al.* (2011) to develop spatially explicit dugong population models for the aerial survey region for both 2011 only and for all surveys from 1987. By using the time series of data, the latter model accounted for temporal changes in the use of local areas by dugongs, including movements resulting from events such as seagrass dieback (Marsh & Kwan 2008).

We estimated dugong distribution and relative abundance at a planning unit of cell size 2 km * 2 km for both models. Based on the relative density of dugongs estimated from the spatially explicit dugong population models and a frequency analysis, we classified each cell in the aerial survey region as very high (> 0.5 dugongs/km^2), high (0.5 – 0.25 dugongs/km^2), medium (0 – 0.25 dugongs/km^2) and low (0 dugongs/km^2) dugong density (Grech and Marsh 2007; Grech *et al.* 2011). The models were compared with the seagrass map of the Dugong Sanctuary obtained by Taylor & Rasheed (2010) and Daniell's (2008) bathymetric model of the region. The spatial distribution of dugong sightings was also compared with the bathymetry model.

Results

2011 survey

This survey demonstrated that it was possible to survey the remote regions of Torres Strait successfully using a light aircraft based at Horn Island. Nevertheless, surveying such a remote area at a low height above sea level is not without risks to human safety and is logistically very demanding because of the stringent weather requirements.

Survey Conditions

The weather conditions were generally good and comparable with previous surveys (Appendix Tables 2 and 3). As expected for March, dodging rain was the greatest challenge and the cloud cover was sometimes greater than ideal, which had the advantage of a concomitant reduction in glare off the surface of the sea.

Dugong sightings

A total of 260 groups of dugongs were sighted during the survey (Figure 2 and Appendix Table 4); the largest group seen was a diffuse group of 20 animals in Block 2A west of Orman Reef. Twenty-two groups of animals were sighted in the Dugong Sanctuary. The modal dugong group size for the entire survey was one and the mean group size for all blocks was between one and two (Appendix Table 5). The proportion of calves was 13%; 9% in the Dugong Sanctuary. Dugongs were sighted in water up to 40 m deep (not corrected for tides); >79% of dugongs were sighted in waters <25m deep (Figure 3), shallower than the deeper waters of the western half of the Dugong Sanctuary (Figure 9 below).

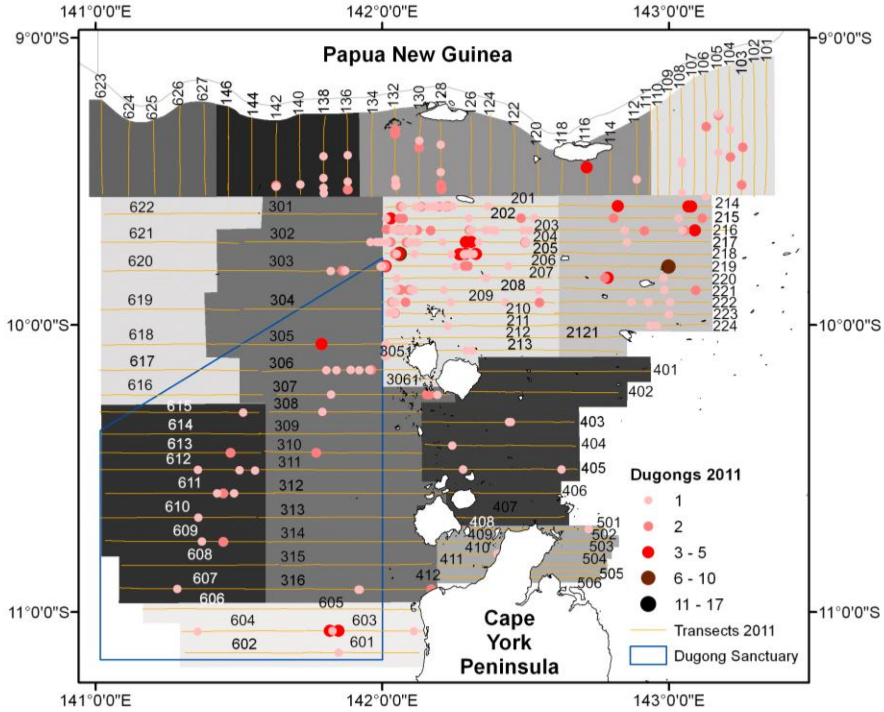

Figure 2. GPS tracks of transects flown in Torres Strait during the aerial survey in March 2011 and the positions and sizes of the dugong groups sighted and the transect numbers.

Estimates of Dugong Population Size

Appendix Table 5 provides details of the mean group sizes and correction factors used for estimating the size of the dugong population in 2011.

<u>Method of Marsh & Sinclair (1989a)</u>

The estimate of dugong abundance in 2011 was 14,035 ± 1891 from the eight blocks (Block 0, 1A, 1B, 2A, 2B, 3, 4 and 5) surveyed since 1987 and 15,526 ± 1915 from the entire 2011 survey region including the blocks in western Torres Strait surveyed for the first time. (Figure 4; Appendix Table 6a). Thus the population of western Torres Strait (Blocks 6-9) comprised an estimated ~10% of the entire Torres Strait dugong population in March 2011.

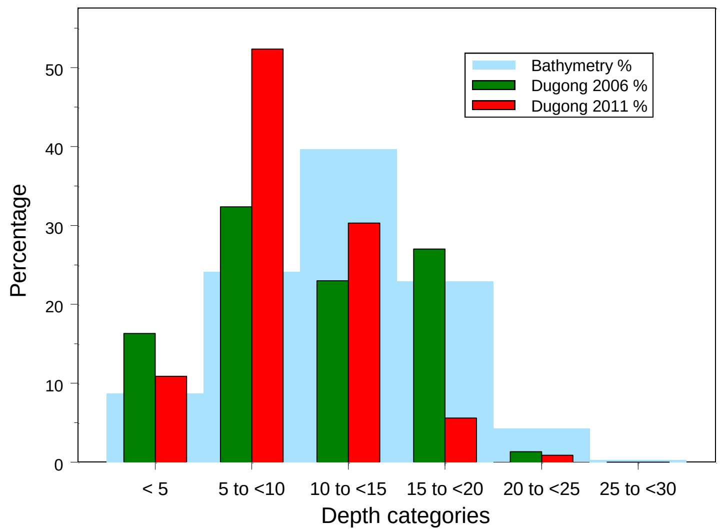

Figure 3. Frequency distribution of dugong sightings with respect to bathymetry (Daniell 2008) for the 2006 and 2011 dugong surveys of Torres Strait. The data indicate that relatively more dugongs were sighted in the 5-10m depth bin in 2011 than in the 2006 survey.

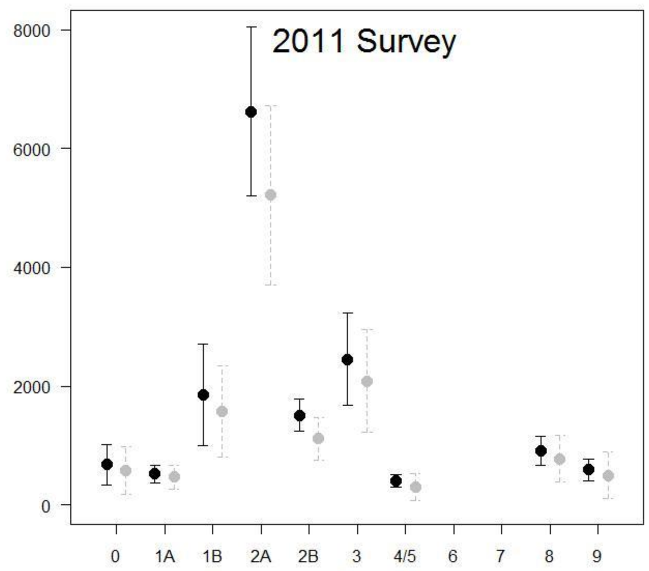

Figure 4. Estimates of dugong abundance in Torres Strait +SE based on the 2011 survey of blocks (0-5); Blocks 6 - 9 were flown for the first time in 2011. The estimate for Blocks 4 and 5 was computed jointly as < 5 dugongs were sighted in each of these blocks. No dugongs were sighted in Blocks 6 and 7. Black circles and lines represent numbers estimated using the technique of Marsh & Sinclair (1989a); grey circles and lines represent the estimates derived using Pollock *et al.* (2006).

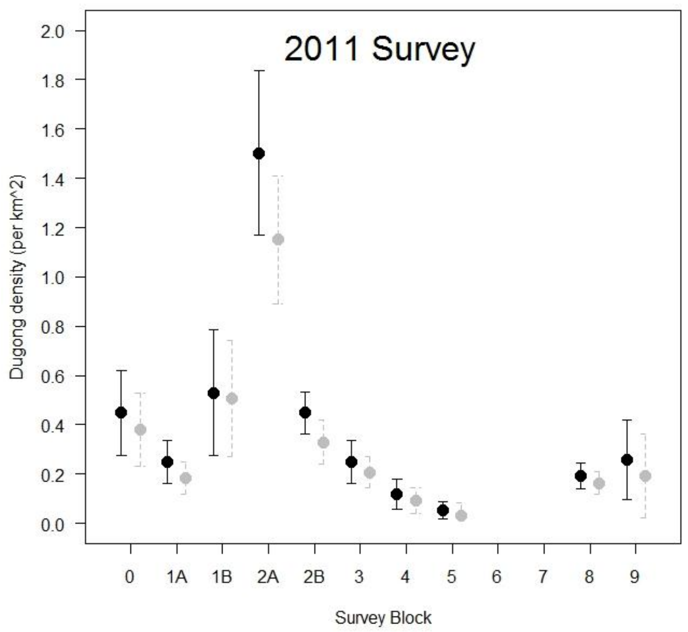

Figure 5. Estimates of dugong density + SE for each Block in Torres Strait based on the 2011 survey. No dugongs were sighted in Blocks 6 and 7. Black circles and lines represent numbers estimated using the technique of Marsh & Sinclair (1989a); grey circles and lines represent the estimates derived using Pollock *et al.* (2006).

Dugong density was highest in Block 2A, followed by Blocks 1B and 2B (Figure 5); no dugongs were sighted in Blocks 6 and 7 and the numbers sighted in Blocks 4 and 5 were so low that we calculated combined population and density estimates for these blocks (Figures 4 and 5; Appendix Tables 6A and B). When the results of the 2011 survey were compared across blocks, the transformed density for Blocks 2A was significantly different from all blocks except 0, 2B and 9 (Table 1). The density for Block 2B was also significantly higher than Block 7.

<u>Method of Pollock *et al.* (2006)</u>
The dugong population estimate based on the methodology of Pollock *et al.* (2006) was 11328 ± 2005 for the eight blocks surveyed previously and 12603 ± 2080 for all 12 blocks (Figure 4 and Appendix Table 6B). The spatial pattern of dugong density was similar to that calculated using the Marsh & Sinclair (1989a) method (Figure 5) and again the population of western Torres Strait (Blocks 6-9) comprised an estimated ~10% of the

entire Torres Strait dugong population. When the results of the 2011 survey were compared across blocks, the density for Blocks 2A was significantly higher than all blocks except Blocks 0, 1B, 2B and 8 (Table 1).

Table 1: Results of fixed ANOVA on dugong density across all blocks surveyed in 2011 from: a) Sinclair (1989a) method and b) Pollock *et al.* (2006). Type III sum of squares were used to examine significant effects due to the unbalanced number of transects in different blocks.

	Num. DF	Denom. DF	Sum of Square	Mean Square	F	P-value
Marsh & Sinclair (1989a)						
Block	11	104	36.5	3.2	4.2	<0.0001
Pollock *et al.* (2006)						
Block	11	104	47.6	4.3	5.0	<0.0001

Spatial modelling 2011

The average relative dugong density for 2011 predicted by the spatially explicit population model (Figure 6) was 0.10 dugongs/km^2 and ranged from 0 to 2.4 dugongs/km^2. The areas of highest relative dugong density were between Turnagain and Mabuiag Islands and along the Warrior Reefs (Figure 6). The model indicates that much of the eastern half of the Dugong Sanctuary supported uncorrected dugong densities of up to 0.5 animals per km^2. The dugong densities tended to be lower in the western Dugong Sanctuary despite the occurrence of seagrass (Figure 7), presumably because the water is deeper in this area.

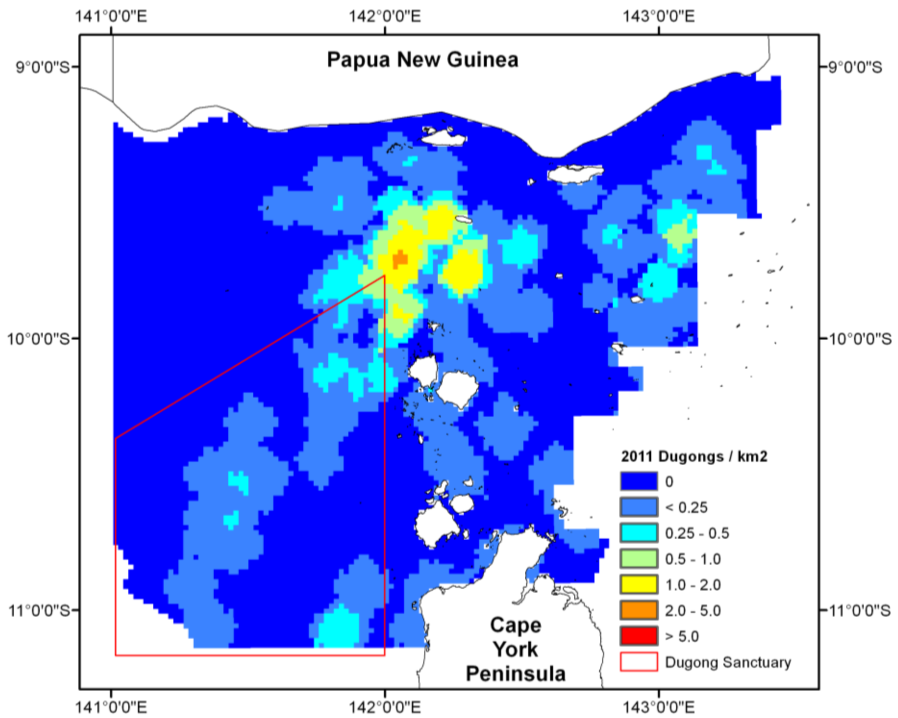

Figure 6. Spatially explicit population model of dugong distribution and relative density (dugongs/km^2) in Torres Strait based on the uncorrected dugong sightings from the aerial survey conducted in 2011.

All surveys 1987-2011

Estimates of Dugong Population Size

<u>Method of Marsh & Sinclair (1989a)</u>
When the results of the 2011 survey for Blocks 0-5 were compared with those for the previous surveys (1987-2006) for the transects in common, dugong density differed significantly among years and blocks (Figure 7A and B; Appendix Figure 1 and Table 2). The random variance component corresponding to the among-transect within-block variation among years (error, 0.82) was much larger than the corresponding value for the variance among transects within blocks (0.14). The result suggests that dugongs make substantial small-scale movements within blocks over time a result consistent with the differences in depth use observed when the spatial pattern of sightings for 2006 was compared with that for 2011 (Figure 3).

<u>Method of Pollock *et al.* (2006)</u>
When the results of the 2011 survey for Blocks 0-5 were compared with those for the surveys conducted in 2001, 2006 and 2011, the effect of block was again significant (Figure 7a; Appendix Figure 1 and Table 2) but there was no difference in estimated dugong density between years, presumably because the results for the 1995 survey were not included (Figure 7A). The difference between the variance components was similar to the results obtained using the Marsh & Sinclair (1989a) methodology, again suggesting that dugongs make substantial small-scale movements within blocks over time.

Table 2: Results of linear fixed- and mixed-model ling of dugong density from all surveys since 1987 using the Marsh & Sinclair (1989a) method and three surveys from 2001 using the Pollock *et al.* (2006) method.

Source of variation	**Num. DF**	**Denom. DF**	**F**	**MCMC P-value**	**Variance component**
Surveys in 1987, 1991, 1996, 2001, 2006 and 2011 (Marsh & Sinclair 1989)					
Block	7	78	16.9	<0.0001	
Among transect within block					0.135
Year	5	390	5.68	0.025	
Block x Year	35	390	1.27	0.205	
Residual (among transect within block variation among years)					0.820
Surveys in 2001, 2006 and 2011 (Pollock *et al.* 2006)					
Block	7	78	15.23	<0.0001	
Among transect within block					<0.0001
Year	2	156	0.82	0.071	
Block x Year	14	156	1.49	0.108	
Residual (among transect within block variation among years)					0.769

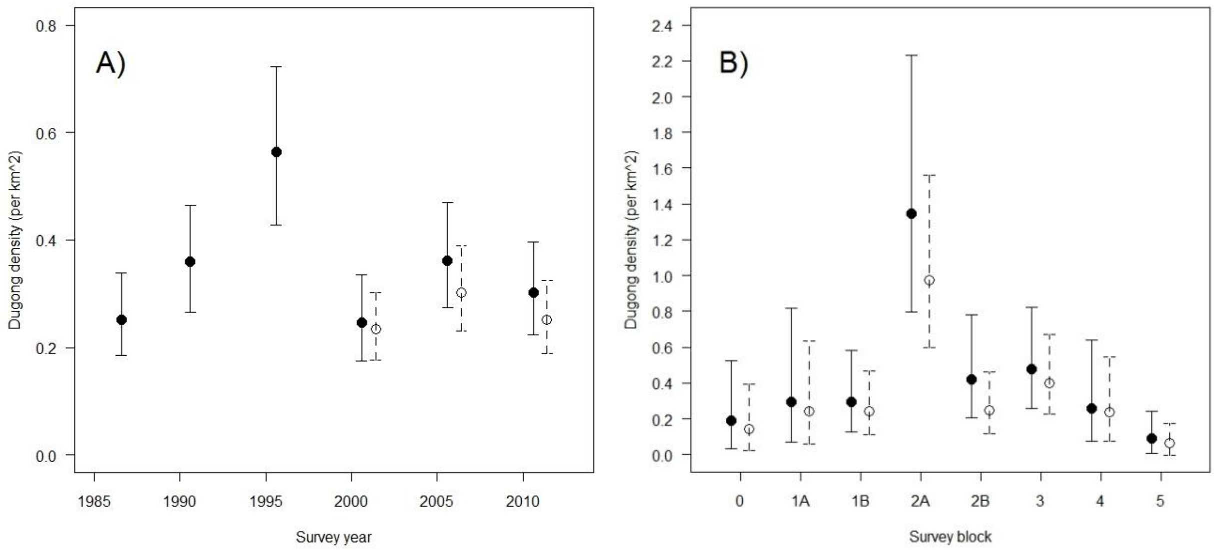

Figure 7. Estimated dugong density (per km^2) in the Torres Strait: (a) in each survey year and (b) in each survey block from all survey years combined. Solid and dashed line indicates the density estimated from Marsh & Sinclair (1989a) method and Pollock *et al.* (2006) respectively. Error bars represent 95% credible intervals for the dugong density.

Comparison between Methodologies

For the 2001, 2006 and 2011 surveys, the estimates of dugong abundance using the Pollock *et al.* (2006) methodology were consistently lower (~ 5-20% Table 3) than using the methodology of Marsh & Sinclair (1989a). There was no consistent pattern between the methodologies with respect to the coefficient of variation of the population estimates (Table 3).

Table 3. Comparison of the dugong population estimates for Blocks 0-5 using methodologies from Marsh & Sinclair (1989a) and Pollock *et al.* (2006). The former methodology produced lower estimates.

Year	Marsh & Sinclair (1989a)		Pollock *et al.* (2006)		Ratio (%) of the estimates from Pollock *et al.* (2006) to Marsh & Sinclair (1989a)
	Population estimates (SE)	CV	Population estimates (SE)	CV	
2001	14106 (2314)	0.164	13465 (2152)	0.160	95.5
2006	19587 (2669)	0.136	14767 (2292)	0.155	75.4
2011	14035 (1891)	0.135	11328 (2005)	0.177	80.7

Spatial modelling across all survey years

The spatial model based on the data from all surveys combined (Figure 8) indicated that ~22% of the area of high and very high dugong density in Torres Strait occurred in the Dugong Sanctuary (Table 4). The dugong densities tended to be lower in the western Dugong Sanctuary despite the occurrence of seagrass (Figure 9), presumably because the water is deeper in this area.

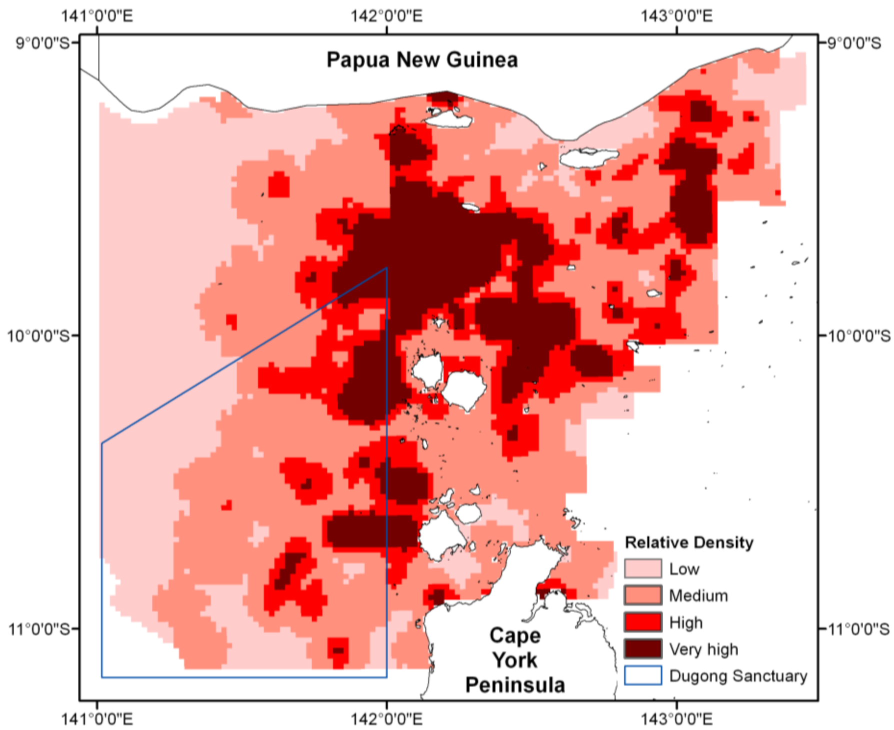

Figure 8. Spatially explicit population model of dugong distribution and relative density in Torres Strait based on the dugong sightings from aerial surveys conducted in 1987, 1991, 1996, 2001, 2005, 2006, and 2011. The Dugong Sanctuary is outlined in blue.

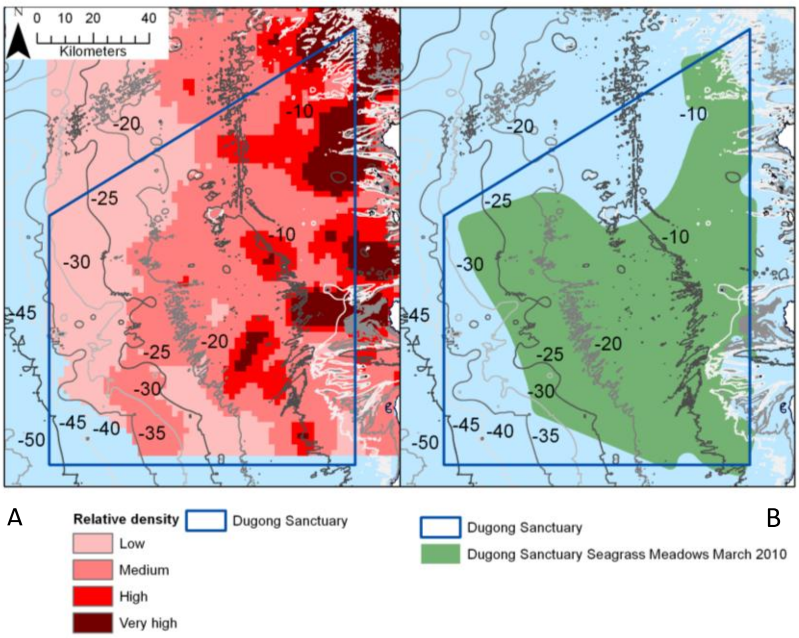

Figure 9. (a) Model of the relative density of dugongs based on dugong sightings in the dugong sanctuary; and, (b) contour lines (Daniell 2008) and dugong sanctuary seagrass distribution mapped in March 2010 (Taylor & Rasheed 2010).

The spatial model based on all surveys combined also indicated that by far the most important dugong area in Torres Strait is the ~10,500 km^2 area (purple box in Figure 10) extending from Badu to Boigu Islands, east to Gerber (Gabba) Island and west to the Warul Kawa Island Indigenous Protected Area (Deliverance Island). This region contains 56% of the 12,656 km^2 of high and very high density dugong habitat in Torres Strait; and 30% of the 23,576 km^2 of high and very high density dugong habitat in eastern Queensland (Figure 11 and Table 4).

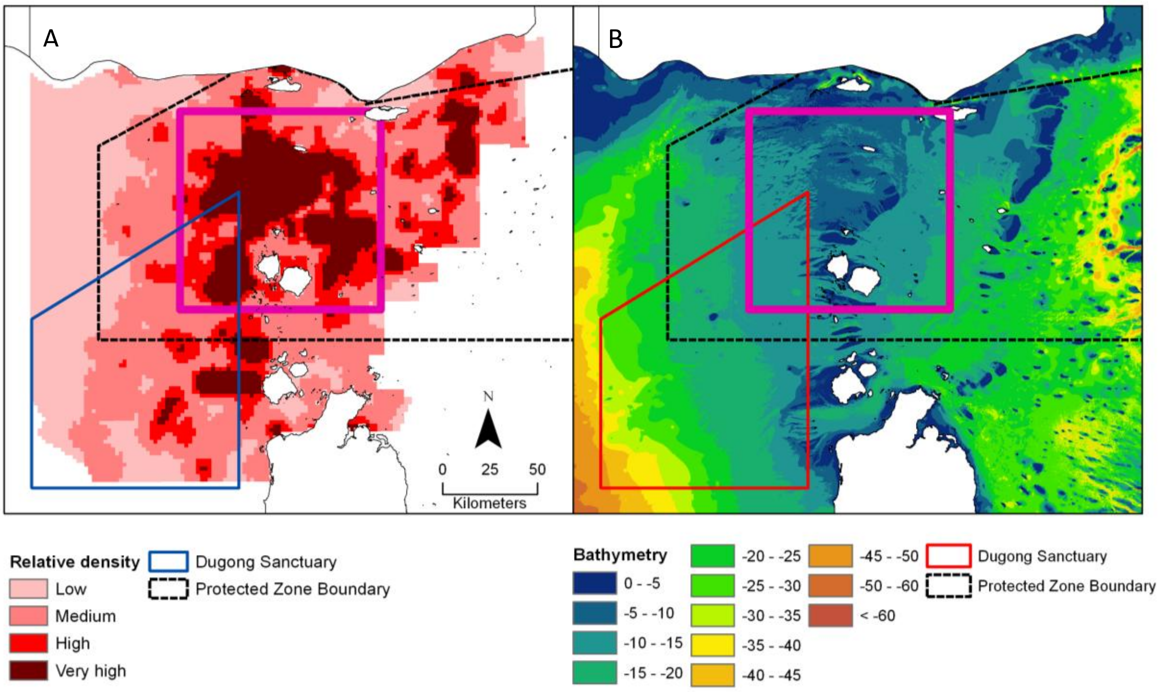

Figure 10. (a) Model of the relative density of dugongs based on dugong sightings from aerial surveys conducted in 1987, 1991, 1996, 2001, 2005, 2006, and 2011 and (b) bathymetric model of Torres Strait (Daniell 2008). The area of exceptionally high dugong density is outlined by the purple box and the Protected Zone Boundary by a black dashed line. This region contains 56% of the high and very high density dugong habitat in Torres Strait; 30% of the high and very high density dugong habitat in eastern Queensland.

Table 4. Total area (km^2) and proportion (%) of dugong planning units of low, medium, high and very high relative densities predicted by the spatially explicit population model (Figure 8) in the entire survey region, the Dugong Sanctuary and the high density area between Badu and Boigu (purple box in Figure 10).

Dugong relative density	Entire survey region	Dugong sanctuary	Badu – Boigu*
Low	11,612 (27)	3,536	124
Medium	18,264 (43)	5,804	3,252
High	6,540 (15)	1,844	2,800
Very high	6,116 (14)	964	4,296

*(purple box Figure 10)

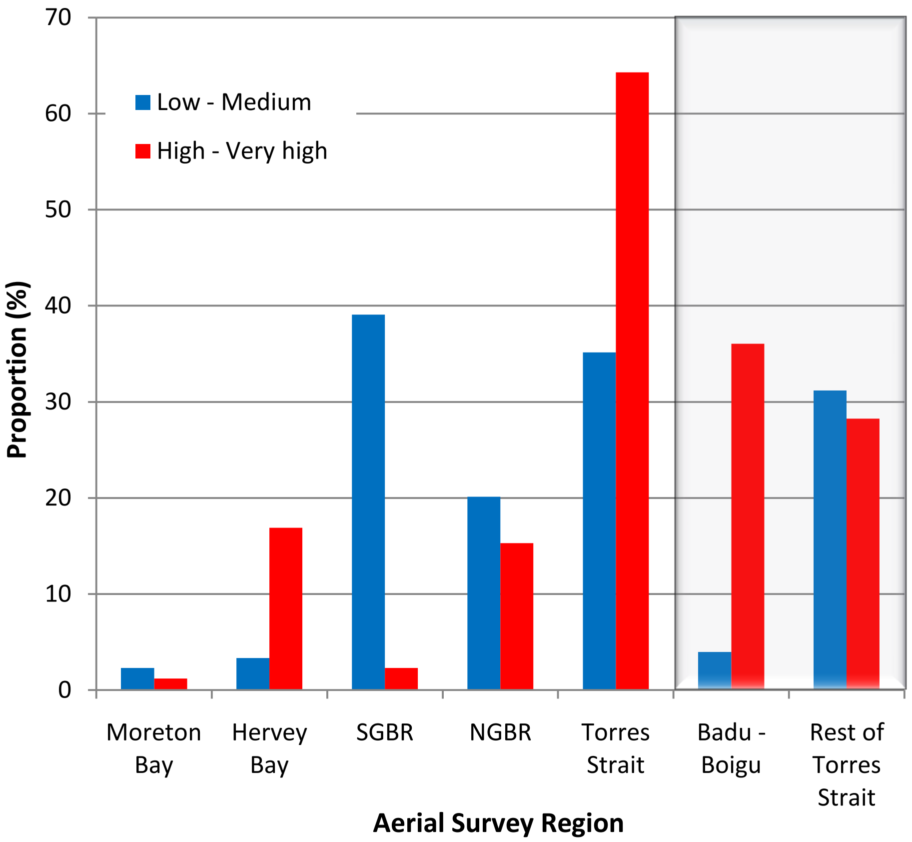

Figure 11. Proportion (%) of the total low - medium and high - very high density dugong planning units within five survey regions across the east coast of Queensland. The Torres Strait component was divided into two regions indicated by the bevelled box: Badu and Boigu Islands (purple box in Figure 10) and rest of Torres Strait.

Discussion

Importance of Torres Strait as dugong habitat

Torres Strait is the most important dugong habitat in Queensland, Australia and probably the world (Marsh *et al.* 2011). The time series of aerial surveys (including this survey) conducted in North-East Australia since the 1980s enable the significance of Torres Strait to be compared quantitatively with other parts of the region including the coastal waters of Queensland and the Northern Territory coast of the Gulf of Carpentaria. Torres Strait contains a remarkable 54% of the high and very high density dugong habitat in this region, 58% of the corresponding habitat in Queensland, dwarfing the Great Barrier Reef region (15%) and Hervey Bay (14%; Table 5). Thus, there is more than three times as much high and very high density dugong habitat in Torres Strait than in the Great Barrier Reef where is it listed as one of that region's World Heritage values. The difference between these regions in estimated dugong population sizes of the Torres Strait and the Northern Great Barrier Reef region is much less e.g. Torres Strait 12,600 in 2011; Northern Great Barrier Reef 8,800 in 2006 (Marsh *et al.* 2007); both figures based on Pollock *et al.* (2006) method. The differences between these results is reflects the differences in the spatial pattern of distribution of dugongs in the two areas and is a reason why the management of dugongs should not be based on spatial data alone but also needs to consider the relationship between anthropogenic mortality and abundance estimates.

Within Torres Strait, the spatial model based on all surveys combined (Figure 8) also indicated that by far the most important dugong area is the ~10,500 km^2 region extending from Badu to Boigu Islands east to Gerber (Gabba) Island and west to the Warul Kawa Island Indigenous Protected Area (Deliverance Island). This region , much of which is in Block 2A (see Figures 2, 4, 5, 6, 7, 8 and 10), contains 56% of the high and very high density dugong habitat in Torres Strait; 30% of the high and very high density dugong habitat in eastern Queensland (Figure 11; Tables 4 and 5); about twice as much as the entire Great Barrier Reef region. The key area is made up of the sandy and coarse sandy algae, seagrass and epibenthos garden habitats of Pitcher *et al.* (2007) and is mainly < 10m deep (Figure 10). Most (89 %) of this habitat is outside the major (*sensu* Grayson 2011) hunting grounds of the communities in the area as defined by Grayson (2011).

The spatial model also indicates that 22% of the area of high and very high dugong density in Torres Strait occurs in the Dugong Sanctuary, illustrating the potentially significant value of the spatial closure of this region if it were enforced (Figures 8 and 9; Table 4). All of this region is outside the major (*sensu* Grayson 2011) hunting grounds of the communities in the area, although some hunting occurs in the eastern parts of the Sanctuary.

Table 5. Total area (km^2) and proportion (%) of dugong planning units of low, medium, high and very high relative densities within the seven survey regions (data from Grech *et al.* 2011 & this report).

	Dugong relative density			
Survey region	**Low**	**Medium**	**High**	**Very high**
Moreton Bay	868 (40)	1,084 (50)	112 (5)	128 (5)
Hervey Bay	492 (8)	2,340 (38.)	1,412 (23)	1,912 (31)
Southern Great Barrier Reef	22,724 (68)	10,496 (31)	316 (1)	140 (0.4)
Northern Great Barrier Reef	3,436 (17)	13,684 (68)	1,540 (8)	1,472 (7)
Torres Strait	*11,612* *(27)*	*18,264* *(43)*	*6,540* *(15)*	*6,116* *(14)*
Gulf of Carpentaria (QLD)	20,528 (60)	11,996 (38)	1,496 (4)	464 (1)
Gulf of Carpentaria (NT)	11,336 (43)	12,920 (49)	1,612 (6)	316 (1)
North-East Australia	**70,996**	**70,784**	**13,028**	**10,548**

Is the Dugong Population of Torres Strait stable?

The variation in the dugong population estimates for the Torres Strait blocks surveyed since 1987 based on the Marsh & Sinclair (1989a) method (approximately 12,000-28,000; Appendix Table 6A) is much larger than for the Northern Great Barrier Reef (8,000-10,000; Marsh *et al.* 2007). This variation has occurred both between surveys and between the methodologies used to generate dugong population estimates for the same survey. Marsh *et al.* (2007) suggested two reasons for this result. Firstly, the proportion of the Torres Strait dugong population surveyed has almost certainly not been constant across surveys prior to 2011 and some of the variation in the dugong population estimates is likely to have resulted from dugong movements between the previous survey region and the unsurveyed region to the west, which this survey demonstrates supports an estimated 10% of the population for the region (much less than the variation between surveys). Secondly, some of the differences between years in Torres Strait, have resulted from noise in the data resulting from uncorrected fluctuations in the availability of dugongs to observers. Hagihara *et al.* (*pers comm.*) have shown that the proportion of time dugongs spend close to the surface and therefore available to observers varies with bathymetry and time of day. Comparison of the frequency distributions of dugong sightings with respect to bathymetry for the 2006 and 2011 dugong surveys of Torres Strait indicate differences between surveys that partially explain the differences between the population estimates (Figure 3). Comparison of the differences between the results of the 2001, 2006 and 2011 surveys for the blocks surveyed on all three occasions using the method of Marsh & Sinclair (1989a) with corresponding values using the method of Pollock *et al.* (2006), provides 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 without further research on availability bias. This research will have to occur external to future surveys.

The time series of aerial surveys of Torres Strait since the mid 1980s for dugongs has not demonstrated a significant decline in dugong density or numbers (Figure 7; Appendix Table 6A), despite long-standing concern about the sustainability of the traditional harvest of dugongs in this region (Hudson 1986; Johannes & McFarlane 1991; Heinsohn *et al.* 2004; Marsh *et al.* 1997, 2004) and the limited management interventions to regulate this harvest to date. We caution against using this result as a reason for reducing the commitment to implementing the Dugong and Marine Turtle Management Plans, because of :(1) the uncertainty of the estimates of the dugong population size and the anthropogenic mortality; (2) the difficulty of detecting trends in the abundance of marine mammals (Taylor *et al.* 2007); (3) the uncertainty surrounding the impact of climate change on the frequency of seagrass diebacks in Torres Strait; (4) the evidence that the life history and reproductive rate of female dugongs are adversely affected by seagrass loss (Marsh & Kwan 2008); (5) 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; and (6) the escalating political and public concerns about dugong hunting e.g. http://dugongandturtles.webs.com/apps/blog/show/8110766-australians-for-animals-help-us-.

Even though the aerial surveys have not detected a decline in dugong numbers in Torres Strait (Table 2; Figure 7A; Appendix Table 6), two modelling approaches (Heinsohn *et al.* 2004, Marsh *et al.* 2004) suggested that the dugong harvest in the 1990s was too high to be sustainable. Nonetheless, this modelling does 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 the availability bias is underestimated and the proportion of time dugongs spend close to the surface and therefore available to observers varies with bathymetry and time of day as discussed above. This explanation is almost certainly true.
2. The dugong catches recorded by Kwan *et al.* (2006) were exceptionally high. Nonetheless even if true, this situation, is unlikely to be the cause of the failure to detect a decline because Kwan's data are from only one of the major hunting communities. Reliable harvest estimates of current harvest are not yet available and need to be obtained with high priority from all the major hunting communities as part of the community ranger program.
3. Dugongs are breeding faster than the Potential Biological Removal (PBR) model assumes. For example if dugong are producing maximally r=0.05 p.a., the sustainable harvest would be some 275 dugongs per annum for Torres Strait for a Recovery Factor of 1 (still much lower than the likely harvest level). Kwan & Marsh (2008) report that the dugongs 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 & Kwan (2008).

Irrespective of whether the current anthropogenic impacts on the dugong population of Torres Strait are sustainable, the dugong population size in the region is substantial (>12,000 individuals) and is genetically healthy exhibiting high haplotypic diversity (Blair *et al. pers comm*). We believe there is time to work with local Traditional Owners 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 'the marine environment' of the region.

Long-term Risks

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 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 Torres Strait. Significant numbers of dugongs occur in areas where netting and Indigenous hunting do not occur. Much of the Torres Strait dugong habitat is remote and there is little hunting in the Dugong Sanctuary or in the key area extending between Badu to Boigu Islands (Figure 10). 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 & Kwan 2008) which should not be ignored, reinforcing the case for spatial closures to hunting to pre-empt future expansion in the area hunted.

Management Options

We consider that the major priority for dugong management in Torres Strait should be the continued support of the culturally acceptable and scientifically robust mechanisms to manage Indigenous hunting. 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. Project officers employed by the Torres Strait Regional Authority (TSRA) have worked with 15 Indigenous communities to develop community-based Dugong and Marine Turtle Management Plans with funding from the Australian Government. These plans are now being implemented with substantial funding from the Australian Government via TSRA totalling some A$20 million to 2013 to support a community-based ranger program. This implementation needs to be supported with high priority. Reliable harvest estimates of current harvest need to be obtained from all the major hunting communities as part of this program. Grayson (2011) offers important insights into how catch monitoring might be effectively implemented.

If the communities also wish to consider spatial closures as a management tool, the data presented here can be used by Traditional Owners to inform their design as recommended below. We suggest that the TSRA give high priority to discussions with the Prescribed Bodies Corporate of the Top Western and Near Western Islands and the Protected Zone Joint Authority about the desirability of: (1) declaring some or all of the high density dugong area extending from Badu to Boigu Islands, east to Gerber (Gabba) Island and west to the Warul Kawa Island Indigenous Protected Area (Deliverance Island) as a no-hunting area for an agreed period; and (2) how the Dugong Sanctuary might be enforced as recommended below. The case for closing these areas to Traditional hunting would be enhanced if the data on the distribution and abundance of large sea turtles collected during the dugong surveys were analysed as these areas also support relatively high densities of large turtles (unpublished data).

Recent research using mitochondrial DNA (which is maternally inherited) demonstrates some regional differentiation of dugong populations (Blair *et al. pers comm.*). 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. 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. pers comm.*; 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 jurisdictional arrangements operating in the two areas, we suggest that priority be given to the policy for managing dugong hunting by the Northern Peninsula Area (NPA) communities and coordinating management across the Inner Islands and NPA regions. The ongoing 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 should also be given high priority. 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). We understand that the UNEP/CMS Dugong Secretariat is working to develop an initiative in this area using economic incentives to persuade community members to reduce the number of dugongs killed (D.Kwan *pers comm.*)

We suggest that TSRA facilitate talks between the Torres Strait Traditional Owners, the Papua New Guinea villagers and the peoples of the Northern Peninsula Area 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, including the harvest of the Papua New Guinean villagers and the peoples of the Northern Peninsula Area. The social and cultural objectives of management in all these jurisdictions also need to be negotiated at regional as well as local scales.

Recommendations

Management

(1) That the major priority for dugong management in Torres Strait be continued support for the implementation of the community-based Dugong and Marine Turtle Management Plans.

(2) That the Torres Strait Regional Authority (TSRA) give high priority to facilitating complementary management between Torres Strait Traditional Owners, PNG villagers and the peoples of the Northern Peninsula Area (Cape York Land Council and the Great Barrier Reef Maine Park Authority). In particular, it will be important to decide whether the regional objective for dugong management in Torres Strait is to maintain the population at its present level or to facilitate its increase. Clarification of this objective is a fundamental pre-requisite to setting a total allowable catch for the Torres Strait dugong fishery.

(3) That the community ranger program give high priority to obtaining robust estimates of the current dugong harvest from all the major hunting communities.

(4) That the TSRA Land and Sea Management Group give high priority to discussions with the Prescribed Bodies Corporate of the Top Western and Near Western Islands and the Protected Zone Joint Authority about the desirability of the following suggestions:

  d. declaring some or all of the high density dugong area extending from Badu to Boigu Islands, east to Gerber (Gabba) Island and west to the Warul Kawa Island Indigenous Protected Area (Deliverance Island) as a no-hunting area for an agreed period;

  e. negotiating with the Australian government for consequential payments for eco-system services in order to secure some long-term funding for community based natural resource management in Torres Strait[3].

  f. asking the Australian government for assistance to enforce the Dugong Sanctuary, perhaps using money raised from private enterprise e.g. through Indigenous Impact Bonds[4].

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[3] Cape York Land Council is considering declaring no-hunting areas off Cape York and asking the Australian Government for consequential funding for ecosystem services (Noel Pearson *pers comm*.). this approach is potentially compatible with the 'Biodiversity Banking Scheme' announced by the Australian Government in August 2011 http://www.environment.gov.au/epbc/publications/pubs/epbc-reform-overview.pdf.

[4] As proposed by Patrick Dobson and Ian Gill http://www.smh.com.au/opinion/politics/a-bran-nue-way-ahead-20110816-1iw7j.html#ixzz1VXzvoJlM

Research and Monitoring

(1) That the dugong aerial surveys be continued at regular (typically 5-year) intervals for the combined region of the northern GBR and Torres Strait with the next survey occurring in November 2013 to enable a seasonal comparison of the dugong's use of the Dugong Sanctuary;
(2) That the correction for availability bias in the Pollock *et al.*(2006) method be improved using the data on dugong diving behaviour;
(3) That the data on turtle distribution in Torres Strait collected during the times series of aerial surveys be analysed with a view to developing a predictive and spatial model that parallels that for dugongs to inform spatial planning in Torres Strait;
(4) That when the technology is available, consideration be given to the feasibility of using Unmanned Aerial Vehicles rather than manned aircraft to conduct the surveys for reasons of human safety and logistics.

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Appendix Tables

Appendix Table 1. Areas of survey blocks and sampling intensity for each block for the aerial surveys conducted in 2006 and 2011. The survey design used in 2011 slightly changed from that used in 2006. The sampling intensity was increased for Block 1A , the transects were truncated 5 nm from Papua New Guinea coast in Blocks 6, 0, 1A and 1B and the area in western Torres Strait (Blocks 6-9) was flown for the first time in 2011 survey.

	2006		2011	
Block	**Area (km²)**	**Sample Intensity (%)**	**Area (km²)**	**Sample Intensity (%)**
0	2339	5.6	1735	4.9
1A	2452	4.5	2207	7.4
1B	3848	4.6	3169	4.4
2A	4420	8.4	4331	8.2
2B	3363	8.6	3317	8.6
3	9666	4.3	9670	4.2
4	3436	4.7	3651	4.3
5	1022	10.9	1015	10.3
6			1638	4.0
7			3795	3.5
8			4688	4.6
9			2421	4.7

Appendix Table 2. Weather conditions encountered during the 2011 surveys in comparison with the prior surveys in Torres Strait and based on historical data. The data for Beaufort Sea State and Glare are means of the modes (range) based the data in Appendix Table 3 and previous reports as summarised in Marsh *et al.* (2007).

	1987	1991	1996	2001	2005	2006	2011
Wind speed (km.h-1)	<15	<15	<10	<15	<10	<15	0-11
Cloud cover (octas)	1-8	0-5	0-7	0-7	0-3	1-6	2-8
Minimum cloud height	270-4000	460-750	1000-5000	2000-5000	2500-4000	1000-2000	1200-3000
Beaufort Sea State	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)	1.3 (0-3.5)
Glare							
North/East	1.4 (0-3)	1.7 (0-3)		0.9 (0-3)	0.79 (0-2)	1.91 (0-3)	2.10 (0-3)
South/West	0.75 (0-3)	2.3 (0-3)		1.3 (0-9)	1.59 (0-3)	1.32 (0-3)	1.69 (0-3)
Visibility (km)	N/A	>20	>10	>20	>10	10-20	10

Appendix Table 3. Beaufort Sea State and Glare for each transect of the 2011 aerial survey for dugongs (refer Figure 2 for positions of transects).

	Beaufort Sea State*			Glare** South/West			Glare** North/East		
Transect	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**
				Block 0					
136	0.5	1	1	2	3		3	3	3
138	0.5	1	0.5	1	2	1	2	3	2
140	0.5	1	1	2	3		2	3	
142	1	1	1	3	3	3	2	3	
144	0	1	1	2	3		2	3	
146	0	2	2	0	3	0	3	3	3
				Block 1A					
101	0	0	0	0	1	1	0	2	
102	0	0	0	0	0	0	1	2	2
103	0	0	0	0	0	0	0	2	0
104	0	0	0	0	1	0	1	3	3
105	0	0	0	0	0	0	1	3	2
106	0	0	0	0	0	0	1	3	2
107	0	0	0	0	1	0	1	3	2
108	0	0	0	0	0	0	0	1	
109	0	0	0	0	0	0	0	0	0
110	0	0	0	2	2	2	0	0	0
				Block 1B					
111	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	1	1	1
114	0	0	0	1	1	1	0	0	0
116	0	0	0	0	0	0	1	3	
118	0	0	0	0	0	0	3	3	3
120	0	0	0	0	0	0	2	3	
122	0	0	0	0	0	0	1	3	3
124	1.5	1.5	1.5	1	3		1	3	3
126	0.5	1	1	1	2	1	2	3	3
128	0.5	1	1	0	2		3	3	
130	0.5	1	1	1	3		0	1	1
132	0.5	1	1	1	3		3	3	3
134	0.5	1	0.5	1	3		1	3	
				Block 2A					
201	2	2.5	2	2	2	2	2	2	2
202	2	2	2	2	2	2	2	2	2
203	1.5	2.5	2	1	2		2	2	2
204	1	1.5		2	2	2	1	2	1
205	1	2	1.5	1	2	2	2	3	2
206	1	2.5	1	1	2	2	0	1	1
207	1	2	2	2	3	3	2	3	3
208	1	2.5		1	2		3	3	3

Transect	Beaufort Sea State*			Glare** South/West			Glare** North/East		
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
Block 2A									
209	1	3.5	1	1	3	2	2	3	3
210	1	2.5	2	0	3	2	0	3	2
211	1	2	1	1	3	3	3	3	3
212	0.5	1	1	1	2	1	3	3	3
213	1	1.5	1	1	3	2	2	3	
3051	1	1	1	3	3	3	3	3	3
3061	0.5	1	1	1	3	3	2	3	2
Block 2B									
214	0	2	2	0	2	2	0	2	2
215	0	2	2	0	2	1	0	2	1
216	0	2	1.5	1	3	2	1	3	2
217	0	2.5		0	2		0	2	
218	0.5	2.5	2	1	3	3	1	3	3
219	0	1	1	1	2	1	0	1	1
220	0.5	1	0.5	1	1	1	0	1	1
221	0.5	1	1	1	1	1	1	2	2
222	0.5	1	1	0	2	2	1	2	
223	1	2	1.5	0	2	2	1	2	2
224	0	2.5	1.5	1	2	2	0	2	2
2121	0	0	0	1	1	1	1	1	1
Block 3									
301	1	2		1	2	2	1	2	2
302	0.5	1.5	1	1	1	1	1	2	2
303	1	2	2	1	2	2	1	2	2
304	1	2	2	2	2	2	2	2	2
305	0	2	2	1	2		1	2	1
306	0.5	2.5	2	2	3		2	3	
307	0.5	2.5	2.5	1	3	1	1	3	1
308	2	2.5	2	2	3	3	2	3	
309	1	2.5	2.5	1	3		1	3	
310	1.5	2.5	2	2	3	3	2	3	3
311	2	2	2	3	3	3	2	3	3
312	1.5	2.5	2	1	3		2	3	3
313	2	2.5	2.5	3	3	3	3	3	3
314	2	3	2.5	2	3	2	1	3	3
315	2	2.5	2.5	1	3	3	3	3	3
316	1	2.5	2	2	3		2	2	
Block 4									
401	0.5	2	1	1	2	2	2	3	3
402	0.5	2	1	1	3		1	3	
403	2	2	2	2	3	3	3	3	3
404	1	2.5	1	1	3	3	2	3	3
405	0	2.5	1	1	3	1	1	3	1

	Beaufort Sea State*			Glare** South/West			Glare** North/East		
Transect	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**
Block 4									
406	1	2.5	1	2	2	2	2	3	2
407	1.5	2.5	2	2	3		2	3	3
Block 5									
408	0	0	0	0	0	0	0	0	0
409	0	0	0	0	0	0	0	0	0
410	0	0	0	0	0	0	2	2	2
411	0	0	0	0	0	0	0	0	0
412	0	0	0	0	0	0	0	0	0
501	0	0	0	0	0	0	0	0	0
502	0	0	0	0	0	0	0	0	0
503	0	0	0	0	0	0	0	1	0
504	0	0	0	0	0	0	0	0	0
505	0	0	0	0	0	0	0	0	0
506	0	0	0	0	0	0	0	0	0
Block 6									
623	1	1	1	3	3	3	3	3	3
624	1	1	1	3	3	3	3	3	3
625	0	1	1	3	3	3	3	3	3
626	0	1	0	0	3		1	3	
627	0	1	1	0	3	3	3	3	3
Block 7									
616	1.5	3.5	2	2	3		3	3	3
617	2	3	2.5	2	3	2	2	3	3
618	2	3		2	3	3	2	3	
619	2	3	2.5	2	3	2	2	3	2
620	2	2.5	2.5	3	3	3	2	3	
621	2	2.5		2	2	2	1	2	2
622	1.5	2.5	2	1	3	3	2	3	2
Block 8									
607	2	2.5	2	2	2	2	3	3	3
608	2	2	2	3	3	3	3	3	3
609	2	2	2	2	2	2	3	3	3
610	2	2	2	3	3	3	3	3	3
611	2	2	2	2	3	2	3	3	3
612	2	2	2	3	3	3	3	3	3
613	2	2.5	2	1	2		2	2	2
614	2	2.5	2	2	3		2	3	3
615	2	2	2	3	3	3	3	3	3
Block 9									
601	2	2.5		1	2		1	2	2
602	0.5	2.5	2.5	0	2	2	0	1	1
603	0.5	2.5	2	1	2	1	2	3	2
604	2	2.5	2	2	3	2	3	3	3

	Beaufort Sea State*			Glare** South/West			Glare** North/East		
Transect	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**	**Min**	**Max**	**Mode**
				Block 9					
605	1	2.5	2.5	1	3		1	2	2
606	2	2.5	2.5	2	3	3	2	2	2

*Beaufort Sea State: 0 = <1 knot; 1 = 1-3 knots; 2 = 4-6 knots; 3 = 7-10 knots.

*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 2011. The raw data were used to estimate dugong population size (refer Figure 2 for positions of transects).

Transect	Adjusted transect height	Transect length	Transect area (km^2)	# groups port	# groups starboard
			Block 0		
136	500	31.6	12.6	1	2
138	500	31.3	12.5	2	2
140	502	31.3	12.6	1	0
142	502	28.8	11.6	2	1
144	488	30.5	11.9	0	0
146	501	58.3	23.4	0	0
			Block 1A		
101	500	52.2	20.9	0	0
102	500	51.6	20.6	0	0
103	500	46.2	18.5	1	1
104	500	50.5	20.2	1	1
105	500	49.2	19.7	3	0
106	500	47.5	19.0	1	1
107	500	46.4	18.6	0	0
108	500	42.1	16.8	2	1
109	500	39.8	15.9	0	0
110	495	35.7	14.1	0	0
			Block 1B		
111	500	34.2	13.7	0	0
112	496	29.4	11.7	0	1
114	500	17.4	7.0	0	0
116	498	14.2	5.7	0	1
118	503	13.5	5.4	0	0
120	492	20.0	7.9	0	0
122	500	27.3	10.9	0	0
124	503	31.6	12.7	0	0
126	498	31.8	12.7	0	0
128	510	28.8	11.8	1	3
130	497	34.2	13.6	0	2
132	495	34.0	13.5	3	5
134	504	32.5	13.1	0	0
			Block 2A		
201	502	66.6	26.7	13	13
202	493	67.0	26.4	1	8
203	508	66.8	27.1	14	13
204	504	67.4	27.2	7	10
205	499	67.0	26.8	7	10
206	500	68.1	27.3	3	10
207	506	65.3	26.4	0	2

Transect	Adjusted transect height	Transect length	Transect area (km2)	# groups port	# groups starboard
			Block 2A		
208	503	66.6	26.8	3	7
209	505	66.7	26.9	3	4
210	505	66.8	27.0	1	3
211	502	67.5	27.1	2	1
212	506	67.2	27.2	0	0
213	509	46.5	19.0	1	1
3051	500	10.5	4.2	1	2
3061	507	18.7	7.6	0	0
			Block 2B		
2131	509	26.1	10.6	0	0
214	503	59.6	24.0	0	3
215	497	59.1	23.5	1	2
216	501	64.6	25.9	2	3
217	500	58.4	23.4	1	0
218	505	57.6	23.3	0	0
219	504	58.2	23.5	2	2
220	504	58.4	23.6	1	2
221	511	57.7	23.6	0	2
222	503	58.0	23.3	0	3
223	503	60.4	24.3	0	1
224	533	57.9	24.7	1	1
			Block 3		
301	496	45.7	18.1	0	0
302	497	63.1	25.1	4	1
303	506	63.1	25.6	1	3
304	497	67.7	26.9	0	0
305	493	79.5	31.3	3	0
306	489	54.9	21.5	4	3
307	503	82.2	33.1	1	3
308	501	59.6	23.9	0	1
309	501	58.8	23.6	0	0
310	507	59.7	24.2	0	1
311	503	59.7	24.0	0	0
312	501	67.9	27.2	0	0
313	498	57.4	22.8	0	0
314	504	61.1	24.6	0	0
315	500	65.2	26.1	0	0
316	499	65.3	26.1	1	2
			Block 4		
401	512	66.5	27.2	0	0
402	506	56.8	23.0	0	0
403	504	58.6	23.6	1	2

Transect	Adjusted transect height	Transect length	Transect area (km2)	# groups port	# groups starboard
			Block 4		
404	506	57.8	23.4	0	1
405	498	59.9	23.9	0	2
406	502	43.8	17.6	0	0
407	500	41.8	16.7	0	0
			Block 5		
408	497	25.6	10.2	0	0
409	500	25.4	10.2	0	0
410	500	23.2	9.3	0	1
411	500	21.0	8.4	0	0
412	500	17.6	7.1	0	0
501	500	25.5	10.2	0	1
502	500	22.0	8.8	0	0
503	498	23.2	9.2	0	0
504	498	26.8	10.7	0	0
505	502	27.4	11.0	0	0
506	500	26.9	10.8	0	0
			Block 6		
623	500	36.8	14.7	0	0
624	500	29.1	11.7	0	0
625	500	29.3	11.7	0	0
626	500	35.3	14.1	0	0
627	499	35.1	14.0	0	0
			Block 7		
616	510	52.3	21.3	0	0
617	508	53.4	21.7	0	0
618	507	39.6	16.1	0	0
619	505	40.2	16.3	0	0
620	500	43.9	17.5	0	0
621	509	40.1	16.3	0	0
622	504	60.3	24.3	0	0
			Block 8		
607	492	56.3	22.2	1	0
608	503	54.6	21.9	0	0
609	496	61.1	24.2	1	1
610	502	59.8	24.0	1	0
611	498	61.1	24.4	1	2
612	500	61.3	24.5	1	2
613	500	62.2	24.9	0	1
614	501	63.0	25.3	0	0
615	496	61.3	24.3	0	1
			Block 9		
601	496	43.7	17.3	0	1

Transect	Adjusted transect height	Transect length	Transect area (km2)	# groups port	# groups starboard
			Block 9		
602	500	46.0	18.4	0	0
603	500	45.3	18.1	2	2
604	498	46.9	18.7	0	1
605	500	52.8	21.1	0	0
606	500	52.6	21.0	0	0

Appendix Table 5. Details of group size estimates and correction factors used in the population estimates for dugongs based on the data collected during the 2011 survey in Torres Strait. The estimate for Availability Bias was used for the Marsh & Sinclair (1989a) method only.

Block	Group size (C.V)	Perception correction factor (C.V)[1]		Availability correction factor (C.V)
		Port	Starboard	
0	1.091 (0.083)	1.070 (0.017)	1.158 (0.024)	2.485 (0.119)
1A	1.417 (0.105)			
1B	1.706 (0.140)			
2A	1.379 (0.045)			
2B	1.704 (0.098)			
3	1.321 (0.096)			
4	1 (0)			
5	1 (0)			
8	1.250 (0.104)			
9	1.667 (0.253)			

[1] There were two changes in the membership of the survey teams during the survey. The same correction factor was used for the entire survey because the number of observations from the changed teams was a very low percentage of the total.

Appendix Table 6. Estimates of dugong population abundance for each block from surveys conducted between 1989 and 2011. Table 6a uses the method of Marsh & Sinclair (1989a); Table 6B the method of Pollock *et al.* (2006) . The estimates were calculated for blocks with >5 sightings; sightings from Block 4 and 5 were therefore combined in 2011 to estimate dugong abundance.

6a. Estimates using method of Marsh & Sinclair (1989a)

	1987		1991		1996		2001		2006		2011	
Block	**Nhat**	**se**	**Nhat**	**Se**	**Nhat**	**se**	**Nhat**	**se**	**Nhat**	**se**	**Nhat**	**se**
0			696	238	1152	381	0	0			679	345
1A	1131	278	1669	999	2427	663	685	317	1280	561	521	150
1B			3705	1529	1681	615	2678	1695	1323	358	1850	857
2A	6424	1679	9113	1798	10869	1600	3504	403	5675	819	6620	1419
2B	2019	573	1467	399	1905	370	583	166	972	268	1512	269
3	2822	1102	6740	1958	8623	2411	5473	1327	6556	1586	2451	777
4	848	347	518	197	984	313	1183	655	3781	1850	402	108
5	76	55	320	277	240	70	0*	0*	0*	0*		
6											0*	0*
7											0*	0*
8											909	242
9											592	180
Total (8 blocks)	**13319**	**2136**	**24225**	**3276**	**27881**	**3095**	**14106**	**2314**	**19587**	**2669**	**14035**	**1891**
Total (12 blocks)											**15536**	**1915**

*No dugongs seen

6b. Estimates using method of Pollock *et al.* (2006)

	2001		2006		2011	
Block	**Nhat**	**se**	**Nhat**	**se**	**Nhat**	**se**
0	0	0			578	404
1A	612	258	858	516	467	206
1B	2607	1022	1005	435	1573	775
2A	3454	782	4362	919	5214	1514
2B	451	274	736	318	1117	359
3	5565	1585	5166	1418	2083	862
4	776	565	2640	1356	297	222
5	0*	0*	0*	0*		
6					0*	0*
7					0*	0*
8					778	386
9					497	396
Total (8 blocks)	**13465**	**2152**	**14767**	**2292**	**11328**	**2005**
Total (12 blocks)					**12603**	**2080**

*No dugongs seen

Appendix Figures.

Appendix Figure 1: Temporal changes (1987-2011) in the estimated dugong population size (± standard error) for Block 0, 1A, 1B, 2A, 2B, 3, 4 and 5. In the 2011 survey, Block 4 and 5 had < 5 dugong sightings and dugong abundance was estimated for the two blocks combined. Black circles and lines represent numbers estimated using the technique of Marsh & Sinclair (1989a); the grey circles and lines are the numbers calculated using Pollock *et al.* (2006). Block 6-9 were flown in 2011 only and so the results are not presented here.