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Technical Report

An assessment of the distribution and abundance of dugongs in the Northern Great Barrier Reef and Torres Strait

Susan Sobtzick, Helen Penrose, Rie Hagihara, Alana Grech, Chris Cleguer and Helene Marsh

Australian Government
Department of the Environment

TropWATER
Centre for Tropical Water and Aquatic Ecosystem Research

JAMES COOK UNIVERSITY AUSTRALIA

Reef & Rainforest RESEARCH CENTRE

An assessment of the distribution and abundance of dugongs in the Northern Great Barrier Reef and Torres Strait

Project 1.2 Marine wildlife management in the Great Barrier Reef World Heritage Area
Project 2.1 Marine turtles and dugongs of Torres Strait

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Cover photographs: Susan Sobtzick and Kelly Cates

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Acronyms Used In This Report

AFMA............ Australian Fisheries Management Authority
CSIRO............ Commonwealth Scientific and Industrial Research Organisation
EPBC Act....... Environment Protection and Biodiversity Conservation Act
GBR............... Great Barrier Reef
GBRMPA....... Great Barrier Reef Marine Park Authority
GBRWHA ...... Great Barrier Reef World Heritage Area
GPS .... Global Positioning System
ILUA.............. Indigenous Land Use Agreement
IUCN.............. International Union for Conservation of Nature
IUU................ illegal, unreported and unregulated
JCU................ James Cook University
MCMC........... Monte Carlo Markov Chains
MPA.............. Marine Protected Area
NPA............... Northern Peninsula Area
PZJA .... Protected Zone Joint Authority
TDR............... time-depth recorder
TSRA .... Torres Strait Regional Authority
TUMRA .... Traditional Resource Use Management Agreements

Abbreviations Used In This Report

C.V. .... Coefficient of variation
DF .... Degrees of freedom
km................. kilometer
m................... meter
s.e. .... Standard Error

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Executive Summary

Background

- Globally significant populations of dugongs (*Dugong dugon*), a species listed as vulnerable to extinction by the IUCN, occur in Australia, in particular the Northern Great Barrier Reef and Torres Strait.
- Australia has international obligations to conserve the dugongs in its waters and the significance of the Great Barrier Reef to the dugong was explicitly mentioned in the nomination of the Great Barrier Reef as a World Heritage site.
- Information on the status and trends in the distribution and abundance of dugongs is critical for the management of both Torres Strait and the Great Barrier Reef World Heritage Area.

Project Aims

- The aim of this project was to provide information required to manage dugongs in the Northern Great Barrier Reef and Torres Strait by continuing the time series of standardised aerial surveys conducted since that late 1980s. The objective of these surveys has been to provide an assessment of the distribution and abundance of the dugong in these areas and a time series for temporal comparisons.

Methods

- Historical surveys of the Northern Great Barrier Reef were conducted in 1985, 1990, 1995, 2000 and 2006; in Torres Strait (in whole or in part) in 1987, 1991, 1994, 1996, 2001, 2005 2006, and 2011. The aerial survey technique for earlier surveys followed Marsh and Sinclair (1989a) and since 2000 was improved by the methodology developed by Pollock *et al.* (2006) to account for the spatial heterogeneity in availability bias.
- This project addressed the confounding effect of dugongs moving between areas between surveys by surveying the entire area from Cooktown through Torres Strait in November 2013, only the second time such as combined survey was undertaken (the first was in 2006).

Key findings

- The 2013 aerial surveys confirm that the Northern Great Barrier Reef and Torres Strait areas support globally significant populations of dugongs. The standardised relative population estimate for the Torres Strait was almost 16,000 animals (± s.e.~3,000); that for the Northern Great Barrier Reef ~6,500 ± s.e.~1,100) using the Pollock *et al.* (2006) methodology.
- The population estimate for Torres Strait was the highest in the time series since the Pollock *et al.* (2006) methodology was first used in 2001, while the corresponding estimate for the Northern Great Barrier Reef was the lowest since 2000.
- The surveys suggest that the proportion of calves in Torres Strait (17.9% in 2013) has been increasing since 2000 while that in the Northern Great Barrier Reef (6% in 2013) has been decreasing.
- The time series of aerial surveys also indicates that there are very large areas of very high and high relative dugong density in both the Northern Great Barrier Reef (~11,000 km^2) and Torres Strait (~20,000 km^2) survey areas.
- In the Northern Great Barrier Reef no significant differences have been detected in dugong density since the time series of surveys began in 1987. In Torres Strait there were some significant differences in dugong density between surveys prior to 2001 but none since then. However, these results should be interpreted with caution because of the difficulty in detecting significant trends in marine mammal populations unless these trends are large.
- The apparent temporal variability in the size and/or distribution of the dugong population of large survey areas such as the Northern Great Barrier Reef or Torres Strait is likely to be the cumulative effect of several confounded factors: (1) temporal and spatial changes in the distribution of the dugong's seagrass food; (2) dugong movements between survey areas; (3) uncorrected fluctuations in the availability of dugongs to observers because of: (a) temporal and

spatial variability in sighting conditions and (b) changes in the water depth in which dugongs are sighted because of their movements between and within survey blocks; and (4) temporal changes in the size of the population.

Management recommendations

(1) That the major priority for dugong management in Torres Strait and the Northern Great Barrier Reef be on-going support for the implementation of community-based management by Traditional Owners.

(2) That the agencies responsible for dugong management in both areas give high priority to: (1) exploring the acceptability of the use of spatial closures to hunting as a management tool with the Traditional Owners; (2) minimising the hazard posed to dugongs and their habitats by the expansion of ports and shipping, and (3) facilitating complementary dugong management across and within justifications, especially in the Northern Peninsula Area.

(3) That the Torres Strait Regional Authority (TSRA) give high priority to: (1) implementing a program to record robust estimates of the current dugong and turtle harvest from all the major hunting communities in Torres Strait, (2) sharing learnings from the catch monitoring process with the agencies responsible for managing the dugong harvest in the Great Barrier Reef World Heritage Area; and (3) continuing negotiations with Papua New Guinea through the Protected Zone Joint Authority (PZJA) about extending spatial closures in Torres Strait.

Research and monitoring recommendations

(1) That the dugong aerial surveys be continued at regular (typically 5-year) intervals for the combined area of the Northern Great Barrier Reef and Torres Strait with the next survey occurring in November 2018.

(2) That geo-referenced data on dugong diving behaviour in Torres Strait and the Northern Great Barrier Reef be obtained with high priority to improve the corrections for availability bias in the Pollock *et al.* (2006) method.

(3) That when the technology matures (see Hodgson *et al.* 2013), consideration be given to the feasibility of using Unmanned Aerial Vehicles for dugong aerial surveys in the Northern Great Barrier Reef and Torres Strait to reduce the risks associated with using manned low flying aircraft in remote areas as was done in these surveys.

(4) That a long-term comprehensive seagrass monitoring program be established for the northern Great Barrier Reef and Torres Strait with particularly emphasis on the seagrass habitats that support significant densities of dugongs.

1 Introduction

As the only surviving member of the family Dugongidae (Marsh *et al.* 2011a), the dugong is a species of high biodiversity value. The dugong is listed as vulnerable to extinction by the International Union for Conservation of Nature (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; 2011a). Significant populations persist in Australian waters, which are now believed to support most of the world's dugongs. Dugongs are listed in Appendix 1 of the Convention of Migratory Species. As a signatory to that Convention and the associated Dugong Memorandum of Understanding, Australia has international obligations to conserve the dugongs in its waters and the species is listed as a Matter of National Environmental Significance under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

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.* 2011a). Indeed, the significance of the Great Barrier Reef to the dugong was explicitly mentioned in the nomination of the Great Barrier Reef as a World Heritage site (GBRMPA 1991).

The dugong population in both the Northern Great Barrier Reef and Torres Strait supports an important traditional harvest undertaken by Indigenous peoples for cultural and dietary reasons, meat and oil. In Torres Strait 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 (which includes the Northern Peninsula Area (NPA), which is part of the Northern Great Barrier Reef World Heritage Area); (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 totemic significance. The issue is also a priority for the local peoples for whom it is has been a concern for many years (see Johannes and MacFarlane 1991), managers in relevant government environment agencies, particularly the Torres Strait Management Agency (TSRA), Australian Fisheries Management Authority (AFMA) and some scientists (Hudson 1986; Johannes and MacFarlane 1991; Marsh 1996; Marsh *et al.* 1997; Marsh *et al.* 2011a). Consequently, the Australian government 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 through various initiatives.

In contrast to the situation in Torres Strait where the dugong is managed as the target species of a traditional fishery, the Great Barrier Reef dugong stock, which is also subject to a range of anthropogenic mortality factors including a 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 Marine Protected Areas (MPAs). Consequently, the Great Barrier Reef Marine Park Authority (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 and Sinclair (1989a) have provided much of the information used to manage dugongs in Australia. The objective of these surveys has been to provide an assessment of the distribution and abundance of the dugong in these areas and a time series for temporal comparisons. The Northern Great Barrier Reef was surveyed in 1985, 1990, 1995, 2000 and 2006; Torres Strait (in whole or in part) in 1987, 1991, 1994, 1996, 2001, 2005, 2006, and 2011. The survey technique was improved by Pollock *et al.* (2006) to account for the spatial heterogeneity in availability bias and the extra data required for the new techniques have been collected only since 2000.

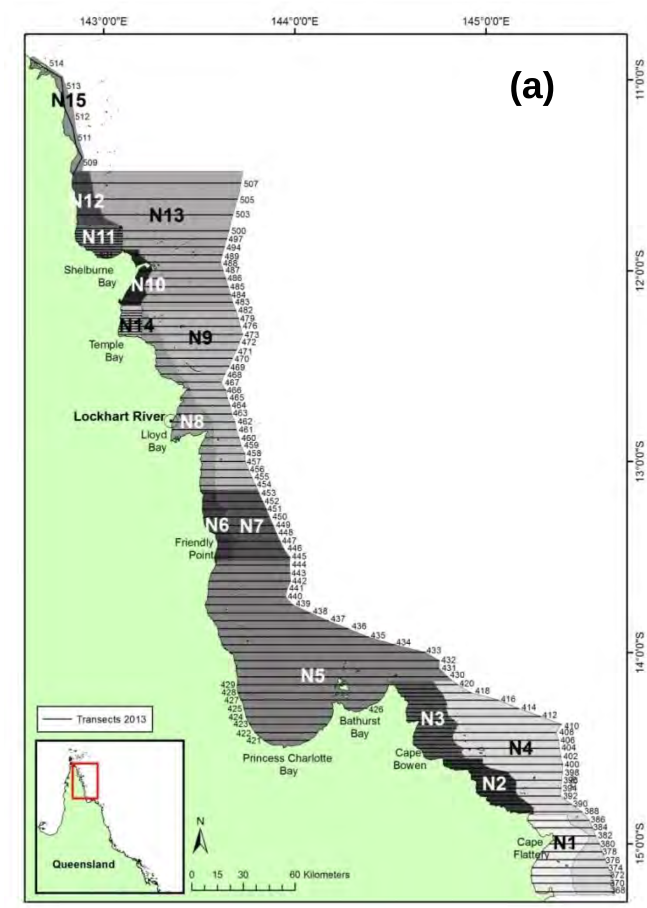
The results of these surveys suggest considerable temporal variability in the size and/or distribution of the dugong population of most survey areas, even though these areas have been very large (typically >30,000 km^2). This apparent variability is likely to be the cumulative effect of several confounded factors: (1) temporal and spatial changes in the distribution of the dugong's seagrass food; (2) dugong movements between survey areas, an effect that has likely been 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: (a) temporal and spatial variability in sighting conditions and (b) changes in the water depth in which dugongs are sighted because of their movements between and within survey blocks (Hagihara *et al.* 2014); and (4) temporal changes in the size of the population.

In this report, we addressed the confounding effect of dugongs moving between areas between surveys by surveying the entire area from Cooktown through Torres Strait in November 2013, only the second time we have been able to undertake such as combined survey (the first was in 2006). We also addressed the problem of temporal and spatial variability in the availability of dugongs to observers due to changes in water turbidity by using the improved methodology developed by Pollock *et al.* (2006). The results of the 2013 survey form the basis of this report on the status and trends of the dugong in the Northern Great Barrier Reef and Torres Strait. The focus of this report is to provide data on dugong sightings and hence population estimates, although summaries on sightings of marine megafauna other than dugongs are included.

2 Methods

2.1 Survey design

The design for the aerial survey conducted in 2013 was based on that used in previous aerial surveys in the survey area lead by researchers at James Cook University. Details of surveys in the Northern Great Barrier Reef and Torres Strait conducted prior to 2013 are provided in Table 1. Figures 1a and 1b show locations of the blocks and orientation and spacing of transects flown in November 2013 in the two survey areas. Four transects in the Northern Great Barrier Reef with previously recorded low dugong density (transects 502, 504, 506, and 508 in Block N13) were not surveyed in 2013 for logistical reasons.



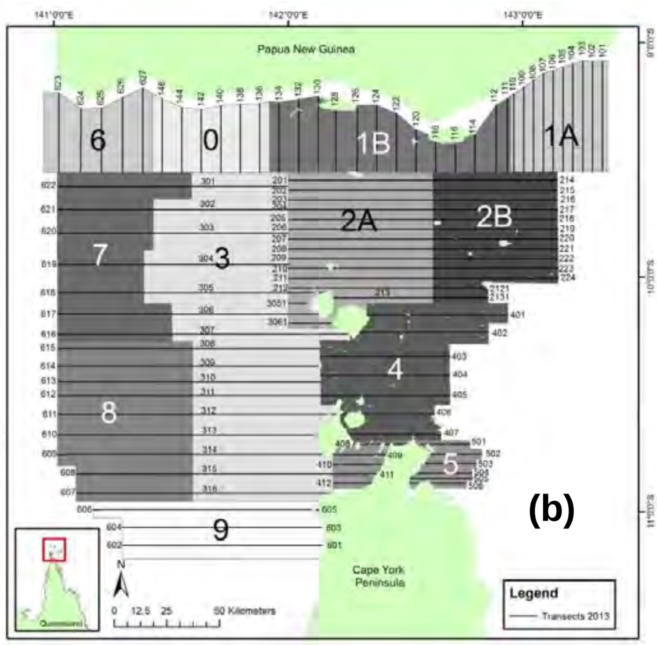


Figure 1. (a) Northern Great Barrier Reef and **(b) Torres Strait** showing blocks and transects flown in the 2013 survev.

Table 1: Details of aerial surveys in the Northern Great Barrier Reef and Torres Strait conducted prior to 2013.

Date of survey	Reference	Date of survey	Reference
Northern Great Barrier Reef		**Torres Strait**	
November 1985	Marsh and Saalfeld, 1989	November 1987	Marsh *et al.*, 1997
November 1990	Marsh and Corkeron, 1996	November 1991	Marsh *et al.*, 1997
November 1995	Marsh and Corkeron, 1996	November 1996	Marsh *et al.*, 1997
November 2000	Marsh and Lawler, 2002	November 2001	Marsh *et al.*, 2004
November 2006	Marsh *et al.*, 2007	November 2006	Marsh *et al.*, 2007
		March 2011	Marsh *et al.*, 2011b

Three surveys teams, each consisting of four observers and one team leader, were assembled to work in the two areas. Observers in both teams were either trained prior to the survey or already had extensive aerial survey experience.

2.2 Survey methodology

The aerial survey methodology followed the strip transect aerial survey technique detailed in Marsh and Sinclair (1989a) and used in earlier surveys in the Northern Great Barrier Reef and Torres Strait (Table 1). A 6-seat, high-wing, twin-engine Partenavia 68B was flown along predetermined transects as close as possible to a ground speed of 100 knots. The survey was conducted at a height of 500 feet (152 m) above sea level as opposed to 450 feet (137 m) flown in most of the previous surveys of these areas (pre 2011). The experimental work of Marsh and Sinclair (1989b) indicates that there should be no difference in dugong sightability between survey heights of 152 and 137 m.

Transects 200 m wide on the water surface on each side of the aircraft were demarcated using fiberglass rods attached to artificial wing struts on the aircraft. Transects were divided into four horizontal sub-strips (very high, high, medium and low) marked on the wing struts. Two tandem teams of observers on each side of the aircraft scanned transects and recorded their sightings onto separate tracks of an audio recorder. The two members of each tandem team operated independently and could neither see nor hear each other when on transect. The location of the sightings in the four sub-strips enabled the survey team to decide if simultaneous sightings by tandem team members were of the same group of animals when reviewing the recordings. The sightings of the tandem observers were also used to calculate survey specific correction corrections for perception bias (*i.e.*, for animals visible in the survey transect but missed by observers) for each side of the aircraft as outlined below (Marsh and Sinclair 1989a, Pollock *et al.* 2006).

Dugongs were the main focus of these surveys, followed by dolphins, marine turtles and other marine megafauna, such as sharks, rays and seasnakes. In areas with very high animal density, observers were asked to prioritise dugong calls and it is likely that other marine animals have been underreported. For each animal sighting, observers recorded the type of animal (*e.g.*, dugong or turtle), total number of animals seen, position in the transect (*e.g.,* low or medium), and the visibility (see Appendix 1: Scales for environmental conditions). In addition, the number of calves was recoded for each dugong and dolphin sighting. Calves were defined as being less than 2/3 of the size of the cow and swimming in close proximity to her. For the calculation of the Perception Correction Factor, cow and calf pairs were counted as one unit since calves are not independent from cows.

Dolphins were identified to species level, where possible. The survey height of 500 feet maximised the likelihood of reliable species identification in passing mode. Each observer provided an assessment of their reliability of cetacean species identification (certain, probable or guess); only 'certain' and 'probable' identifications were counted as identified.

All animal sightings were recorded, including those that did not fall within the demarked transect strip, in which case the animals were recorded as 'inside' (below) or 'outside' (above) the transect strip.

The survey leader collected data on environmental conditions at the beginning of each flight (cloud cover, cloud height, wind speed and direction, and air visibility) and each transect (cloud cover). Every few minutes during each transect, and whenever conditions changed, the survey leader recorded sea state, visibility, and glare on each side (assessed by the mid-seat observers).

2.3 Dugong population size and density

The data from each survey area were analysed to determine estimates of relative dugong abundance and dugong density, following the methodologies developed by Marsh and Sinclair (1989a) as later modified by Pollock *et al.* (2006). These methods attempt to correct for availability bias (animals not available to observers because of water visibility) and perception bias (animals visible in the survey transect but missed by observers *sensu* Marsh and Sinclair (1989a). All population estimates are provided $\pm$ standard errors (s.e.).

2.4 Statistical analyses

2.4.1 Calf count

Logistic regression was used to examine if the proportions of calves (response) differed among survey years and areas (Northern Great Barrier Reef: 1984, 1990, 1996, 2000, 2006, and 2013; and Torres Strait: 1987, 1991, 1996, 2001, 2006, and 2013). The survey in the Torres Strait in 2011 was excluded from the analysis as the survey was conducted in a different season (March, as opposed to November/December). Year was treated as a continuous independent variable; survey area as a categorical independent variable. As the total number of dugongs sighted differed among years and survey area, these numbers were used as weight in the logistic regression model. Statistical analyses were executed in SPlus version 8 (TIBCO Software 2007).

2.4.2 Distribution of dugongs across bathymetric ranges

A loglinear model was used to examine whether the frequency distribution of uncorrected dugong sightings across different water depth categories varied between survey years. Water depth was identified using the bathymetric model generated by Lewis (2001). Each dugong sighting was classified into a 5 m bathymetric bin. Because numbers of observations in the deep depth categories in both areas were small, all sightings deeper than 20 m (for the Northern Great Barrier Reef) or deeper than 15 m (for Torres Strait) were combined to meet the assumptions of the statistical tests.

The relative sizes of the depth categories surveyed differed between survey areas. For example, waters deeper than 20 m were a much higher percentage of the survey area in the Northern Great Barrier Reef survey (surface transect area of 1450 km^2, compared with 264 to 345 km^2 for other water depth categories). In Torres Strait, waters less than 5 m were relatively uncommon (156 km^2), compared with other depth categories (ranging from 319 to 558 km^2). To account for these differences, the surface area was used as "offset" in the loglinear model. The independent categorical variables (Depth and Year) and their interaction were used to fit each model. Separate tests were performed for the data from the Northern Great Barrier Reef and Torres Strait. Statistical analyses were executed in R 3.0.3 (R Development Core Team 2014).

2.4.3 Comparison of dugong density with historical surveys

Differences in dugong density among all surveys conducted since 1985 (Northern Great Barrier Reef) or 1987 (Torres Strait) and blocks (0, 1A, 1B, 2A, 2B, 3, 4, and 5 in Torres Strait and N1-N14 in the Northern Great Barrier Reef) were examined using linear mixed-effects models using data generated by the methodology of Marsh and Sinclair (1989a). The methodology of Pollock *et al.* (2006) was used to analyse the significance of the variation in dugong density for surveys from 2000-2013 (Northern Great Barrier Reef) or 2001-2013 (Torres Strait).

Separate statistical tests were conducted for each survey area. Only results from blocks and transects that were flown in all the surveys years in question were examined, which resulted in the exclusion of some transects and blocks from the analyses.

Statistical analyses followed Marsh *et al.* (2007). Years and blocks were treated as fixed effects; transects within blocks as random effects as there was large variation in animal density within blocks. F-ratios were calculated from the split-plot fixed model using transect as subplots of block. The statistical significance of the fixed effects was determined by simulation using Monte Carlo Markov Chains (MCMC) based on the estimated mixed-effects model parameters. The model used the restricted maximum likelihood estimation. Dugong density was transformed ($\ln(y + 0.1)$) to ensure homogeneous mean-variance components and the transformed density was used as the response variable. Where appropriate, unplanned comparisons were performed to detect significant differences in the dugong density between blocks.

2.5 Spatial modelling

The spatial data from the 2013 aerial survey were integrated with dugong sightings from aerial surveys conducted in 1990, 1995, 2000, and 2006 (Northern Great Barrier Reef) and 1987, 1991, 1996, 2001, 2006, and 2011 (Torres Strait) (for data references see Table 1; 1994 and 2005 Torres Strait surveys were excluded from the analysis as they covered block 2A only) to form a common GIS database. Using the uncorrected data on dugong distribution and abundance and the method of Grech and Marsh (2007; described below), spatially explicit dugong population models were developed within the aerial survey areas for: (1) the 2013 survey only and (2) all historical surveys combined. 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 and Kwan 2008).

Universal kriging is a geostatistical estimation method that returns unbiased linear estimates of point values where trends in data vary and regression coefficients are unknown. The spatial autocorrelation of the data was investigated by a variogram analysis using the Geostatistical Analyst extension of ArcGIS 10.3. Dugong distribution and relative density were estimated at the scale of 2 km x 2 km cells because this scale: (1) corresponds with the scale of the aerial survey data allowing the model to account for: (a) slight changes in altitude of the aircraft (which affects transect width at the surface); and, (b) the blind area under the aircraft; and, (2) is recommended under Criterion B of the International Union for Conservation of Nature and Natural Resources Red List for species that are mobile and distributed over broad spatial scales. Based on the relative density of dugongs estimated from the spatially explicit dugong population models and the frequency analysis of Grech and Marsh (2007) and Grech *et al.* (2011), cells in the aerial survey areas were classified into four categories: Very High (> 0.5 dugongs/km^2), High (0.5 – 0.25 dugongs/km^2), Medium (0.25 – 0.000001 dugongs/km^2) and Low (0 dugongs/km^2) relative dugong density. Density units with 0 dugongs / km^2 were included to ensure that the spatial layers extended across the entire survey area and because dugongs are likely to move across units where they were not detected during the surveys.

This classification approach makes the assumption that dugong relative density is a robust index of dugong habitat utilisation. This assumption is partially justified because specialised areas for dugong reproduction and migratory corridors have not been identified and density estimates are regarded as a suitable surrogate measurement of habitat utilisation (Hooker and Gerber 2004). However, this approach does not correct for the differences in the availability of dugongs due to spatial changes in water turbidity and water depth and probably underestimates the relative importance to dugongs of turbid habitats and waters deeper than about 5 m.

3 Results

3.1 Survey flights summary

The Northern Great Barrier Reef was surveyed from 30th October – 27th November 2013, and the Torres Strait was surveyed from 11th – 28th November 2013. Table 2 summarizes the details of survey flights, dates and teams. Sampling intensities varied between individual blocks resulting in 3.7-25.3% survey intensity in the Northern Great Barrier Reef and 3.6-11.2% in Torres Strait (see Appendix 2: Sampling intensity).

Table 2: Overview of survey flights undertaken in the Northern Great Barrier Reef (GBR) and Torres Strait by three different survey teams.

Date	Transect numbers flown by the three teams			
	Northern GBR	team	Torres Strait	team
30/10/2013	368-397	3		
31/10/2013	398-409	3		
09/11/2013	421-426	3		
11/11/2013	418; 438-445	3	601-607; 316	1
15/11/2013			110-124	1
16/11/2013			126-146	1
18/11/2013	410-413; 432-433	3	219-224; 401-407	2
19/11/2013	414-417; 419; 430-431; 434-	3	101-104; 214-218	2
20/11/2013	420; 427-429; 446-453	3	105-109; 408; 501-506	2
21/11/2013	454-473	3		
22/11/2013			201-205	2
23/11/2013	474-489	3	206-210; 306-311	2
25/11/2013	494; 497-501	3	211-213, 2121; 2131; 3051;	2
26/11/2013	507-514	3	312-315; 409-412; 623-627	2,3
27/11/2013	490-493; 495-496; 503-505	3	301-305; 614-619	2
28/11/2013			608-613; 620-622	2

3.2 Conditions

The survey teams were forced to spend considerable periods on the ground due to challenging weather conditions with occasional high winds, and an early start of the wet season characterized by patchy rain and thunderstorms. Nonetheless, all teams completed their surveys on schedule and were able to conduct survey flights in appropriate conditions that were comparable to previous surveys (Appendix 3: Weather conditions).

Glare varied throughout the surveys as a result of changing sun angles and sea state. In both survey areas, mean glare (*i.e.,* mean of modes for each transect) was as expected, higher for observers facing south than observers facing north (Appendix 3). In Torres Strait, multiple transects along the coast of Papua New Guinea were flown in a north/south orientation across the depth gradient to minimize the variation between transects and for these transects, glare was higher for observers facing west that for those facing east. The mean Beaufort sea state (*i.e.,* mean of modes for each transect) in the Northern Great Barrier Reef was low (1.72) and within the range experienced during previous surveys (Appendix 3). In Torres Strait, mean sea state in 2013 (2.3) was higher than in any of the earlier surveys. In both survey areas, short sections of individual transects were surveyed in sea state 4, totaling 11.4 mins of six transects in the Northern Great Barrier Reef (10.5% of the total survey time of those six transects or <1% of the total survey time for the entire area); and ~59 mins of 15 transects in Torres Strait (32.3% of the total survey time of those 15 transects or 3% of the total survey time for the entire survey area). These proportions of transects flown in sea state 4 were considered sufficiently small to not warrant repeating the transects.

3.3 Observations

The sightings reported here (unless otherwise stated) only include animals sighted on transect. Although occasionally additional animals were recorded outside the marked transect strip, observers were not spending effort on surveying areas outside the transect strip and sightings in those areas were opportunistic. Details of sightings are provided in Table 3 and locations of sightings are shown in Appendix 4 (for the Northern Great Barrier Reef) and 5 (for Torres Strait).

Table 3: Summary of all sightings of marine megafauna in **(a) the Northern Great Barrier Reef**, and **(b) Torres Strait** during aerial surveys conducted in November 2013.

(a) Northern Great Barrier Reef					
	Number of groups	**Number of individuals[a]**	**Number of calves[a]**	**% calves**	**Average group size**
Dugongs[b]	270	381 (69)	23 (2)	6%[c]	1.4
Dolphins	134	367 (125)	21 (6)	5.7%	2.7
Tursiops spp.	*25*	*43 (7)*	*3*	*7.0%*	*1.7*
Sousa spp.	*13*	*28 (11)*	*2 (3)*	*7.1%*	*2.2*
Stenella spp.	*12*	*96 (18)*	*5*	*5.2%*	*8.0*
Orcaella heinsohni	*1*	*1*	*0*	*0%*	*1*
Unidentified spp.	*82*	*199 (89)*	*11 (3)*	*5.5%*	*2.4*
Marine turtles	1,394	1,702 (205)			1.2
Sharks	156	199 (17)			1.3
Rays	249	313 (63)			1.3
Seasnakes	147	148 (25)			1.0
(b) Torres Strait					
	Number of groups	**Number of individuals[a]**	**Number of calves[a]**	**% calves**	**Average group size**
Dugongs[d]	311	464 (134)	83 (22)	17.9%[c]	1.5
Dolphins	72	160 (74)	13 (11)	8.1%	2.2
Tursiops spp.	*39*	*95 (39)*	*4 (1)*	*4.2%*	*2.4*
Sousa spp.	*20*	*45 (6)*	*4*	*8.8%*	*2.3*
Unidentified spp.	*13*	*20 (29)*	*5 (10)*	*17.2%*	*1.5*
Marine turtles	1,639	1,896 (384)			1.2
Sharks	105	123 (14)			1.2
Rays	125	191 (29)			1.5
Seasnakes	165	165 (30)			1.0

[a] Number of individuals sighted within the transect. Number in bracket represents additional animal spotted off transect. [b] In addition, one herd of 49 dugongs (incl. one calf) was sighted on transect 399. [c] Excluding calves sighted in herds. [d] Includes one dugong group consisting of 15 animals, 7 of them calves.

3.3.1 Dugong sightings

A total of 270 dugong groups, consisting of 381 animals (including 23 calves, *i.e.,* 6%) was sighted in the Northern Great Barrier Reef (Table 3). In addition, one herd of 49 dugongs was spotted on transect 399, south of Cape Bowen (14° 36'18 S; 144° 50'57 E). The average group size for the entire survey area was 1.4 dugongs.

In Torres Strait, 311 groups of dugongs were sighted, a total of 464 individual animals (Table 3). The number of calves in that area was high with 83 calves (*i.e.* 17.9%). The average group size in Torres Strait was 1.5 dugongs.

3.3.2 Dugong calf counts

We analyzed the factors associated with temporal and spatial changes in the number of calves as a proportion of dugong sightings. The interaction between year and survey area was significant, indicating that the logistic curves from the two survey areas were not parallel (Figure 2). Although the proportions of calves were similar between the two survey areas before 2000, after 2000 the proportion of calves in Torres Strait increased whereas the proportion of calves in the Northern Great Barrier Reef declined (Figure 2). Overall, the proportions of calves differed significantly between survey areas but there was no significant effect of years (Table 4). Separate logistic regressions for each survey area with year binned into two levels (pre-2000 and post-2000) showed that the proportion of calves in the Northern Great Barrier Reef post-2000 was significantly smaller post-2000 than pre-2000 (73.2% decline). In Torres Strait, the proportion of calves significantly increased by 23% post-2000 compared with the earlier period. Figure 2 shows the predicted values based on the separate logistic regression.

Table 4: Results of the logistic regression to examine the effects of year and area associated with the proportions of calves sighted in Northern Great Barrier Reef (1984, 1990, 1996, 2000, 2006, and 2013) and Torres Strait (1987, 1991, 1996, 2001, 2006, and 2013).

Analysis of deviance	Df	Deviance	Residual Df	Residual Deviance	Pr (>Chi)
Null	1		11	38.02	
Year	1	0.27	10	37.74	0.60
I (Year^2)	1	0.89	9	36.85	0.34
Area	1	8.20	8	28.65	<0.01
Year x Area	1	17.57	7	11.08	<0.0001
I (Year^2) x Area	1	8.00	6	3.09	<0.01

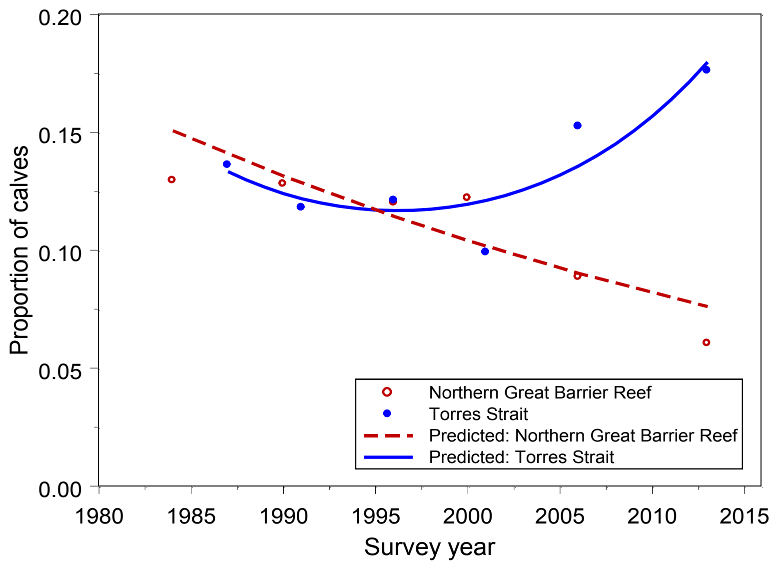


Figure 2: Proportions of calves (y value) plotted against the total number of dugongs sighted in Northern Great Barrier Reef (red open circle) and Torres Strait (blue closed circle). Each line represents a predicted proportion of calves for the Northern Great Barrier Reef (dotted line) and Torres Strait (solid line).

3.3.3 Dugong sightings with respect to bathymetry

3.3.3.1 Northern Great Barrier Reef

In the Northern Great Barrier Reef, dugongs were seen in waters up to 41 m deep (not corrected for tides). Over the entire survey area, more than a half (52%) of the dugongs sighted were in water less than 5 m deep (72% in waters less than 10 m deep, 88% in waters less than 15 m deep, and 96% in water less than 20 m deep, see Figure 3a; note the numbers in this figure were not weighted for the area of each depth category).

Dugong distribution (weighted for area of depth category) varied significantly between depth categories and years (Table 5a). Depth categories was associated with the strongest effect (Deviance of 2882.1) among the three terms (*i.e.,* depth, year, and depth x year interaction), followed by year (Deviance of 233.4; Table 5a). Pairwise comparisons show that within a survey year, the proportion of dugong sightings in shallower waters was usually significantly higher than in deeper waters (as indicated by "H" for higher observations within the same survey year, Figure 4a). The smallest proportions of dugongs were sighted in deeper waters both 15 to < 20 m deep (coefficient of -3.306) and >20 m deep (coefficient of - 3.711, see Appendix 6). The pattern of dugong sightings across the various depth categories were not significantly different in 2006 and 2013, but there was a significant difference between 2000 and 2006 ($z = 10.03$, $p < 0.001$) and 2000 and 2013 ($z = -9.25$, $p < 0.001$); relatively more dugongs were sighted in 2000. Pairwise comparisons of sightings in individual depth categories across the survey years show that relatively low numbers of dugongs were sighted in the 15-20m category in 2000, a significantly higher proportion was sighted in that depth category in the following survey (2006). Apart from this difference, the same or a significantly lower proportion of the overall dugongs sighted were in all the other depth categories in more recent surveys (Figure 4a).

3.3.3.2 Torres Strait

In Torres Strait in 2013, dugongs were seen in waters up to 29 m deep (not corrected for tides). In contrast to the Northern Great Barrier Reef, over the entire Torres Strait survey area, only 9% of all dugong sightings occurred in waters less than 5 m deep (Figure 3b). Most dugongs were seen in waters 5-10 deep (30%) and 10-15 m deep (50%). As in the Northern Great Barrier Reef, year, depth, and their interaction were all associated with significant effects on dugong distribution (Table 5b). Depth had the strongest effect (Deviance of 525.6). The relative numbers of dugong sightings were the smallest in waters ≥15 m deep in all years, (Deviance of - 1.298) (Appendix 6). The distribution of dugongs differed in the three survey years (Deviance of 39.4) but that effect was very small. Pair-wise comparisons of relative dugong numbers across depth categories within a year indicated that in the Torres Strait (like the Northern Great Barrier Reef), a significantly higher proportion of dugongs was sighted in shallow waters than in the deepest water depth category (>15m), but there were fewer significant differences in the proportions sighted in the 5-10m and 10-15m depth categories (Figure 4b).

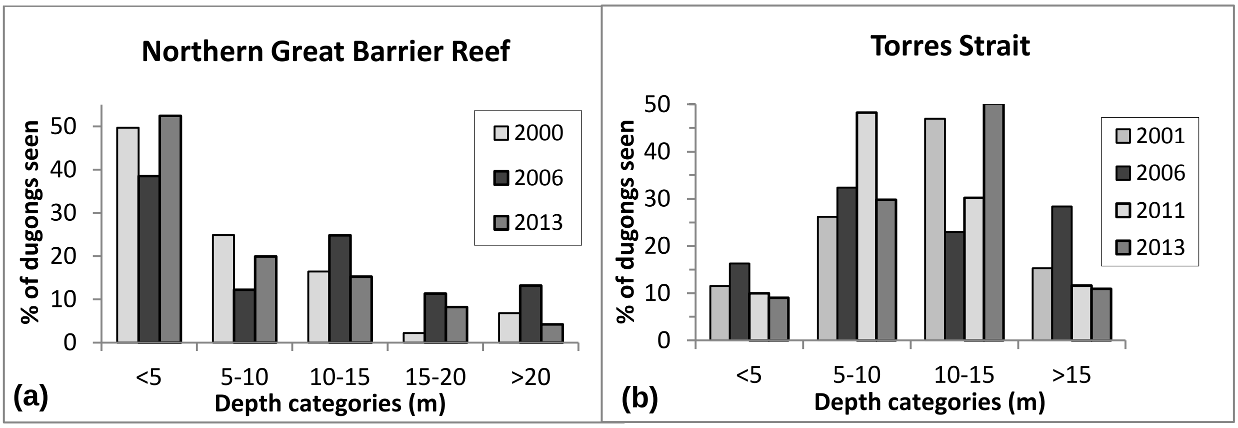


Figure 3: Frequency distribution of dugong sightings with respect to bathymetry in: **(a) Northern Great Barrier Reef** in 2000, 2006, and 2013; and **(b) Torres Strait** in 2001, 2006, 2011, and 2013. Note that the percentages have not been weighted for the area of each depth category in contrast to the analysis in Table 5 below.

Table 5: Results of log-linear models to analyse the relationship between the proportion of dugong sightings (dependent variable) and water depth category and survey year (independent variables) for: **a) Northern Great Barrier Reef and b) Torres Strait**. The area of the various depth categories in the survey area have been used as an offset.

a) Northern Great Barrier Reef					
Analysis of deviance	**Df**	**Deviance**	**Residual Df**	**Residual Deviance**	**Pr (>Chi)**
Null			14	3251.2	
Year	2	233.4	12	3017.8	<0.0001
Depth	4	2882.1	8	135.8	<0.0001
Year **x** Depth	8	135.8	0	0	<0.0001
b) Torres Strait					
Analysis of deviance	**Df**	**Deviance**	**Residual Df**	**Residual Deviance**	**Pr (>Chi)**
Null			15	700.2	
Year	3	39.4	12	660.7	<0.0001
Depth	3	525.6	9	135.1	<0.0001
Year **x** Depth	9	135.1	0	0	<0.0001

a) Northern Great Barrier Reef

Year	Depth (m)	2000 <5	2000 5-10	2000 10-15	2000 15-20	2000 ≥ 20	2006 <5	2006 5-10	2006 10-15	2006 15-20	2006 ≥ 20	2013 <5	2013 5-10	2013 10-15	2013 15-20	2013 ≥ 20
2000	<5	X	H	H	H	H										
	5-10		X	H	H	H										
	10-15			X	H	H										
	15-20				X	ns										
	≥20					X										
2006	<5	L					X	H	H	H	H					
	5-10		L					X	L	ns	H					
	10-15			ns					X	H	H					
	15-20				H					X	H					
	≥20					ns					X					
2013	<5	L					ns					X	H	H	H	H
	5-10		L					ns					X	H	H	H
	10-15			L					L					X	H	H
	15-20				ns					L					X	H
	≥20					L					L					X

b) Torres Strait

Year	Depth (m)	2001 <5	2001 5-10	2001 10-15	2001 ≥ 15	2006 <5	2006 5-10	2006 10-15	2006 ≥ 15	2011 <5	2011 5-10	2011 10-15	2011 ≥ 15	2013 <5	2013 5-10	2013 10-15	2013 ≥ 15
2001	<5	X	ns	ns	H												
	5-10		X	ns	H												
	10-15			X	H												
	≥ 15				X												
2006	<5	H				X	ns	H	H								
	5-10		H				X	H	H								
	10-15			L				X	ns								
	≥ 15				H				X								
2011	<5	ns				L				X	L	ns	H				
	5-10		ns				H				X	H	H				
	10-15			ns				ns				X	H				
	≥ 15				ns				L				X				
2013	<5	ns				ns				ns				X	L	L	H
	5-10		H				ns				L				X	ns	H
	10-15			H				H				H				X	H
	≥ 15				ns				L				ns				X

Figure 4. Relevant results of the pair-wise comparisons between the relative frequencies of dugongs sightings in different survey years and depth categories from **a) the Northern Great Barrier Reef**, and **b) Torres Strait**. Within the same year, higher "H" and lower "L" sighting frequencies were determined based on comparing results for the shallower water depth category with the deeper one (red circled example: in the Northern Great Barrier Reef in 2000, dugong numbers in the depth category <5m were significantly higher than dugong numbers in the 5-10m depth category) Between years, comparisons were based on the more recent survey (blue circled example: in the Northern Great Barrier Reef, the depth category <5m had significantly lower dugong numbers in 2013 than in 2000). Note: One in 20 of these comparisons would be expected to be significantly different by chance alone.

3.4 Population size estimates and trends

Population size estimates are presented here for the Pollock *et al.* (2006) method only. This method is superior to the Marsh and Sinclair (1998a) method because the more recent method considers the spatial heterogeneity in the availability correction factors. However, since our pre-2000 surveys provide results for the Marsh and Sinclair (1989a) method only, both methods are presented when comparing dugong densities over time.

The raw data for sightings of dugong groups for each transect in each block surveyed in November 2013 used to estimate population size are detailed in Appendix 7. Details of correction factors are provided in Appendix 8.

The probability of observers sighting dugongs, given they were available for detection, was high in all teams. The perception probability estimates, based on the generalised Lincoln-Petersen models fitted using the MARK program, suggest that the double-observer teams sighted 91-99% of dugongs that were available (Table 6).

Table 6: Details of models and perception probability for each team.

Team	Model [a]	Probability estimates [b] (± s.e.)	Perception probability of each tandem team
1	Port/Starboard observers different	Both Port 0.92 (± 0.04) Both Starboard 0.80 (± 0.07)	Port 0.99 Stbd 0.96
2	Prim/Sec observers different	Both Primary 0.98 (± 0.01) Both Secondary 0.84 (± 0.02)	Port 0.99 Stbd 0.99
3	Port/Starboard observers different	Both Port 0.70 (± 0.03) Both Starboard 0.80 (± 0.02)	Port 0.91 Stbd 0.96

[a] The generalised Lincoln-Petersen model of best fit according to Akaike's Information Criterion (AIC) using the MARK program (White and Burnham 1999), where the perception probability was either the same for all observers, varied according to experience (primary or secondary observers), varied according to side of the aircraft (port or starboard), or was different for every observer. [b] Probability estimate provided by the model

3.4.1 Northern Great Barrier Reef

In November 2013, the dugong population size in the Northern Great Barrier Reef was estimated to be 6558 (s.e. ± 1141) animals. This estimate was the lowest for the area since 2000 (Table 7). Comparison between individual blocks (Figure 5) shows that block N5 (Princess Charlotte Bay) consistently supported more dugongs than any other survey block. For most blocks, the 2013 population size estimates were below estimates from 2006 (exception is block N3) and estimates from 2000 (exceptions are blocks N6 and N8).

Table 7: Estimates of relative dugong abundance (+ s.e.) using the Pollock *et al.* (2006) methodology for each survey block in the Northern Great Barrier Reef for aerial surveys conducted between 2000 and 2013 inclusive. The block locations are illustrated in Figure 1a. No population estimates were obtained for blocks where less than five dugong groups were sighted. Historical data from Marsh *et al.* (2007).

Population size estimates (+ s.e.) for the Northern Great Barrier Reef			
Block	**2000**	**2006**	**2013**
N1	73 (52)	tfs	tfs
N2	1617 (623)	1293 (466)	820 (278)
N3	1742 (600)	498 (249)	1077 (612)
N4	1060 (380)	1629 (693)	973 (367)
N5	2832 (1019)	3061 (1333)	1990 (675)
N6	472 (221)	tfs	504 (306)
N7	nds	tfs	tfs
N8	632 (313)	1407 (725)	979 (394)
N9	tfs	tfs	tfs
N10	tfs	tfs	tfs
N11	287 (191)	293 (116)	108 (71)
N12	tfs	tfs	tfs
N13	468 (256)	492 (211)	tfs
N14	547 (152)	139 (106)	107 (75)
N15	ns	tfs	nds
TOTAL	**9730 (1485)**	**8812 (1769)**	**6558 (1141)**

tfs – too few sightings for population estimations; ns – not surveyed
nds- no dugong seen on transect

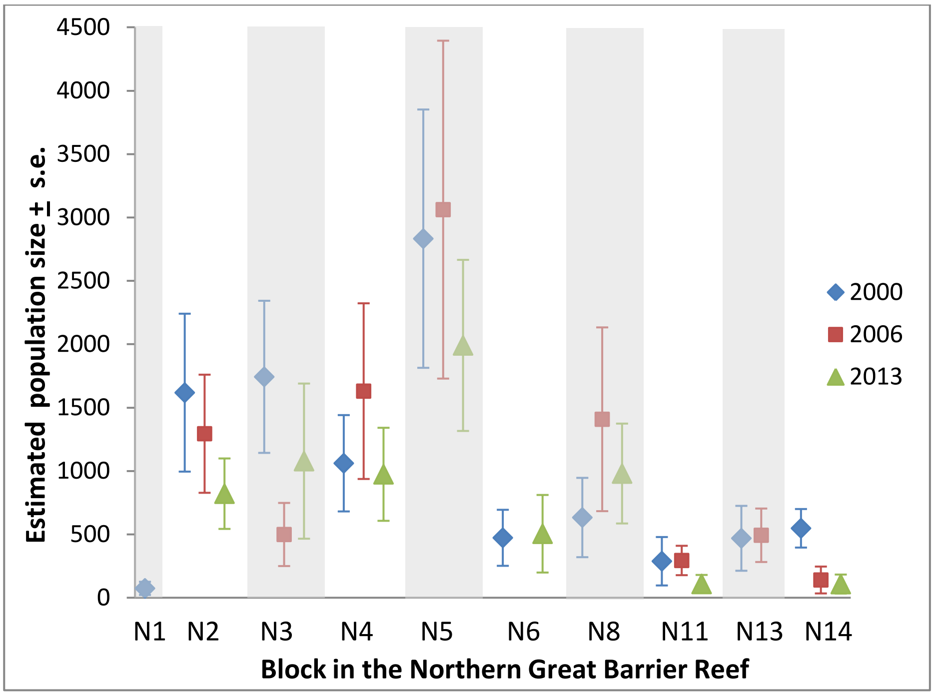


Figure 5: Estimated population sizes (+ s.e.) for individual blocks in the Northern Great Barrier Reef (shaded to differentiate) surveyed in 2000, 2006, and 2013. Estimates were obtained using the method of Pollock *et al.* (2006). For locations of blocks refer to Figure 1a. No estimates were obtained for blocks N7, N9, N10, N12 and N15 because of the low number of sightings. Historical data from Marsh *et al.* (2007).

There was a significant interaction between dugong densities in individual blocks and survey years generated using the Marsh and Sinclair (1989a) method ($F_{55,795}$ = 1.73, p = 0.006; Table 8), as illustrated in Figure 6. The larger variance component of the Residual (among transect within block variation among years) (0.76) compared with the block variance component (0.24) indicated substantial movements of dugongs among transects within the same block over time Table 8).

Table 8: Results of linear mixed – effects model comparing dugong density for the Northern Great Barrier Reef produced by (a) the Marsh and Sinclair (1989a) method across a time series of six surveys over 29 years (1985-2013) and (b) the Pollock *et al.* (2006) method (3 surveys across 14 years 2000-2013).

	Source of variation	Num DF	Denom. DF	F	MCMC P-value	Variance component
(a) Marsh and Sinclair (1989a) method	**Survey Years 1985, 1990, 1995, 2000, 2006, 2013**					
	Block	11	159	18.46	<0.0001	
	Among transect within block					0.244
	Year	5	795	2.99	0.375	
	Block x Year	55	795	1.73	0.006	
	Residual (among transect within block variation among years)					0.762
(b) Pollock *et al.* (2006) method	**Survey Years 2000, 2006, 2013**					
	Block	13	188	8.796	<0.0001	
	Among transect within block					0.348
	Year	2	376	2.856	0.381	
	Block x Year	26	376	1.594	0.230	
	Residual (among transect within block variation among years)					0.753

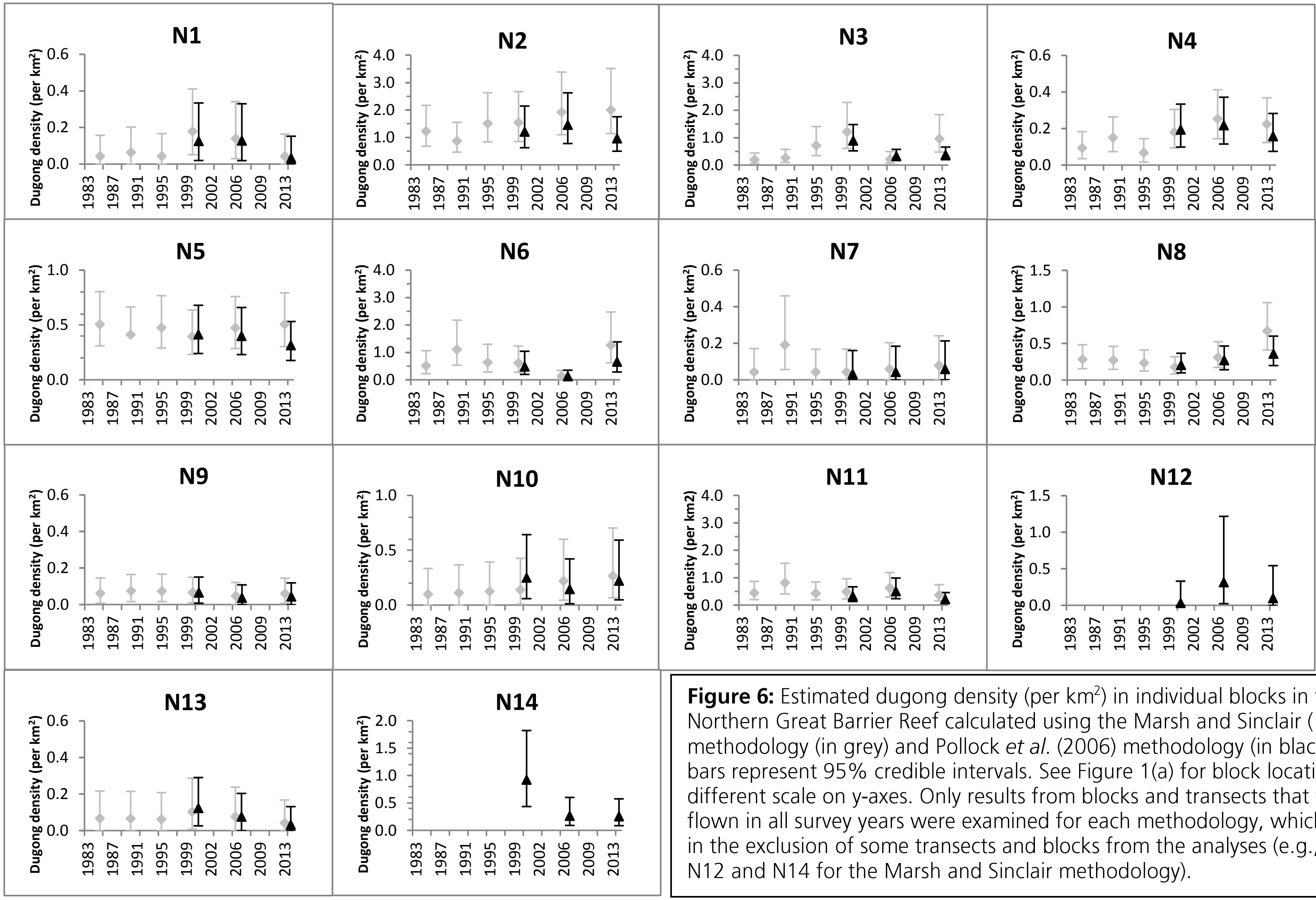


Figure 6: Estimated dugong density (per km^2) in individual blocks in the Northern Great Barrier Reef calculated using the Marsh and Sinclair (1989a) methodology (in grey) and Pollock *et al*. (2006) methodology (in black). Error bars represent 95% credible intervals. See Figure 1(a) for block locations. Note different scale on y-axes. Only results from blocks and transects that were flown in all survey years were examined for each methodology, which resulted in the exclusion of some transects and blocks from the analyses (e.g., Blocks N12 and N14 for the Marsh and Sinclair methodology).

The Marsh and Sinclair (1989a) method did not show any significant differences in dugong densities in the Northern Great Barrier Reef between years ($F_{5,795}$ = 2.99, p = 0.375) (Figure 7, Table 8a). However, differences in densities between individual blocks were significant ($F_{11,159}$ = 18.46, p<0.0001, Figure 6). Unplanned comparisons between pairs of blocks showed that this overall difference in densities was caused by numerous inter-block differences in dugong density (Appendix 9), with densities in Block N2 (Starcke River region) in particular being significantly different (higher) from densities in any other block.

Even though there was no significant interaction between block and year, results from the analyses of dugong densities generated by the Pollock *et al.* (2006) method largely confirm the findings using the Marsh and Sinclair (1989a) methodology. Differences in dugong densities between blocks were highly significant ($F_{13,188}$ = 2.99, p<0.0001) and there was no significant difference between years ($F_{2,376}$ = 2.86, p = 0.381) (Figure 6, Table 8b). Unplanned comparisons of blocks using densities estimated with the Pollock *et al.* (2006) method showed similar results as for the Marsh and Sinclair (1989a) method (*i.e.,* Block N2 was significantly different from any other block (Figure 6) including Blocks N12 and N14, which were not included in the Marsh and Sinclair (1989a) method because they were not surveyed prior to 2011). The difference between the variance components was similar to the results obtained using the Marsh and Sinclair (1989a) methodology, again suggesting that dugongs make substantial small-scale movements within blocks over time.

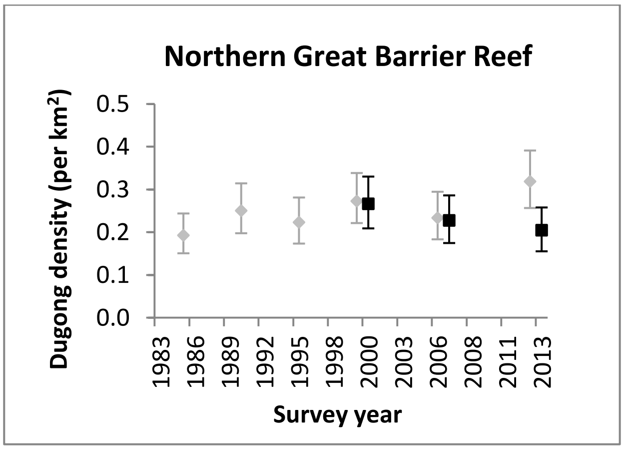


Figure 7: Estimated dugong density (per km^2) based on the Marsh and Sinclair (1989a) method (in grey) and Pollock *et al.* (2006) method (in black) in the Northern Great Barrier Reef in the survey years 1985, 1990, 1995, 2000, 2006, and 2013 for all blocks combined. Error bars represent 95% credible intervals.

3.4.2 Torres Strait

Dugong population size in the Torres Strait was estimated to be 15727 (± 2942) in November 2013, which is the highest estimate since 2001 (Table 9). The survey area was expanded in 2011 and so there are limits to the inferences that can be drawn from these comparisons. Nonetheless, if the temporal comparisons are limited to Blocks 1-5, the 2013 estimate is still the highest since 2001 (Table 9), when the Pollock *et al.* (2006) method was introduced. In every survey year, the highest abundance estimates were from Block 2A between Badu and Boigu and Block 3 immediately to the west of Block 2A (Figure 8). However, the estimate for Block 3 in 2011 was less than half of that from the other surveys.

There was a significant interaction in dugong density between block and year in Torres Strait using the Marsh and Sinclair 1989a method ($F_{42,468}$ = 1.59, p = 0.045, Table 10a; Figure 9). The larger variance component of the Residual (among transect within block variation among years) (0.86) compared with the block variance component (0.19) indicated substantial movements of dugongs among transects within the same block over time. Density also differed significantly between years ($F_{6,468}$ = 7.54, p =

0.024) (Figures 9 and 10, Table 10a), and between blocks ($F_{7, 78} = 16.18$, $p<0.0001$) (Figure 9, Table 10a). Unplanned comparisons of densities for individual blocks showed that densities in Block 2A were significantly different (higher) from densities in any other block and Block 5 was significantly different (lower) from most other block (Appendix 9).

Table 9: Estimates of relative dugong abundance using the Pollock *et al.* (2006) methodology for each survey block in the Torres Strait for various surveys conducted between 2001 and 2013 inclusive. All surveys were in November/December unless otherwise indicated. The block locations are in Figure 1b. No population estimates were obtained for blocks where less than five dugong groups were sighted. In 2011, sightings from Blocks 4 and 5 were combined to estimate abundance.

Population size estimates (± s.e.) for Torres Strait				
Block	**2001**	**2006**	**2011***	**2013**
0	nds	nds	578 (404)	401 (343)
1A	612 (258)	858 (516)	467 (206)	tfs
1B	2607 (1022)	1005 (435)	1573 (775)	1626 (593)
2A	3454 (782)	4362 (919)	5214 (1514)	5879 (1727)
2B	451 (274)	736 (318)	1117 (359)	792 (368)
3	5565 (1585)	5166 (1418)	2083 (862)	5542 (2159)
4	776 (565)	2640 (1356)	297 (222)	1487 (638)
5	nds	nds		tfs
6	ns	ns	nds	nds
7	ns	ns	nds	nds
8	ns	ns	778 (386)	tfs
9	ns	ns	497 (396)	tfs
TOTAL	**13465 (2152)**	**14767 (2292)**	**12603 (2080)**	**15727 (2942)**

*Due to unsuitable weather conditions in November, this Torres Strait survey was conducted in March 2011.
tfs – too few sightings for population estimations, nds- no dugong seen on transect; ns – not surveyed.

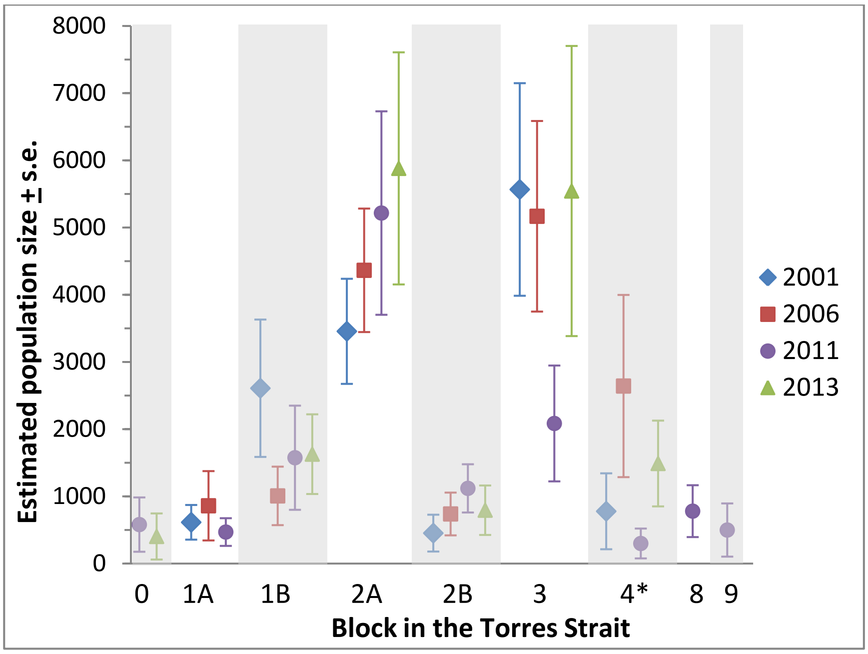


Figure 8: Estimated population sizes (± s.e.) for individual blocks in the Torres Strait (shaded for easier distinction) surveyed in 2001, 2006, 2011 and 2013. All surveys but 2011 were conducted in November/December (2011 in March). Estimates were obtained using the method of Pollock *et al.* (2006). For locations of blocks refer to Figure 1b. Due to low number of sightings, no estimates were obtained for blocks 5, 6 and 7. Historical data from Marsh *et al.* (2011b). *In 2011, sightings from Blocks 4 and 5 were combined to estimate abundance.

Table 10: Results of linear mixed – effects model comparing dugong density in Torres Strait produced by (a) the Marsh and Sinclair (1989a) method across a time series of 27 years (1987-2013) and (b) the Pollock *et al.* (2006) method across 13 years (2001-2013).

	Source of variation	Num DF	Denom. DF	F	p-value	Variance component
(a) Marsh and Sinclair (1989a) method	**Survey Years 1987, 1991, 1996, 2001, 2006, 2011, 2013**					
	Block	7	78	16.18	<0.0001	
	Among transect within block					0.189
	Year	6	468	7.54	0.024	
	Block x Year	42	468	1.59	0.045	
	Residual (among transect within block variation among years)					0.863
(b) Pollock *et al.* (2006) method	**Survey Years 2001, 2006, 2011, 2013**					
	Block	7	78	15.23	<0.0001	
	Among transect within block					0.093
	Year	3	234	0.96	0.126	
	Block x Year	21	234	1.48	0.141	
	Residual (among transect within block variation among years)					0.705

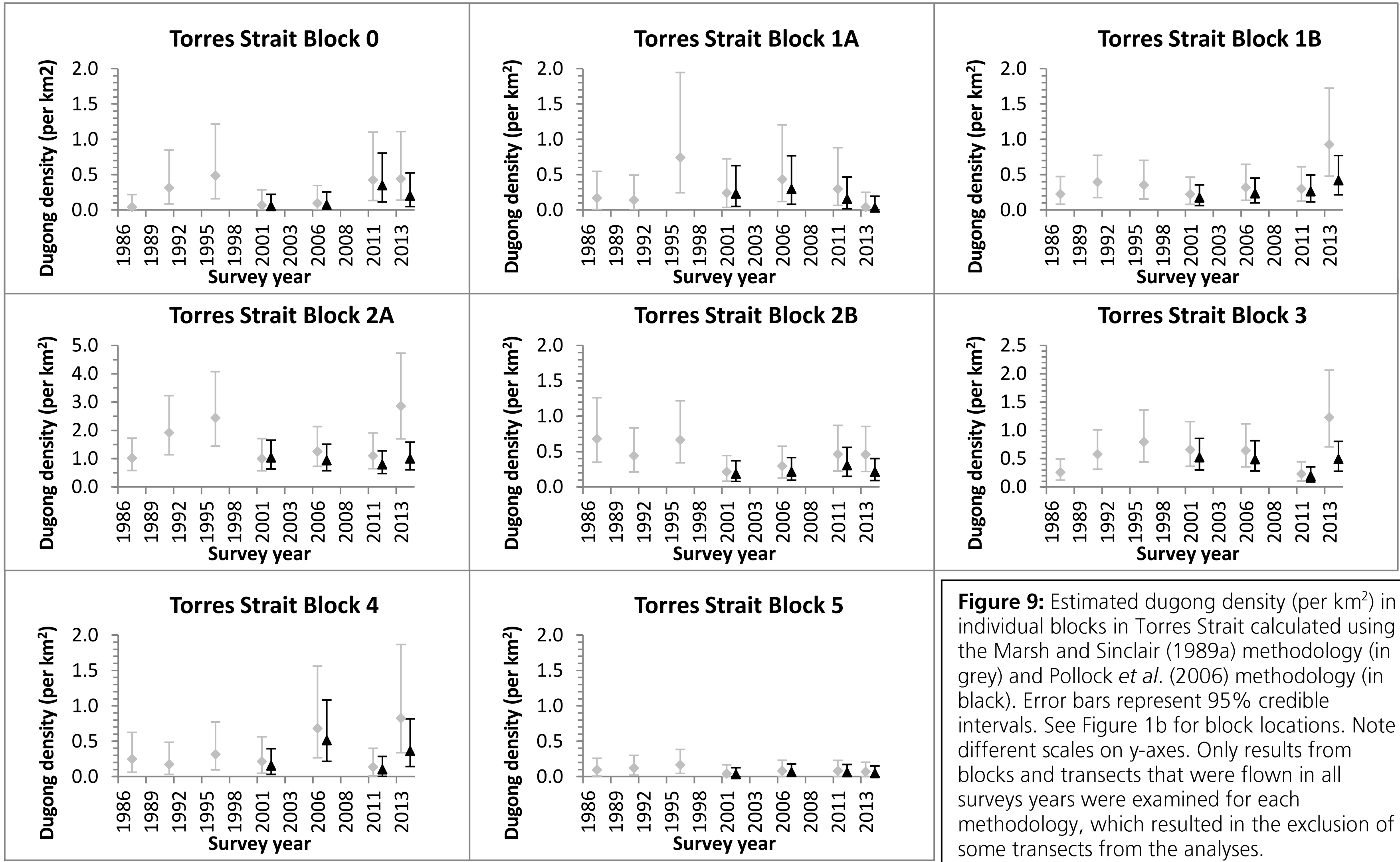


Figure 9: Estimated dugong density (per km²) in individual blocks in Torres Strait calculated using the Marsh and Sinclair (1989a) methodology (in grey) and Pollock *et al*. (2006) methodology (in black). Error bars represent 95% credible intervals. See Figure 1b for block locations. Note different scales on y-axes. Only results from blocks and transects that were flown in all surveys years were examined for each methodology, which resulted in the exclusion of some transects from the analyses.

When comparing dugong densities generated by the Pollock *et al.* (2006) method, the effect of block was again significant (Table 10b, Figure 10) but there was no significant difference in estimated dugong density between years, presumably because the result for the 1995 survey, which had higher dugong density than the four years included in the Pollock *et al.* analyses was not included (see Figure 10). The difference between the variance components was similar to the results obtained using the Marsh and Sinclair (1989a) methodology, again suggesting that dugongs make substantial small-scale movements within blocks over time. Unplanned comparisons of dugong densities estimated using the Pollock *et al.*(2006) method confirm the findings from the Marsh and Sinclair (1989a) method as that densities in various blocks were significantly different from each other (Appendix 9). Block 2A in particular was significantly different from any other block (having higher estimated densities), see Figure 9) and the dugong densities in Block 5 were different (lower) from most other blocks. In addition, there were relatively few dugongs seen in the Dugong Sanctuary in 2013 (November) compared with 2011 (March).

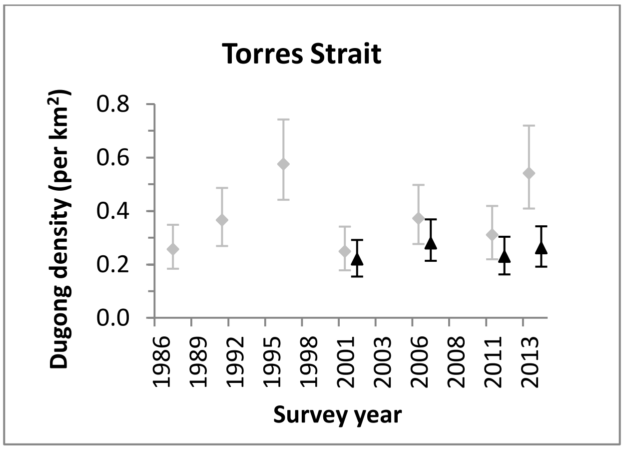


Figure 10: Estimated dugong density (per km^2) based on the Marsh and Sinclair method (in grey) and Pollock *et al.* (2006) method (in black) in Torres Strait in the survey years 1987, 1991, 1996, 2001, 2006, 2011, and 2013 for all blocks combined. Error bars represent 95% credible intervals.

3.5 Spatial modelling

3.5.1 Northern Great Barrier Reef

The spatially-explicit model of dugong distribution and relative density of the Northern Great Barrier Reef based on the 2013 survey showed an almost continuous distribution of dugongs along the coast (Figure 11). The locations where dugong relative density was estimated to be very high (i.e., > 0.5 dugongs / km^2) were Shelburne and Temple Bays, and between Cape Bowen and Cape Flattery, where dugong relative densities reached up to 3.6 dugongs / km^2.

The spatial model that incorporated data from all aerial surveys (Figure 12) showed very high and high dugong relative densities along most of the coast and on large reefs in Princess Charlotte Bay. Regions of very high dugong relative density were between Cape Flattery and Cape Bowen; Bathurst Bay; the eastern section of Princess Charlotte Bay; between Princess Charlotte Bay and around Friendly Point; as well as Lloyd, Temple, and Shelburne Bays. These areas correspond with sites of very high dugong density modelled by Grech *et al.* (2011).

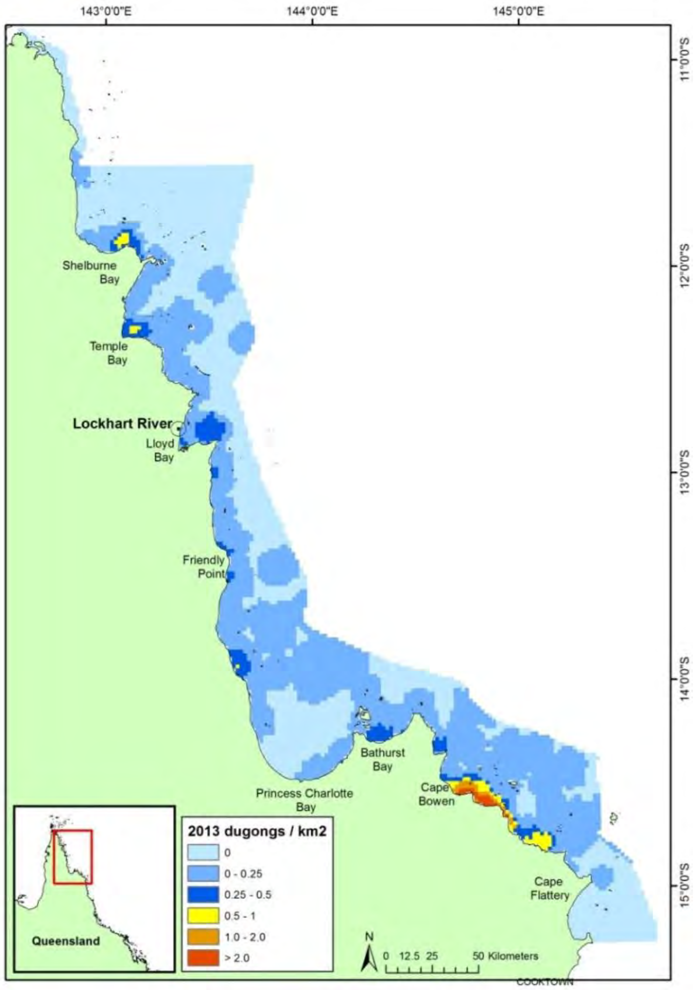


Figure 11: Spatially-explicit model of dugong relative density in the Northern Great Barrier Reef using uncorrected data from the aerial survey conducted in 2013.

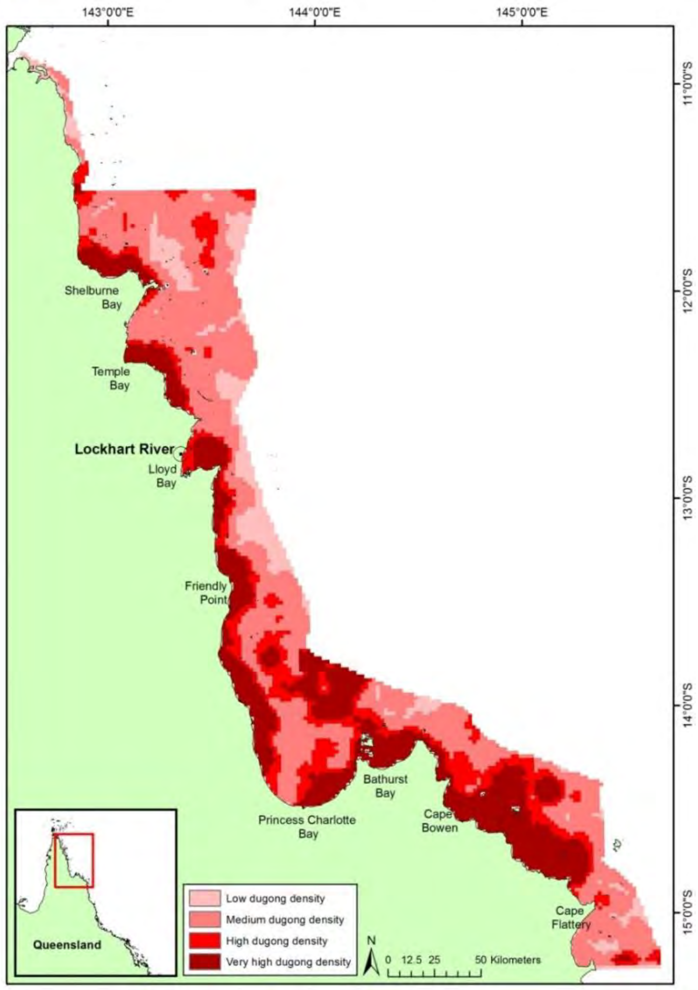


Figure 12: Spatially-explicit model of dugong relative density in the Northern Great Barrier Reef using uncorrected data from the aerial surveys conducted in 1990, 1995, 2000, 2006, and 2013 combined.

3.5.2 Torres Strait

The 2013 spatially-explicit model of dugong distribution and relative density in 2013 showed a central area of very high dugong relative density, and a wide spread of medium – high dugong densities across the aerial survey area, except in the west and north west where densities were low (*i.e.*, 0 dugongs/km^2) (Figure 13). Values ranged from 0 to 3.85 dugongs/km^2. Areas with the highest estimated dugong relative densities were located west of Buru Island and between Buru and Mabuiag Island. In 2013, the eastern half of the dugong sanctuary supported higher dugong relative densities than the western half, despite the occurrence of seagrass in that area (see Marsh *et al.* 2011b). However, dugong relative density in the western half of the dugong sanctuary may have been under-estimated since that area is characterised by deeper water and the spatially explicit model is based on data uncorrected for varying dugong availability in deeper waters (Hagihara *et al.* 2014).

The spatial model that incorporated data from all aerial surveys of Torres Strait (Figure 14) shows a large, central area where dugong relative density was estimated to be very high (from south of Boigu Island to north of Badu and Mua Islands; and west of Badu and Muralug Islands). These areas correspond with sites of very high dugong relative density modelled by Marsh *et al.* (2011b).

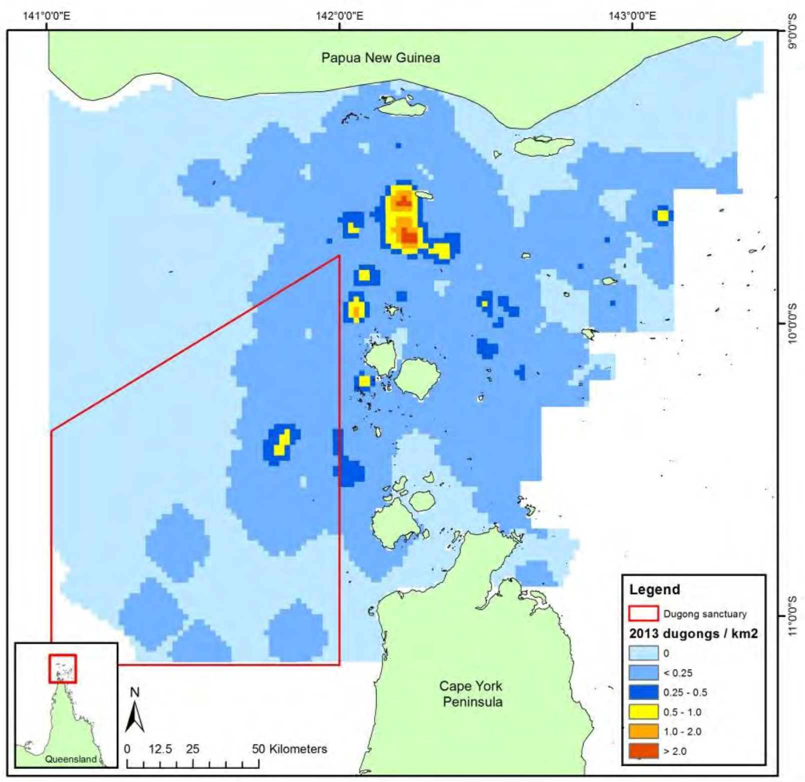


Figure 13: Spatially explicit model of dugong distribution and relative density in Torres Strait using uncorrected data from the aerial surveys conducted in 2013.

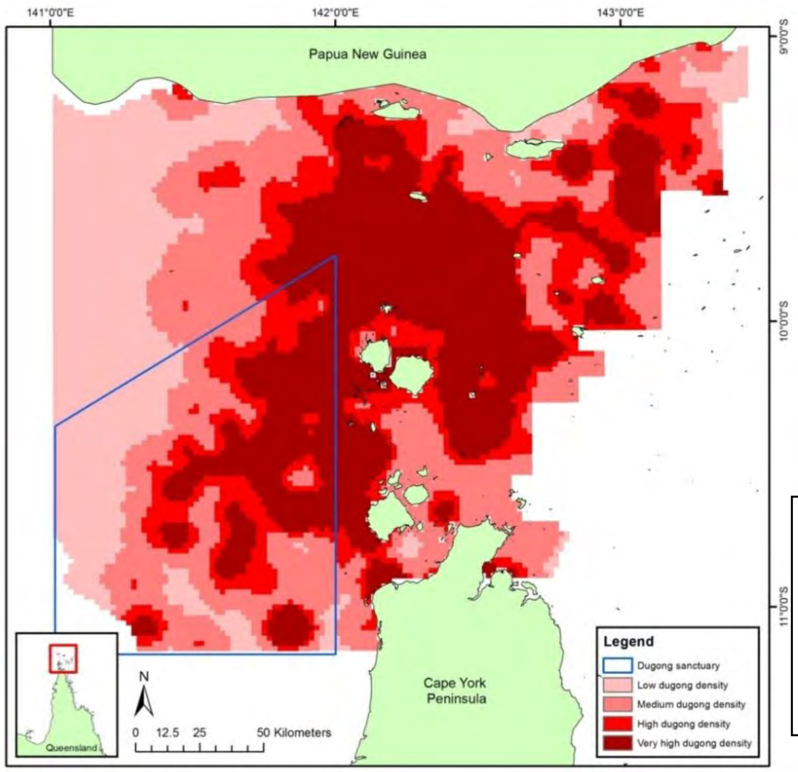


Figure 14: Spatially explicit population model of dugong distribution and relative density in Torres Strait based on uncorrected data from aerial surveys conducted in the years 1987, 1991, 1996, 2001, 2006, 2011, and 2013.

3.5.3 Comparison between Survey Areas

The spatial models derived from aerial survey data across multiple years (Figures 13 and 15) indicated that Torres Strait has a much higher proportion of dugong density units with high and very high relative density than the Northern Great Barrier Reef (Table 11). In the Northern Great Barrier Reef, fewer units have low dugong density and more units have medium dugong density than the Torres Strait. The Dugong Sanctuary, which is part of the Torres Strait, has similar proportions of low, medium, high and very high density units as the entire Torres Strait (Table 11).

Table 11: Total area (km^2) and proportion (%) of dugong density units of low, medium, high and very high relative densities predicted by the spatially explicit composite models (Figures 12, 14 and Grech *et al.*, 2011) of the different survey areas covered by the 2013 survey. The corresponding data for the Southern Great Barrier Reef (excluding the 2011 survey) have been included for comparison and Grech *et al.*, 2011).

Survey area	Dugong relative density			
	Low	Medium	High	Very high
Torres Strait	8,953 (21.5%)	12,493 (30%)	7,288 (17.5%)	12,909 (31%)
Dugong sanctuary*	2,794 (23%)	3,644 (30%)	2,308 (19%)	3,401 (28%)
Northern Great Barrier Reef	2,560 (10%)	12,287 (48%)	3,840 (15%)	6,911 (27%)
Southern Great Barrier Reef	22,724 (67.5%)	10,496 (31%)	316 (1%)	140 (0.5%)

* part of the Torres Strait

4 Discussion

4.1 Status of the dugong in the Northern Great Barrier Reef and Torres Strait

The 2013 aerial surveys confirm that the Northern Great Barrier Reef and Torres Strait support globally significant populations of dugongs. The standardised relative population estimate for the Torres Strait was almost 16,000 animals (± s.e. ~3,000); that for the Northern Great Barrier Reef ~6,500 ± s.e.~1,100) using the Pollock *et al.* (2006) methodology. These results confirm the importance of these areas compared with the Southern Great Barrier Reef, where dugongs are also a World Heritage Value (Figure 15).

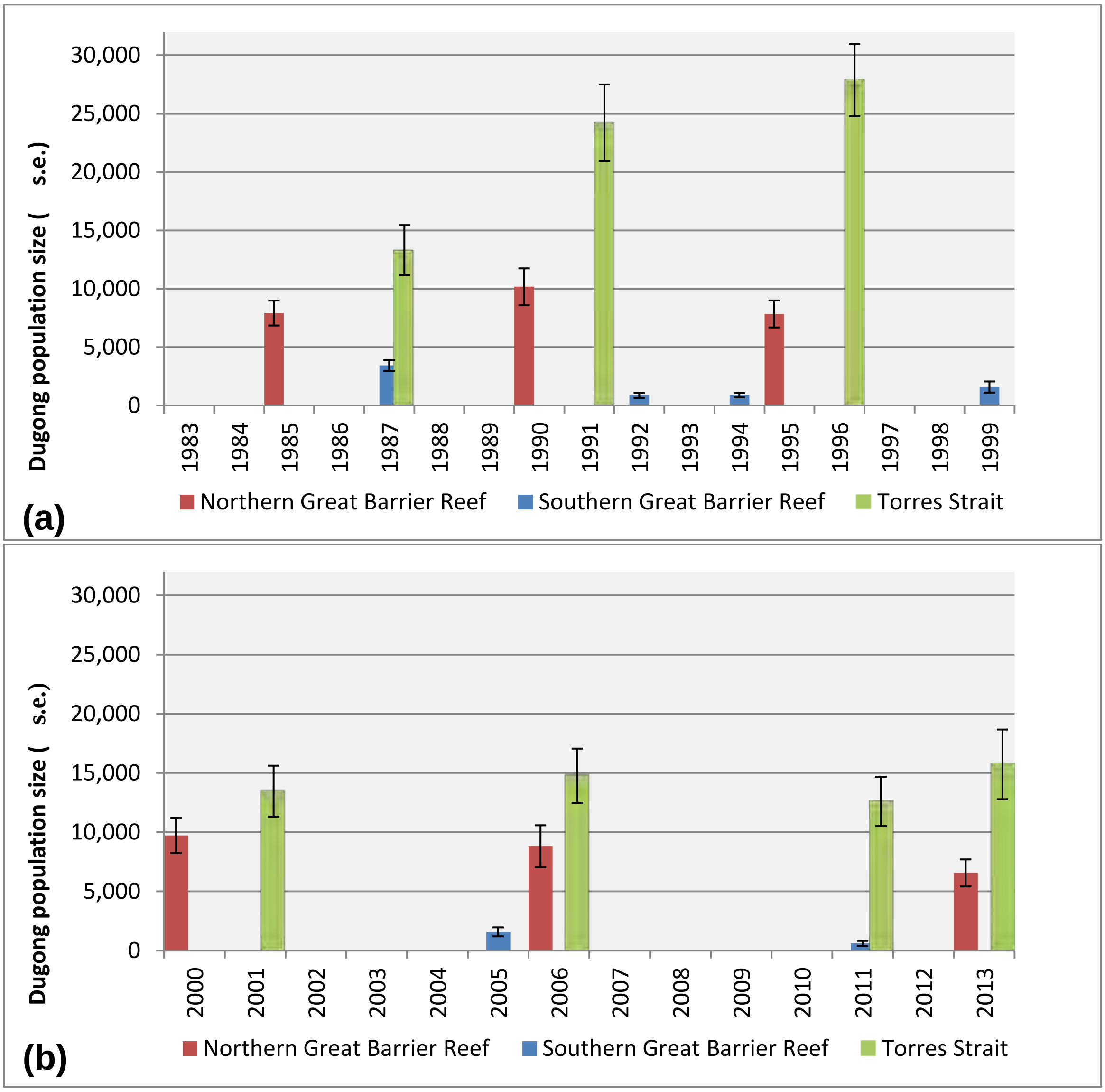


Figure 15: Dugong population size estimates for the Northern Great Barrier Reef, Southern Great Barrier Reef and Torres Strait (± s.e). (a) Estimates from 1985-1999 were obtained using the Marsh and Sinclair (1989a) method; (b) estimates from 2000-2013 were obtained using the Pollock *et al.* (2006) method. Data from Marsh *et al.*, 2007; Marsh *et al.*, 2011; Sobtzick *et al.* 2012; and this report. Note that the area surveyed in the Torres Strait from 2011 on was larger than in earlier surveys and this difference explains some of the difference between years. However, the 2015 estimate for Blocks 1-5 which were surveyed in all years since the Pollock *et al.* method (2006) was introduced is still higher than for any other year using this method.

Our aerial survey estimates of population size are standardised underestimates. Hagihara *et al.* (2014) studied dugongs fitted with satellite telemetry units and time-depth recorders (TDRs) in eastern Australia to investigate the influence of various environmental factors on dugong surfacing times. They found that the dugongs' availability for detection differed with water depth and that the dugong population estimates using depth-specific availabilities were generally higher than those obtained using availabilities that were constant across water depths (as we have done in this report). The availability bias is greater for animals in deeper waters. This underestimation is likely to be relatively larger in Torres Strait where only 9% of dugongs were sighted in water < 5 m deep than in the Great Barrier Reef where 53% of dugongs were sighted in shallow waters.

In the Northern Great Barrier Reef, no significant differences have been detected in dugong density since the time series of surveys began in 1987 using the Marsh and Sinclair (1989a) methodology or since the more robust Pollock *et al*. (2006) method was implemented in 2000 (Table 8). In Torres Strait there were some significant differences in dugong density between surveys prior to the Pollock *et al.* (2006) methodology being implemented in 2001 but none since then (Table 10). However, these results should be interpreted with caution because of the difficulty in detecting significant trends in marine mammal populations unless these trends are large (Taylor *et al.* 2007). We have not attempted an analysis to determine the power of our time series to detect trends because such analyses assume the availability bias is either constant across surveys or quantifiable. Given that the effect of bathymetry on diving behaviour (Hagihara *et al.* 2014) has not been quantified for dugongs in either the Northern Great Barrier Reef or Torres Strait, this assumption is not justified, especially as our time series of surveys indicate that dugongs are distributed differently within and among surveys blocks in different surveys (Tables 5, 8 and 10; Figures 4 and 10).

Our time series of aerial surveys also indicates that there are very large areas of very high and high dugong density in both the Northern Great Barrier Reef (~11,000 km^2) and Torres Strait (~20,000 km^2). In contrast, the Southern Great Barrier Reef has <500 km^2 of very high and high density dugong habitat (Table 11).

Despite these generally positive results, there are differences between the patterns of results for the two survey areas (Table 12). The dugong population estimate and mean density for the blocks common to all surveys of Torres Strait (Blocks 0-5) was the highest in the time series since the Pollock *et al.* (2006) methodology was first used in 2001, while the corresponding estimates for the Northern Great Barrier Reef were the lowest since 2000. In addition, the surveys suggest that the proportion of calves in Torres Strait has been increasing since 2000 while that in the Northern Great Barrier Reef has been decreasing (Figure 2 and Tables 4 and 12). The reasons for these differences are uncertain and discussed below.

Table 12: **Rank of performance indicators for surveys in the Northern Great Barrier Reef and Torres Strait.** Collectively these performance indicators indicate that the status of the dugong in the Northern Great Barrier Reef was worse than in Torres Strait in 2013. These indicators are suggested here because of the difficulties in detecting statistically significant change in marine mammal populations (Taylor *et al*. 2007). The indicators should be considered collectively rather than individually.

Performance indicator based on surveys for which required data[1] were collected[2]	**Northern Great Barrier Reef** N=3 except for % calves for which N=6	**Torres Strait** N=4 except for % calves for which N =6
Mean population size	Rank 3	Rank 1[4]
Mean density	Rank 3	Rank 1[4]
% calves[3]	Rank 6	Rank 1[5]

[1]data required by Pollock *et al.* (2007) methodology (NGBR 2000, 2006, 2013; Torres Strait 2001; 2006, 2011, 2013)
[2]rank 1 is best
[3] calculated from all surveys since 1980s
[4] blocks 0-5 only
[5] entire survey area

4.2 Possible reasons for differences between survey areas with regard to the status of the dugong in 2013

As explained in the Introduction, the apparent temporal variability in the size and/or distribution of the dugong population of large survey areas such as the Northern Great Barrier Reef or Torres Strait is likely to be the cumulative effect of several confounded factors: (1) temporal and spatial changes in the distribution of the dugong's seagrass food; (2) dugong movements between survey areas; (3) uncorrected fluctuations in the availability of dugongs to observers because of: (a) temporal and spatial variability in sighting conditions and (b) changes in the water depth in which dugongs are sighted because of their movements between and within survey blocks (Hagihara *et al.* 2014); and (4) temporal changes in the size of the population. It is impossible to be definitive about the influence of these confounded factors on time series for the two survey areas. We discuss each of these factors below with particular reference to the possibility suggested by the time series that the dugong population of the Northern Great Barrier Reef may be declining, even if this decline is not yet statistically significant.

4.2.1 Temporal and spatial changes in the distribution of the dugong's seagrass food

Marsh *et al.* (2011a) summarise the evidence that the life history and reproductive rate of female dugongs are adversely affected by seagrass loss which causes dugongs to breed later and less often. Meager and Limpus (2014) also demonstrated the adverse impact of sustained periods of elevated freshwater discharge, which is associated with seagrass loss, on dugong mortality. However, the effect of seagrass loss on reproduction cannot be separated from a possible density-dependent response to changes in population size. Seagrass loss due to extreme weather events in the Northern Great Barrier Reef is a plausible explanation for the differences in the calving rate since 2000 between the Northern Great Barrier Reef and Torres Strait. However, the required seagrass data are not available from either area to accept or reject this hypothesis (Rob Coles pers. comm. 2014) but tropical cyclones occur more frequently in the Northern Great Barrier Reef than in Torres Strait (http://www.bom.gov.au/) and are more likely to damage seagrass meadows in the former area.

4.2.2 Dugong movements between survey areas

Dugong movements have not been documented between the Northern Great Barrier Reef and Torres Strait although dugongs are certainly capable of moving distances equivalent to that between the two areas (Sheppard *et al.* 2006, Gredzens *et al.* 2014). The time series of surveys suggests considerable movement of dugongs between survey blocks within both the Northern Great Barrier Reef and Torres Strait survey areas (Tables 8 and 10). In addition, movements of dugongs between the Northern and Southern Great Barrier Reef have been established by satellite tracking (Sheppard *et al.* 2006) and are consistent with the genetic evidence (Blair *et al.* 2014 and unpublished). Thus population movement between the Northern and Southern Great Barrier Reef may explain some of the variation in the dugong population estimates of both these areas. Some of this movement may be associated with seagrass diebacks (Marsh and Kwan 2008, Marsh *et al*. 2011a) including the loss of seagrass resulting from the extreme weather events on the urban coast in 2010/2011 (Sobtzick *et al*. 2012, Rasheed *et al.* 2014).

4.2.3 Uncorrected fluctuations in the availability of dugongs to observers

There is evidence for uncorrected fluctuations in dugong density in the survey areas as discussed above. Until these changes in the availability bias are quantified, it will be impossible to evaluate how much they explain the temporal fluctuations in dugong population size in the Northern Great Barrier Reef and Torres Strait. However, in the Northern Great Barrier Reef, the pattern of dugong sightings across depth categories was not significantly different in 2006 and 2013 suggesting that this factor is unlikely to explain the (non-significant) difference in the population estimates obtained from the surveys conducted in those years.

4.2.4 Temporal changes in the size of the population

The greatest concern is that the dugong population in the Northern Great Barrier Reef may be declining due to unsustainable anthropogenic mortality from all sources rather than temporary emigration. It is impossible to evaluate this hypothesis without improved data on the size of the dugong population and anthropogenic mortality from all causes. This mortality information will be very difficult to obtain because of the remoteness of the area, which contributes to: (1) the lack of catch monitoring of the Indigenous harvest (which experience suggests will take many years to implement effectively), (2) the lack of observers on commercial fishing vessels and (3) the lack of a wildlife stranding program. In addition, it would be very difficult to estimate survivorship of such a large, dispersed population in such a large, remote area using alternative methodologies such as mark-recapture or close-kin genetic techniques because of the need to sample a relatively high proportion of the population over a large remote area.

4.3 Long-term risks to dugongs in the survey areas

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 populations 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 the Northern Great Barrier Reef and Torres Strait waters, except perhaps off the coast of Papua New Guinea where there may by an issue of food security. Condition (3) applies in both areas where dugongs and green turtles are hunted by the same people using the same vessels and equipment (see Delisle *et al.* 2014 for Torres Strait). In Torres Strait, many dugong and turtle hunters are also crayfishers and thus are able to hunt opportunistically while fishing (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 Great Barrier Reef, netting no longer occurs in >90% of dugong habitat as explained below (Grech *et al.* 2008) 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.; Marsh unpublished) and an estimated 90% of high density dugong habitat is not hunted (Grech and Marsh unpublished data). In addition, about two-thirds of the high density dugong habitat in Torres Strait is never hunted as explained below (Grayson 2011, Grech and Marsh unpublished). The high proportion of the dugong habitat that is never hunted undoubtedly contributes to the sustainability of dugong hunting in these areas.

4.3.1 Key threats

Dugongs are long-lived and slow to mature. The greatest risk to dugongs comes from anthropogenic mortality (Marsh *et al.* 2011a). The major sources of direct anthropogenic mortality to dugong in the Northern Great Barrier Reef and Torres Strait are:

(1) Unknown levels of harvest by Indigenous peoples (both areas);
(2) The bycatch of dugongs in commercial fishers using large mesh nets (Northern Great Barrier Reef);
(3) Unknown levels of harvest by neighbouring countries of the Asia/Pacific region, especially Papua New Guinea (Torres Strait);
(4) Illegal poaching by Australians and foreign fishers (both areas but especially Torres Strait);
and
(5) Entanglement in and ingestion of marine debris (unquantified but some risk in Torres Strait).

In contrast to the Southern Great Barrier Reef and especially Moreton Bay, there is no contemporary evidence that vessel strike is a significant mortality factor in the Northern Great Barrier Reef or Torres Strait, because the overlap between vessel traffic and dugong habitat is at present relatively low.

In our opinion, the major risks to the dugong in this area are Points 1-4 above. It is impossible to evaluate the relative impact of these threats without additional data. The first four risks above are considered in the Management Options below. We also discuss the potentially burgeoning risk to the generally pristine dugong habitats in the survey area (see Halpern *et al.* 2008) from oil spills and damage to seagrass beds as a result of the increase in commercial shipping through the reef and Torres Strait resulting from current and proposed port expansions along the urban Great Barrier Reef coast (e.g., Grech *et al.* 2013).

As part of its election promise, the current Australian government committed $700,000 towards cleaning up marine debris along the Far North Queensland Coast, the Torres Strait Islands and in the Coral Sea on the understanding that marine debris – especially 'ghost nets' – provide significant risks to dugongs and turtles[1] and the management of this risk is not discussed further here. However, the impact of ghost nets on dugongs in both Torres Strait and the Northern Great Barrier Reef is unknown an likely to be very low at least in the Northern Great Barrier Reef (K. Dobbs GBRMPA, pers. comm. 2014).

4.4 Management options

It is inevitable that dugongs in the Great Barrier Reef World Heritage Area will be managed separately from dugongs in Torres Strait as a result of the very different jurisdictions operating in the two areas and their associated laws. Accordingly, we discuss the management options for each area separately below. We also discuss the need for co-ordinated management across both jurisdictions.

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[1] http://www.greghunt.com.au/Home/LatestNews/tabid/133/articleType/ArticleView/articleId/2611/Coalition-announces-Dugong-Turtle-Protection-Plan.aspx

4.4.1 Northern Great Barrier Reef

As discussed above, some dugong population indicators are less positive for the Northern Great Barrier Reef than for Torres Strait, although the reasons for the differences are uncertain and likely complex. However, in view of the difficulty of detecting trends in the abundance of marine mammals (Taylor *et al.* 2007), we suggest that management of the dugong population in this area should be precautionary. Given their Native Title rights, it will be vital to continue to negotiate management arrangements that are fully supported by the region's Traditional Owners. The remoteness of the area makes conventional surveillance and enforcement extremely expensive, hence the GBRMPA program of Indigenous compliance training and dedicated rangers.

4.4.1.1 Management of Indigenous hunting

The current Australian Government's policy is to work with Indigenous leaders towards an initial two-year moratorium on the taking of dugongs[2]. Within the Great Barrier Reef, the practice has been to support Traditional Owners to assert their cultural authority over sea country and voluntarily regulate the dugong and turtle harvest through the Traditional Owners developing formal agreements, the Traditional Resource Use Management Agreements or TUMRAs (Havemann *et al.* 2005). Two TUMRAs have been accredited within the Northern Great Barrier Reef survey area:

- the Lama Lama TUMRA covering sea country that extends through Princess Charlotte Bay to the Normanby River[3];
- the Wuthathi TUMRA covering sea country in the Shelburne Bay area of Cape York[4].

In addition, the implementation of the Kuuku Ya'u People's Indigenous Land Use Agreement (ILUA) is managed in the same way as a Traditional Use of Marine Resources Agreement. This ILUA recognises Traditional Owner native title rights and interests in the management of nearly 2000 km^2 of sea within the Great Barrier Reef Marine Park, in an area north of Lockhart River. This agreement includes a limit on the annual take of dugongs from the ILUA area in a calendar year. This number is usually 15 but may vary, subject to determination procedures set out in the ILUA.

Formal agreements have not yet been accredited for the main hunting areas of several key communities adjacent to the Northern Great Barrier Reef, such as Lockhart River, Hope Vale and the Northern Peninsula Area communities. We understand that some communities are in the process of negotiating hunting rules. As for the Torres Strait communities (Marsh *et al.* 2011a), the draft hunting rules for Lockhart River are largely aimed at regulating the behaviour of young hunters with respect to cultural norms. In their evaluation of the development and implementation of the now defunct Hope Vale Aboriginal Community Green Turtle and Dugong Hunting Management Plan, which was finalised in 2000, Nursey-Bray *et al.* (2010) 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.

TUMRAs for the key communities adjacent to the Northern Great Barrier Reef are likely to be more challenging to negotiate than those negotiated to date. We recommend that these negotiations are given high priority by the Great Barrier Reef Marine Park Authority and the Queensland Government, especially in view of the dugong population indicators reported here.

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[2]http://www.greghunt.com.au/Home/LatestNews/tabid/133/articleType/ArticleView/articleId/2611/Coalition-announces-Dugong-Turtle-Protection-Plan.aspx

[3] http://www.gbrmpa.gov.au/__data/assets/pdf_file/0006/90393/map-of-Lama-Lama-TUMRA-region.pdf

[4]http://www.gbrmpa.gov.au/__data/assets/pdf_file/0003/4791/gbrmpa_Wuthathi_TUMRA_Region_Map_A3_Schedule_2.pdf

Anecdotal information provided to Marsh by Traditional Owners at Lockhart (in 2014) and Hope Vale (in the 1980s and 1990s) indicates that most hunting occurs close to shore and relatively close to communities. The constraints on hunting are similar to those in Torres Strait (Grayson 2011, Delisle 2013, Delisle *et al.* 2014): the incomes of Traditional Owners are low, fuel is expensive and outboard engines are often out of commission and unable to be repaired in the community. Thus at present, hunting rarely occurs in a very high proportion (>90% Grech and Marsh unpublished) of the high density dugong habitats off Cape York (Figure 12). Thus most of the dugong habitat off Cape York currently operates as an unofficial dugong sanctuary with respect to hunting. However, improved road access is opening up much more of the coastal areas of Cape York for legal (and illegal) hunting and potentially other anthropogenic mortality factors. Our survey results indicate an almost continuous distribution of dugongs along much of the Cape York coast (Figure 12) and improved road access will provide access to many more places to launch boats and stockpile fuel. We suggest that it would be appropriate for the negotiations between the key communities off Cape York and the management agencies to concentrate on the definition and enforcement of the boundaries for hunting areas rather than on allowable catches or hunting moratoria, especially in view of: (1) the uncertainty about the dugong population sizes and trends explained above; (2) the current rapid improvement in road access; and (3) the challenges of implementing a robust system of catch recording explained above.

4.4.1.2 Management of illegal hunting

The Australian Government is in the process of introducing Federal legislation to triple the penalties for poaching and illegal transportation of turtle and dugong meat[5]. The Traditional Owners at Lockhart River advised Marsh in 2014 that they are most concerned about poaching from Indigenous hunters based at Weipa on the western side of Cape York. The Lockhart Traditional Owners try to prevent these poachers hunting in their sea country by blocking their road access with a locked gate. This example reinforces the need to manage road access to the dugong habitats along the Cape York coast that have been documented by the JCU time series of aerial surveys (Figure 12).

4.4.1.3 Management of commercial fishing using large mesh nets

The changes in the management arrangements in the last 10 years or so have greatly reduced the risk to dugongs from commercial large mesh netting in the Northern Great Barrier Reef. Grech *et al.* (2008) estimated that commercial netting was banned from approximately 64% of the high density dugong habitat, 44% of medium density dugong habitat and 31% of low density habitat based on the spatial models generated from the James Cook University aerial survey data to 2006. However the actual area where netting is conducted at the time of their study is much less than these figures indicate due to the coarse resolution of recorded effort and changes since their paper was published. Grech *et al.* (2008) identified areas where additional spatial closures would significantly reduce the remaining risk of netting to dugongs including Lookout Point in the Starke River region (Block N2), and Friendly Point (Block N6). As they pointed out, it would also be useful to review the efficacy of the arrangements for the Bathurst Head region in Princess Charlotte Bay (Block N5 - this region is partly covered by some of the Princess Charlotte Bay Special Management Area in marine parks managed by the Commonwealth and Queensland Governments, where commercial netting using large mesh nets is limited to licence holders who have a specific fishing history. The 2014 state government review of the management of Queensland fisheries http://www.daff.qld.gov.au/fisheries/consultations-and-legislation/reviews-surveys-and-consultations/fisheries-management-review/terms-of-reference provides an additional and welcome opportunity to consider these matters. Additional spatial closures to commercial netting in the northern Great Barrier Reef region could assist negotiations between Traditional Owners and Management Agencies about the spatial management of dugong hunting in the Northern Great Barrier Reef along the lines suggested above.

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[5]http://www.greghunt.com.au/Home/LatestNews/tabid/133/articleType/ArticleView/articleId/2611/Coalition-announces-Dugong-Turtle-Protection-Plan.aspx

4.4.1.4 Management of ports and shipping

In response to concerns about current port expansion along the urban Great Barrier Reef coast (e.g., Grech *et al.* 2013), the Queensland government developed the Queensland Ports Strategy (State of Queensland 2014) as a blueprint for managing and improving the efficiency and environmental management of the state's ports network over the next decade. The Strategy established five Priority Port Development Areas: Abbot Point, Brisbane, Gladstone, Hay Point/Mackay, and Townsville (none of which is in the Northern Great Barrier Reef). The Strategy also prohibits capital dredging outside these Priority Port Development Areas in waters within and adjoining the Great Barrier Reef World Heritage Area for the next ten years, thus prohibiting capital dredging of all ports in the Northern Great Barrier Reef during that period. However, the Strategy *per se* will not prevent the establishment of a proposed port to export coal from the Wongai Project in the Laura Basin, because there is no dredging involved and the proposal pre-dates the Queensland Ports Strategy. The proposed port is in Bathurst Bay, a high density dugong area (Figure 12), which also supports a population of the rare Australian snubfin dolphin (Parra *et al.* 2006 and H. Penrose unpublished data 2014). A port in Bathurst Bay would be of conservation concern because it would increase the risk of mortality from vessel strike to both species of marine mammals, introduce coal dust into the Great Barrier Reef (Burns 2014) and perhaps negatively affect seagrass from increased sedimentation from vessel propellers stirring up the seabed in shallow areas.

An additional concern is the projected increase in vessel traffic traversing the Northern Great Barrier Reef as a result of the port expansion along the urban Great Barrier Reef coast. The shipping lane passes close to the major dugong habitats between Cape Flattery and Cape Melville (see Figure 12) and this region has been identified as a Marine Environment High Risk Area (Qld Transport and GBRMPA 2000).

4.4.2 Torres Strait

Our standardized aerial surveys since 1987 have not detected a decline in the dugong population of Torres Strait suggesting that the current level of anthropogenic mortality is likely to be sustainable. In addition, the population is genetically healthy (Blair *et al.* 2014) and the results of our 2013 survey indicate that that calf counts are very high suggesting excellent breeding conditions.

4.4.2.1 Management of Indigenous hunting

In the light of these positive indicators, we consider that the major priority for dugong management in Torres Strait should be the continued support of the culturally acceptable and scientifically robust community-based mechanisms to manage Indigenous hunting. Alternative management approaches such as meat subsidies, a moratorium on the catch, or a ban on the transport of dugong meat from Torres Strait to mainland Australia are almost certain to be expensive, unenforceable and have serious negative impact on the status of the dugong in the Great Barrier Reef World Heritage Area (Delisle 2013, Delisle *et al.* 2014).

The recent progress with community-based management of the Torres Strait dugong and turtle harvest has been remarkable. With funding from the Australian Government, project officers employed by the Torres Strait Regional Authority have worked with 15 Indigenous communities to develop community-based Turtle and Dugong Management Plans. These plans have reinforced the statutory management arrangements imposed by the Commonwealth *Torres Strait Fisheries Act 1984* and its regulations by reinforcing cultural practices and protocols designed to control hunting (Marsh *et al.* 2011a). These plans are now being implemented with substantial funding from the Australian Government. This work needs to be appropriately supported with long-term program funding from government.

The determination of a sustainable catch for the Torres Strait dugong fishery will require robust information on the sizes of both the dugong population and the catch. As discussed above, the relative population estimates obtained from our aerial surveys of Torres Strait (Table 9) are likely to be substantial underestimates, because of the bathymetry of Torres Strait. Hagihara *et al.'s* (2014) research was carried out on dugongs in a very different bathymetric environment to Torres Strait and so it will be important to replicate this work in Torres Strait to obtain availability correction factors appropriate to that area. Such research is planned for late 2014 as a collaboration between James Cook University and the Torres Strait Regional Authority.

Reliable estimates of the current dugong catch of each of the major hunting communities will also be necessary to evaluate the likely sustainability of the dugong harvest. Grayson (2011) offers important insights into how catch monitoring might be effectively implemented by transferring the reporting burden from the hunters to Indigenous survey agents, who will be trained to collect longitudinal data from each hunter at regular intervals. In work commissioned by TSRA, this longitudinal approach is being adapted from techniques used to survey recreational fishers (Pollock *et al.* 1994) and widely used in Australia for national and State surveys of recreational fishers (Lyle *et al.* 2002, Henry and Lyle 2003).

The third step required to establish an appropriate total allowable catch for the Torres Strait dugong fishery will be to decide on a regional objective for dugong management. It will be important for the Traditional Owners to decide whether they wish to maintain the population at its present level or to allow it to increase. This decision is a fundamental pre-requisite to developing catch quotas for this fishery, which must include the harvest of the Papua New Guinean villagers and the peoples of the Northern Peninsula Area. We suggest that TSRA facilitate further discussions between the Torres Strait Traditional Owners, the Papua New Guinea villagers and the peoples of the Northern Peninsula Area about this matter.

The current Dugong Management Plans have been developed separately by each community. The development of a total allowable catch for the Torres Strait dugong fishery will also require these plans to be co-ordinated across communities to allocate the total allowable catch among communities in an agreed manner. Gredzens *et al.* (2014) demonstrated using GPS satellite telemetry that the home ranges of dugongs in Torres Strait are generally much larger than those in the other areas where dugongs have been tracked (e.g., Hervey Bay, Shoalwater Bay and Cleveland Bay, Australia; Lease Islands, Indonesia). Individual animals ranged widely across the sea countries of Torres Strait communities; one animal crossed the international boundary between Australian and Papuan New Guinean waters. These results indicate the need for co-ordinated management of dugongs across jurisdictions.

Further consideration of spatial closures as a management tool will also require cross-jurisdictional collaboration, if this approach is supported by the Traditional Owners in the post-Native Title environment of Torres Strait. Grayson (2011) demonstrated that most hunting occurs within 30 km of communities and that consequently much of the high density dugong area in Torres Strait (Figure 14) is never hunted. Grech and Marsh (unpublished 2012) extended this work to demonstrate that only about 40% of high and very high dugong density in Torres Strait is actually hunted. The official Dugong Sanctuary in western Torres Strait comprises about a third of the unhunted area; the remainder is an unofficial sanctuary that results from: (1) cultural protocols that dictate where hunting should occur; (2) the *Torres Strait Fisheries Act* 1984 (C'lth) requirement that hunting must be carried out from vessels 6 m long or less, thereby limiting the amount of fuel that can be carried; and (3) the Torres Strait Islanders' double burden of low incomes and high commodity prices (Delisle 2013), especially the high cost of fuel in Torres Strait up to $3 a litre.

Our spatial model (see Figure 14) could be used by Traditional Owners to inform the design of future spatial closures. We suggest that the TSRA continue to give high priority to further 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 of the high density dugong areas as a no-hunting areas for an agreed period; and (2) determining how the Dugong Sanctuary might be extended. The case for closing additional areas to traditional hunting will also be enhanced by the current work being conducted by JCU in collaboration with CSIRO on the data on the distribution and relative abundance of the large turtles seen on dugong aerial surveys (Appendix 5b) because dugongs and turtles are hunted together (Delisle *et al.* 2014) and there is a move to make the Dugong Sanctuary a Dugong and Turtle Sanctuary.

4.4.2.2 Management of illegal hunting

Delisle *et al.'s* (2014) study of the amount of dugong and turtle meat consumed by the Torres Islander Diaspora and their information about the process of sharing dugong and turtle meat do not accord with allegations of an organised practice of 'illegal killing, poaching and transportation of turtle and dugong meat' (see http://www.greghunt.com.au/Media/MediaReleases/tabid/86/articleType/ArticleView/articleId/2638/Coalition-announces-Reef-2050-Plan.aspx). However, it is likely that illegal, unreported and unregulated (IUU) vessels capture dugongs in Torres Strait and Coastwatch sightings indicate the number of such vessels increased in recent years (Field *et al.* 2009). There is evidence of dugong artefacts (bones, teeth, tears and oil) being sold in Bali markets in 2013 (Nijman and Nekaris 2014), which accords with accounts of Indonesian traders travelling along the coast of Papua New Guinea to buy such artefacts along with other marine products (Sara Busilacchi CSIRO pers. comm. 2013). We suggest that it would be appropriate for the Australian Crime Commission investigation into the practice of illegal killing, poaching and transportation of turtle and dugong meat to investigate dugong captures by IUU vessels and the allegations of illegal trade on the Papua New Guinea coast.

4.4.2.3 Management of commercial fishing

In contrast to the situation on the north-eastern coast of Australia, we understand that the incidental catch of dugongs in large mesh nets set by commercial operators rarely occurs in Torres Strait except: (1) possibly in parts of the Northern Peninsula Area and (2) definitely in the Treaty villages along the Papua New Guinea coast (where the development of alternative livelihoods will be a pre-requisite for effective change in practice). In Australian waters, the biggest indirect impact on dugongs of changes to commercial fishing arrangements in Torres Strait would be to provide Indigenous crayfishers with excise relief on fuel. This action would probably have the unintended consequence of increasing hunting as most Indigenous crayfishers also hunt dugongs and turtles (Kwan *et al*. 2006).

4.4.2.4 Management of ports and shipping

Waterhouse *et al.* (2012) conducted a qualitative assessment of the key threats to the Torres Strait from water quality issues. They concluded that the threats from poor waters quality to the environmental values of the area are currently relatively minor and that the largest threats in the future are most likely to be associated with the transit of many more large ships through the area. The volume of shipping transiting Torres Strait waters is projected to increase dramatically in the near future as a result of: (1) the port expansion along the urban Great Barrier Reef coast (Grech *et al.* 2013); (2) the development of a deep water sea port off the Island of Daru for the export of resources from the Ok Tedi Mine; and (3) expanded transhipment opportunities for other bulk commodities from PNG and northern Australia. Waterhouse *et al.* (2012) conclude that these increases will result in greatly increased risk of accidents such as oil spills in the Torres Strait. Currently there is very limited capacity to respond in any meaningful way to a large oil spill in Torres Strait. Because of the limited water exchange in and out of Torres Strait, there are concerns that if Torres Strait water became polluted, it would probably remain for some time, posing a risk to the seagrass communities on which dugongs depend and to the animals themselves (Marsh *et al*. 2011a). Islanders blame the extensive seagrass dieback event that occurred in Torres Strait in the 1970s on the oil spill from the *Oceanic Grandeur* in March 1970 (Johannes and McFarlane 1991). However, this conclusion does not accord with the oceanographic evidence. The map of dugong distribution and abundance resulting from our aerial surveys (Figure 14) could inform the development of oil spill response capability in Torres Strait.

4.5 Need for coordinated management

Despite the jurisdictional and logistical differences between Torres Strait and the Northern Great Barrier Reef, there are several reasons why it is important that dugong management is co-ordinated across these jurisdictions:

(1) It is likely that dugongs move from one area to another, especially in the Northern Peninsula Area;
(2) The Northern Peninsula Area straddles the two areas;
(3) There is considerable potential for mutual learning though a program of shared adaptive management;
(4) Management practices in one area have the potential to impact on the status of dugong stocks in the other area as a result of displaced effort.

Genetic, satellite tracking and aerial survey data all indicate that the appropriate ecological scale for management is some hundreds of kilometres (Sheppard *et al.* 2006, Blair *et al.* 2014, Gredzen *et al.* 2014). 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, we suggest that priority be given to joint policy for managing dugong hunting by the Northern Peninsula Area communities. There would also be considerable advantages to encouraging mutual learning e.g. with respect to catch monitoring.

In addition, it will be important to: (1) coordinate management across the dugong's range in Australia, under the proposed National Dugong and Turtle Protection Plan[6]; and (2) continue discussions with Papua New Guinea to identify ways in which arrangements for management of 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) and the Guiding Framework that resulted from the Daru Turtle and Dugong Workshop held in February 2009 indicated that community leaders from the Treaty villages are keen to build on that experience (Marsh unpublished data).

The Great Barrier Reef Marine Park Authority has determined that the ecological objective of dugong management in the GBRWHA should be population recovery (GBRMPA 2013). As mentioned above, the relevant management authorities and Traditional Owners need to decide on a regional objective for dugong management in Torres Strait. 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 the proposed National Dugong and Turtle Protection Plan.

The surveys conducted are expensive, especially the costs associated with keeping a crew on the ground in remote areas when the weather conditions are unsuitable for dugong survey work. In addition, the risks associated with flying light aircraft low over the sea in remote areas are not inconsequential. These problems could be reduced by using Unmanned Aerial Vehicles for dugong aerial surveys in the Northern Great Barrier Reef and Torres Strait when the technology matures (see Hodgson *et al.* 2013).

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[6] http://www.greghunt.com.au/Home/LatestNews/tabid/133/articleType/ArticleView/articleId/2611/Coalition-announces-Dugong-Turtle-Protection-Plan.aspx

5 Recommendations

5.1 Management

(1) That the major priority for dugong management in Torres Strait and the Northern Great Barrier Reef be on-going support for the implementation of community-based management.

(2) That the agencies responsible for dugong management in both areas give high priority to: (1) exploring the acceptability of the use of spatial closures to hunting as a management tool with the Traditional Owners; (2) minimising the hazard posed to dugongs and their habitats by the expansion of ports and shipping, and (3) facilitating complementary dugong management across and within justifications, especially the Northern Peninsula Area.

(3) That the TSRA give high priority to: (1) implementing a program to record robust estimates of the current dugong and turtle harvest from all the major hunting communities in Torres Strait, (2) sharing learnings from the catch monitoring process with the agencies responsible for managing the dugong harvest in the Great Barrier Reef World Heritage Area, and (3) continuing negotiations with Papua New Guinea through the PZJA about extending spatial closures in Torres Strait.

5.2 Research and monitoring

(1) That the dugong aerial surveys be continued at regular (typically 5-year) intervals for the combined area of the Northern Great Barrier Reef and Torres Strait with the next survey occurring in November 2018.

(2) That geo-referenced data on dugong diving behaviour in Torres Strait and the Northern Great Barrier Reef be obtained with high priority to improve the corrections for availability bias in the Pollock *et al*. (2006) method.

(3) That when the technology matures (see Hodgson *et al.* 2013), consideration be given to the feasibility of using Unmanned Aerial Vehicles for dugong aerial surveys in the Northern Great Barrier Reef and Torres Strait to reduce the risks associated with using manned low flying aircraft in remote areas as was done in these surveys.

(4) That a long-term comprehensive seagrass monitoring program be established for the northern Great Barrier Reef and Torres Strait with particularly emphasis on the seagrass habitats that support significant densities of dugongs.

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APPENDICES

APPENDIX 1: Scales for environmental conditions

Water visibility Scale

Visibility	Water Quality	Depth Range	Visibility of Sea Floor
1	Clear	Shallow	Clearly visible
2	Variable	Variable	Visible but unclear
3	Clear	Deep	Not visible
4	Turbid	Variable	Not visible

Glare Scale

Glare	Proportion of view affected
0	No glare
1	< 25% of view affected
2	25-50% of view affected
3	> 50% of view affected

APPENDIX 2: Sampling intensity

Areas of survey blocks and sampling intensity for each block for the aerial surveys conducted (a) in 2000, 2006 and 2013 in the northern Great Barrier Reef and (b) 2001, 2006, 2011 and 2013 in the Torres Strait. Historical data from Marsh and Lawler, 2002; Marsh *et al.*, 2003; Marsh *et al.*, 2007; and Marsh *et al.*, 2011.

(a) Northern Great Barrier Reef

	2000		2006		2013	
Block	**Area (km^2)**	**Sample Intensity (%)**	**Area (km^2)**	**Sample Intensity (%)**	**Area (km^2)**	**Sample Intensity (%)**
N1	1040	17.2	1041	9.0	1046	8.8
N2	673	17.5	674	16.7	677	16.9
N3	1055	16.8	1049	17.2	1055	17.6
N4	5526	8.7	3598	8.9	3616	9.0
N5	7991	8.7	7281	8.8	7276	9.0
N6	463	8.6	464	8.7	464	8.8
N7	389	22.0	1064	8.8	1067	9.1
N8	977	8.4	982	8.5	979	8.7
N9	3075	8.6	2905	8.6	2900	8.8
N10	277	8.9	278	9.0	278	9.2
N11	428	24.9	430	25.3	429	25.3
N12	314	9.2	415	9.1	413	3.7
N13	4564	8.7	4838	8.4	4827	6.3
N14	224	22.3	225	22.5	225	23.1
N15	ns	ns	260	12.3	345	9.7

(b) Torres Strait

	2001		2006		2011		2013	
Block	**Area (km^2)**	**Sample Intensity (%)**	**Area (km^2)**	**Sample Intensity (%)**	**Area (km^2)**	**Sample Intensity (%)**	**Area (km^2)**	**Sample Intensity (%)**
0	2172	4.4	2339	5.6	1735	4.9	1758	4.4
1A	2657	8.5	2452	4.5	2207	7.4	2160	8.9
1B	3784	4.3	3848	4.6	3169	4.4	3027	4.9
2A	4339	8.4	4420	8.4	4331	8.2	4324	8.2
2B	3290	8.4	3363	8.6	3317	8.6	3283	8.6
3	9651	4.1	9666	4.3	9670	4.2	9582	4.5
4	3636	4.3	3436	8.6	3651	4.3	3638	4.4
5	1031	10.2	1022	10.9	1015	10.3	1015	11.2
6	ns	ns	ns	ns	1638	4.0	1769	3.9
7	ns	ns	ns	ns	3795	3.5	3840	3.6
8	ns	ns	ns	ns	4688	4.6	4596	4.9
9	ns	ns	ns	ns	2421	4.7	2651	4.5

APPENDIX 3: Weather conditions

(a) Weather conditions encountered during the 2013 aerial surveys of the **Northern Great Barrier Reef** in comparison to the prior surveys of the same areas: historical data from Marsh *et al*. (2007).
Means of modes for each transect

Year of survey		1985	1990	1995	2000	2006	2013
Max wind speed ($km*h^{-1}$)		<28	<15	<15	<18	<15	<11
Cloud cover range (oktas)		0-5	0-7	2-7	2-8	0-8	1-8
Cloud height range (ft)		305-1525	1500-35000	305-1220	300-10000	1500-2000	2500-6000
Beaufort sea state# (range)		1.5 (0-4)	1.5 (0-3)	3 (1-4)	1.65	1.9 (0-4)	1.72 (0-4)
Glare# (range)	**North**				1.44 (0-3)	1.95 (0-3)	1.16 (0-3)
	South				1.69 (0-3)	1.16 (0-3)	1.73 (0-3)
	Overall	1 (0-2.5)	2.2 (1-3)	1.5 (0-3)	1.9 (0-3)	2.21 (0-3)	1.48 (0-3)
Air visibility (km)		>8	N/A	>10	>10	>10	>10

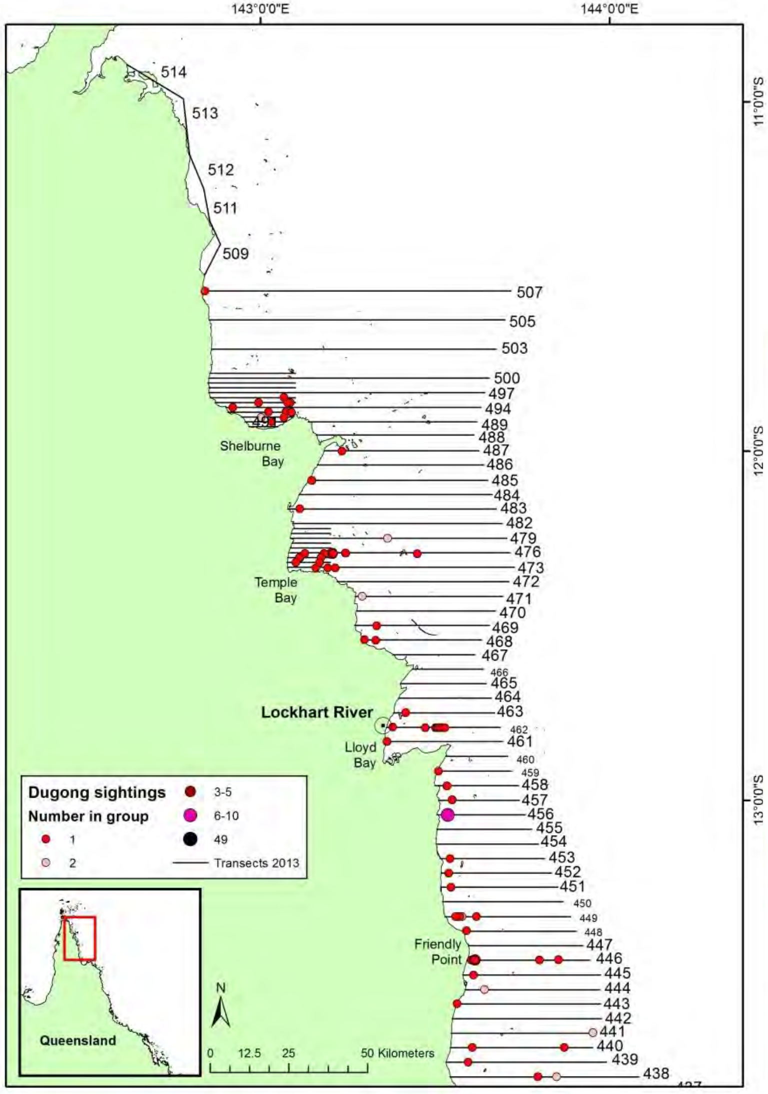
(b) Weather conditions encountered during the 2013 aerial surveys of **Torres Strait** in comparison to the prior surveys of the same areas: historical data from Marsh *et al*. (2007) and (2011b).

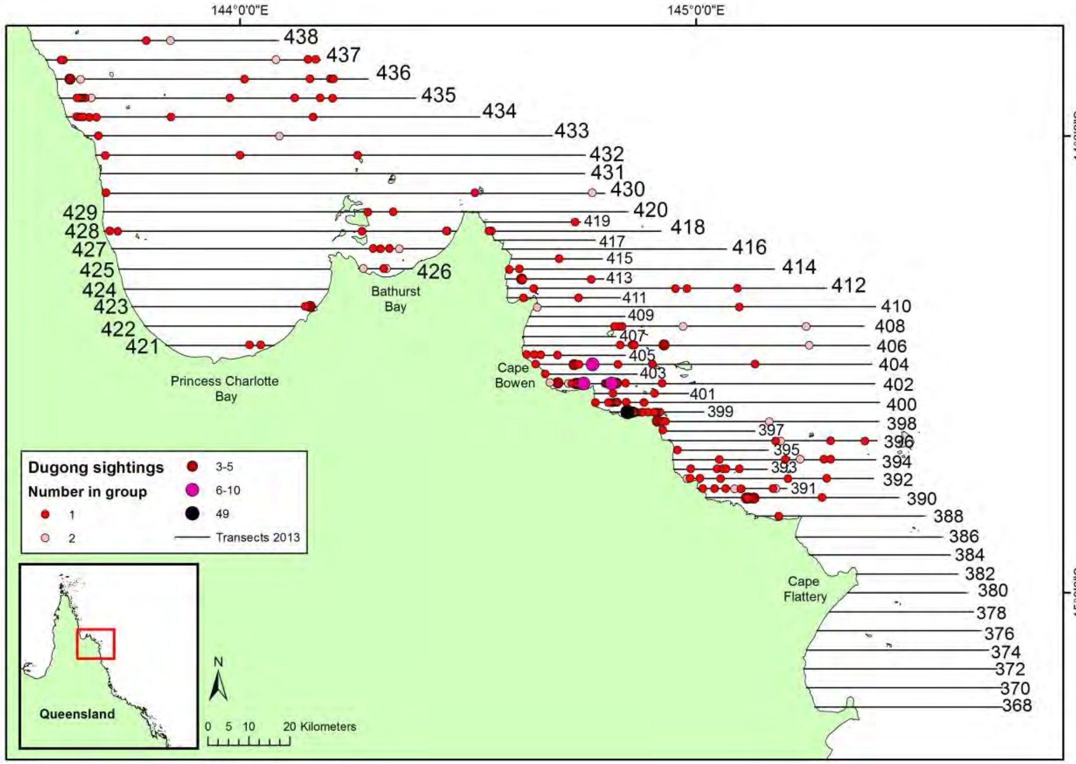
Means of modes for each transect

Year of survey		1987	1991	1996	2001	2006	2011	2013
Max wind speed ($km*h^{-1}$)		<15	<15	<10	<15	<15	<11	<14
Cloud cover range (oktas)		1-8	0-5	0-7	0-7	1-6	2-8	1-8
Cloud height range (ft)		270-4000	460-750	1000-5000	2000-5000	1000-2000	1200-3000	1000-4500
Beaufort sea state# (range)		1.3 (0-4)	1.9 (0-4)	1.1 (0-3)	1.4 (0-3)	2.2 (0-3)	1.3 (0-4)	2.3 (1-4)
Glare# (range)	**North**	1.4 (0-3)	1.7 (0-3)		0.9 (0-3)	1.91 (0-3)	2.1 (0-3)	1.4 (0-3)
	South	0.75 (0-3)	2.3 (0-3)		1.3 (0-3)	1.32 (0-3)	1.69 (0-3)	2.24 (0-3)
	East							1.29 (0-3)
	West							2.24 (0-3)
Air visibility (km)		N/A	>20	>10	>20	>10	>10	>10

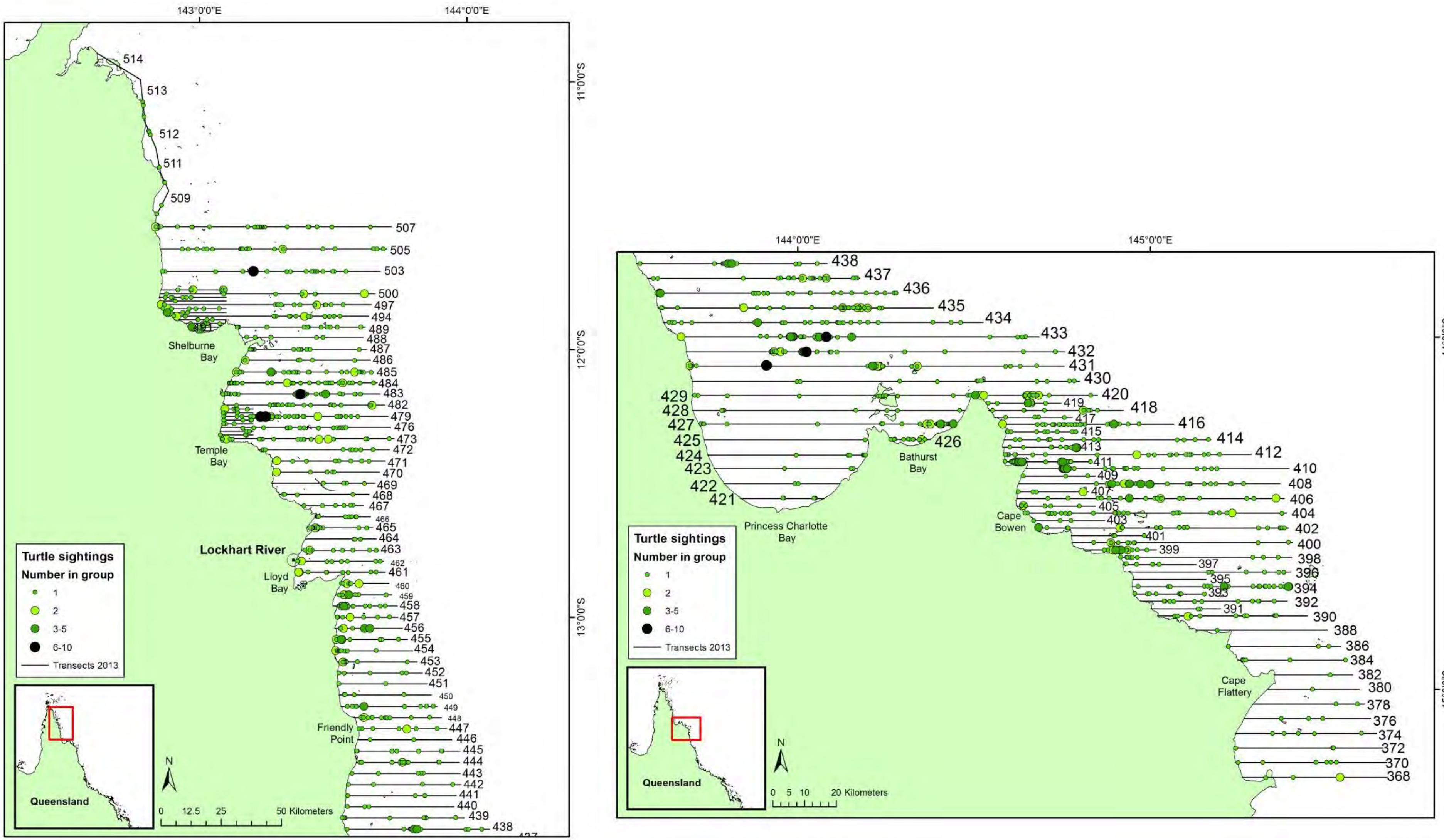
APPENDIX 4: Animal sightings in the Northern Great Barrier Reef

(a) GPS tracks of transects (three digit numbers) surveyed in the Northern Great Barrier Reef in November 2013 and the position and number of **dugongs** sighted.

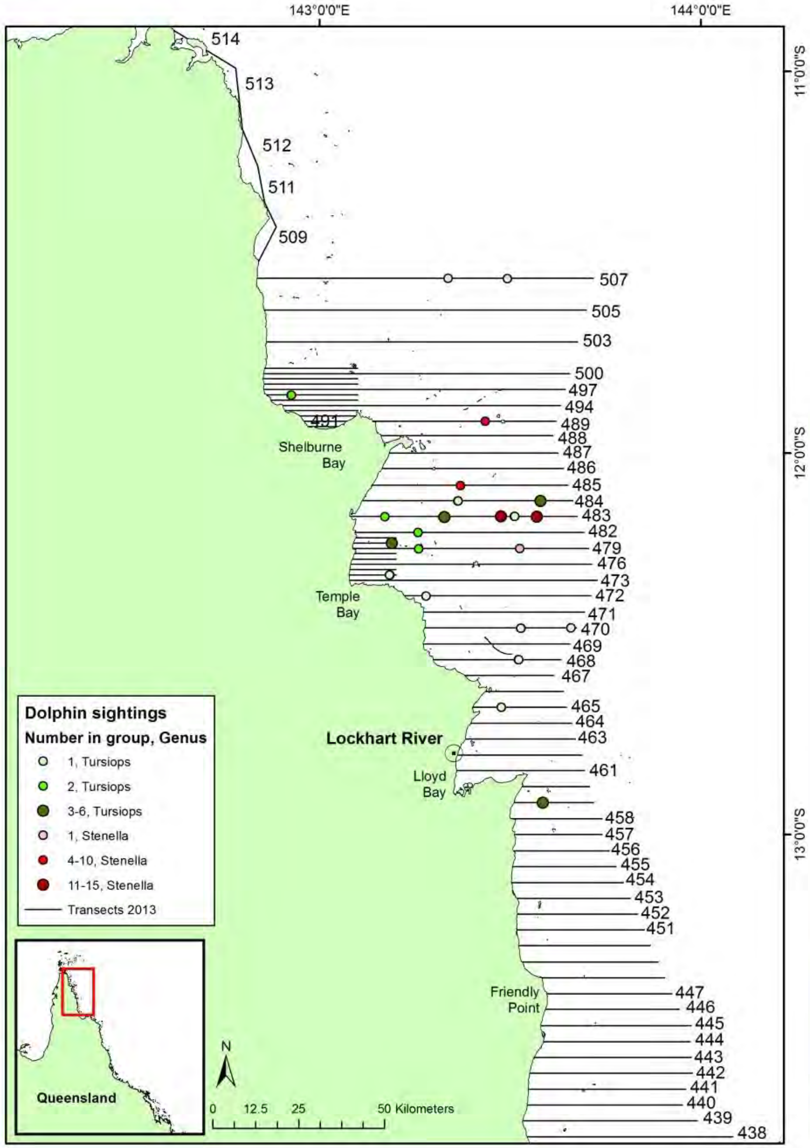


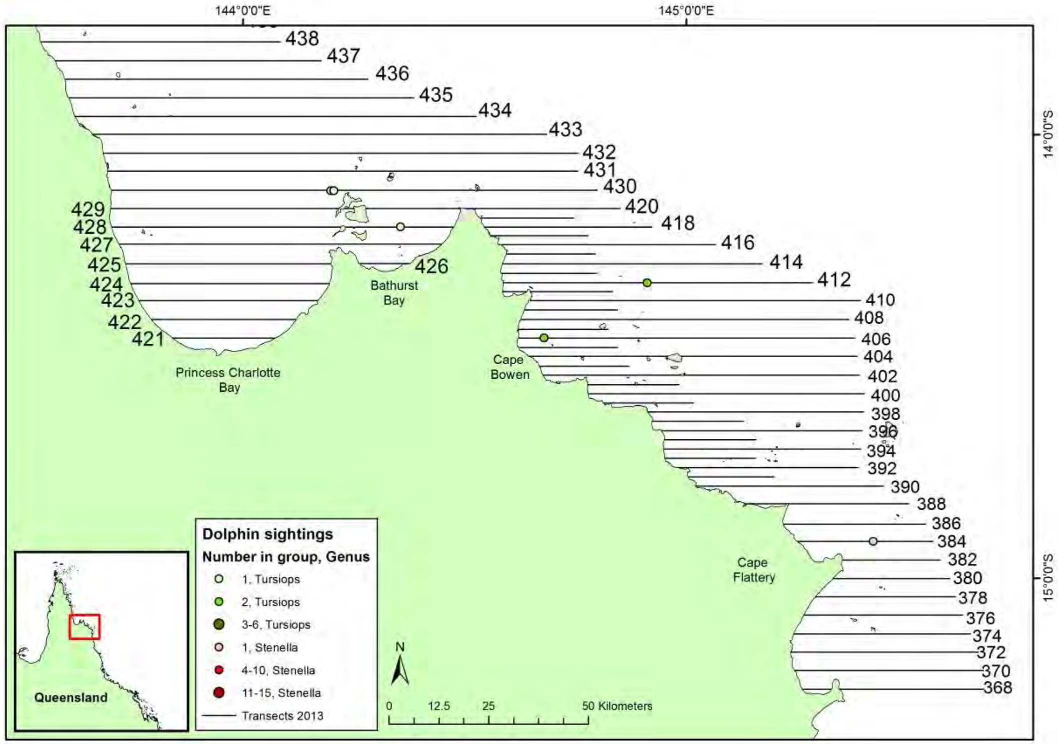


(b) GPS tracks of transects (three digit numbers) surveyed in the Northern Great Barrier Reef in November 2013 and the position and number of **turtles** sighted.

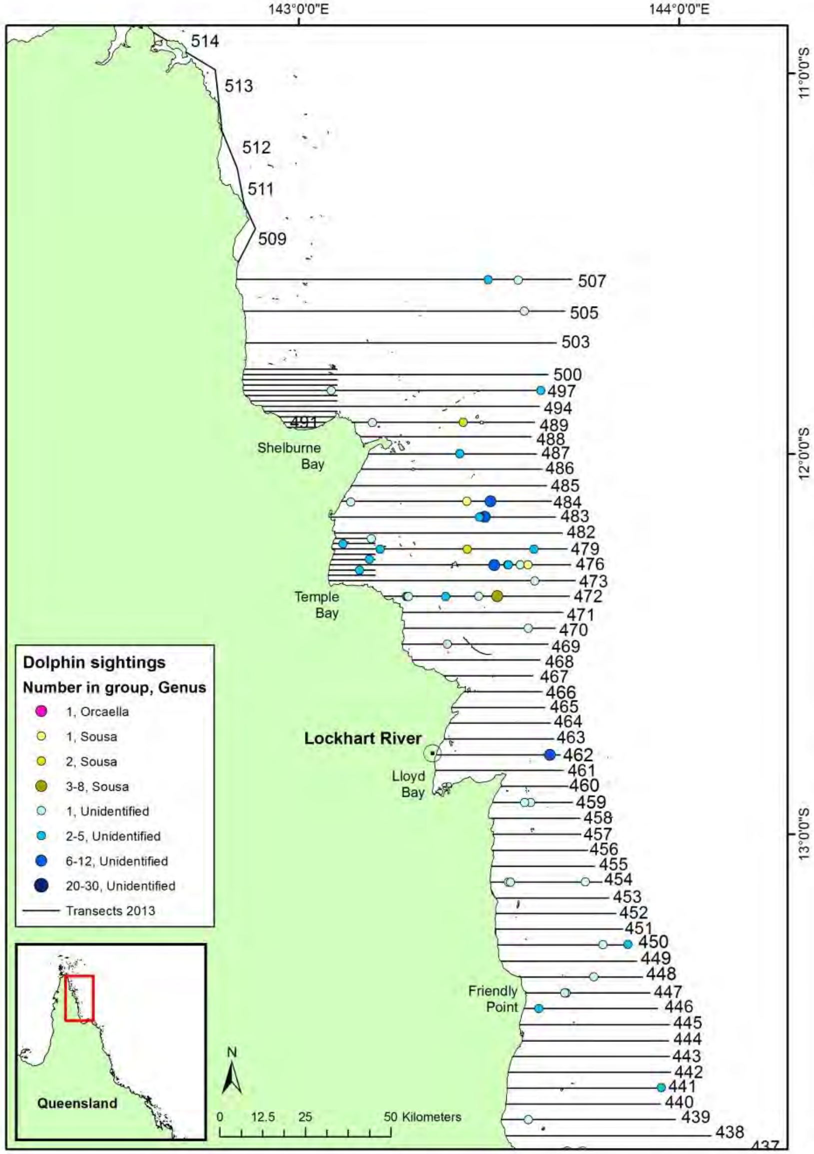


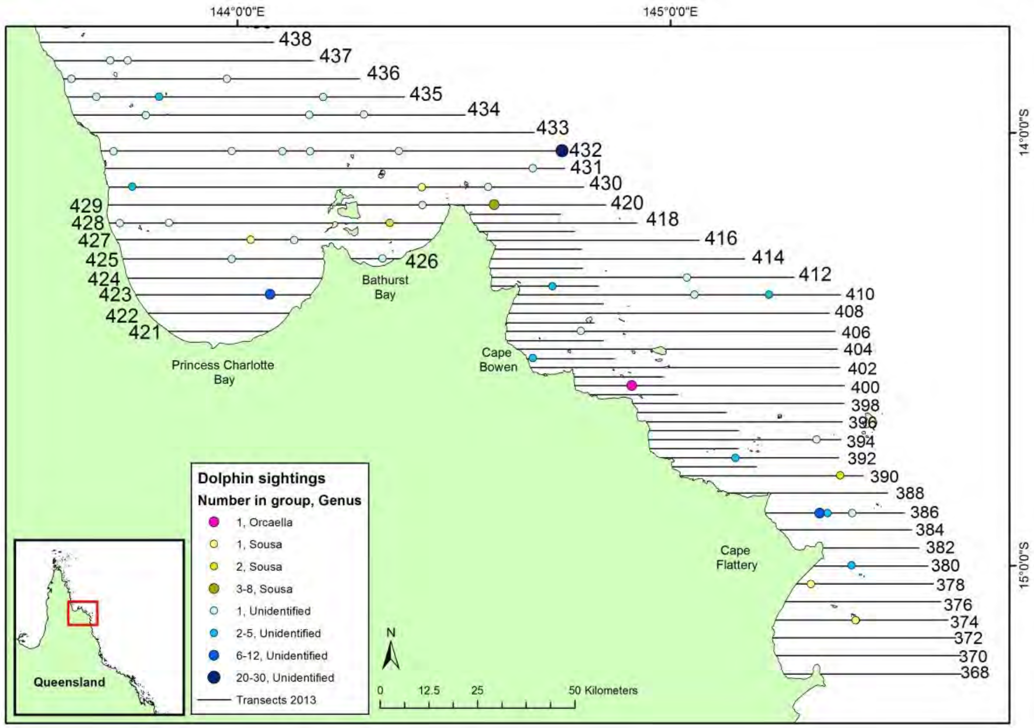
(c) GPS tracks of transects (three digit numbers) surveyed in the Northern Great Barrier Reef in November 2013 and the position and number of **dolphins (*Tursiops* and *Stenella* spp.)** sighted.



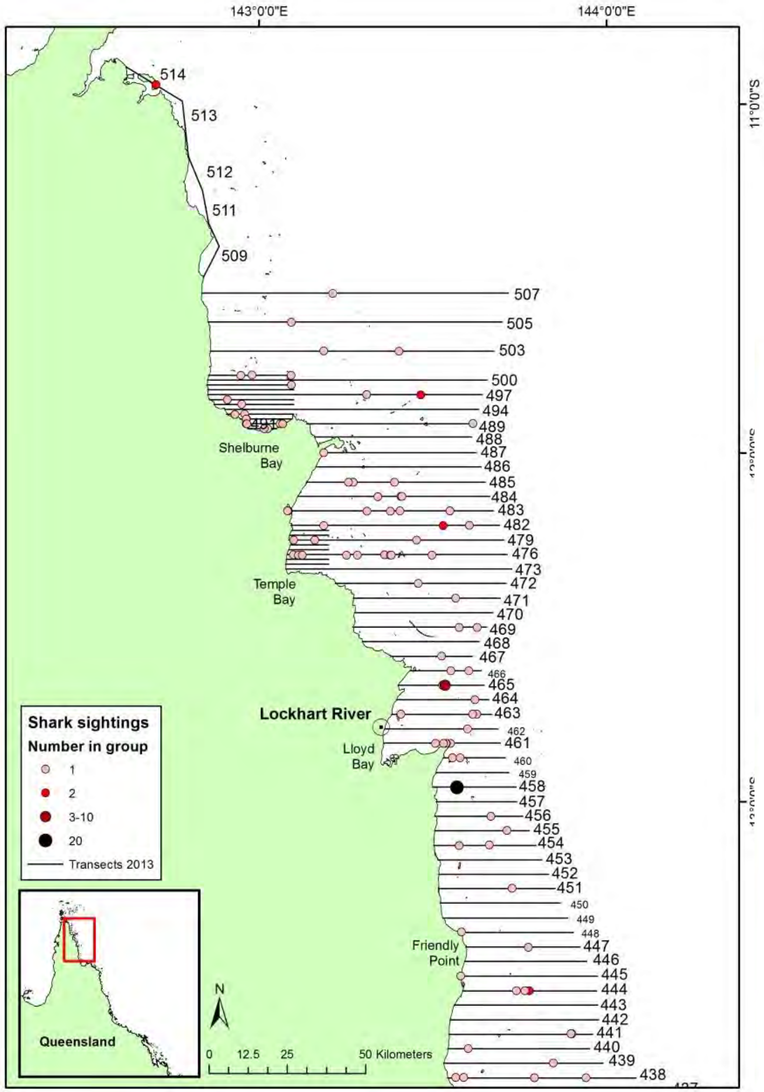


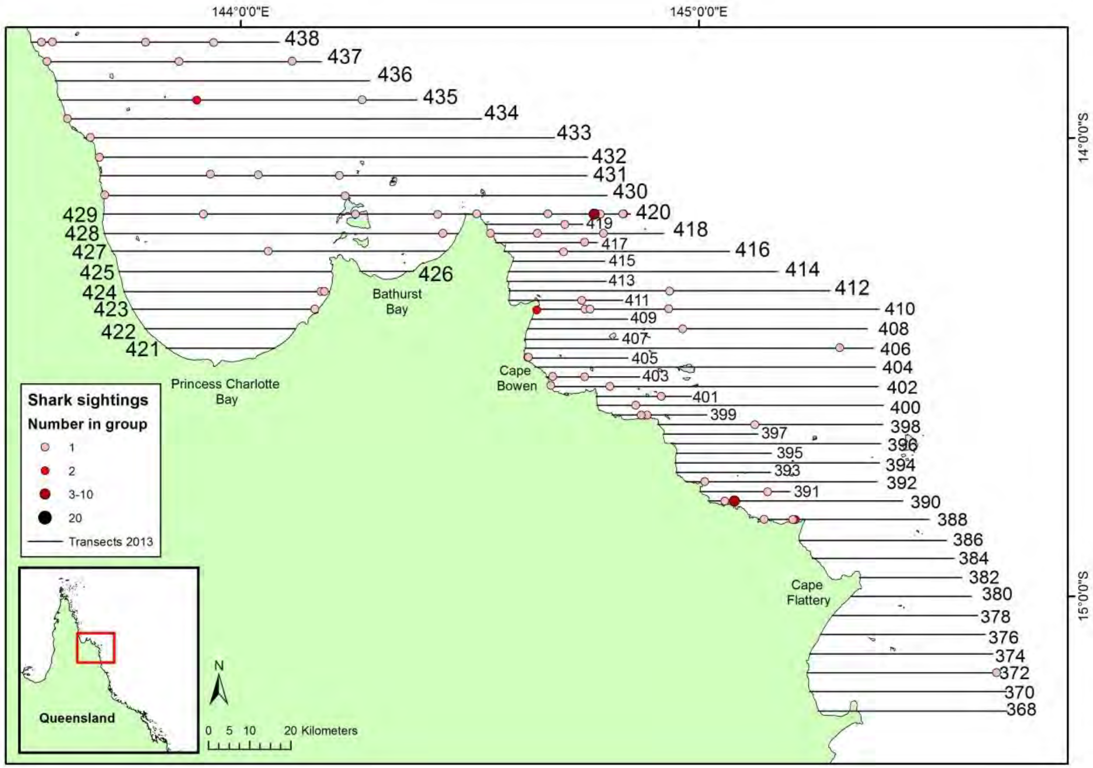
(d) GPS tracks of transects (three digit numbers) surveyed in the Northern Great Barrier Reef in November 2013 and the position and number of **dolphins (*Orcaella, Sousa, and unidentified species*)** sighted.



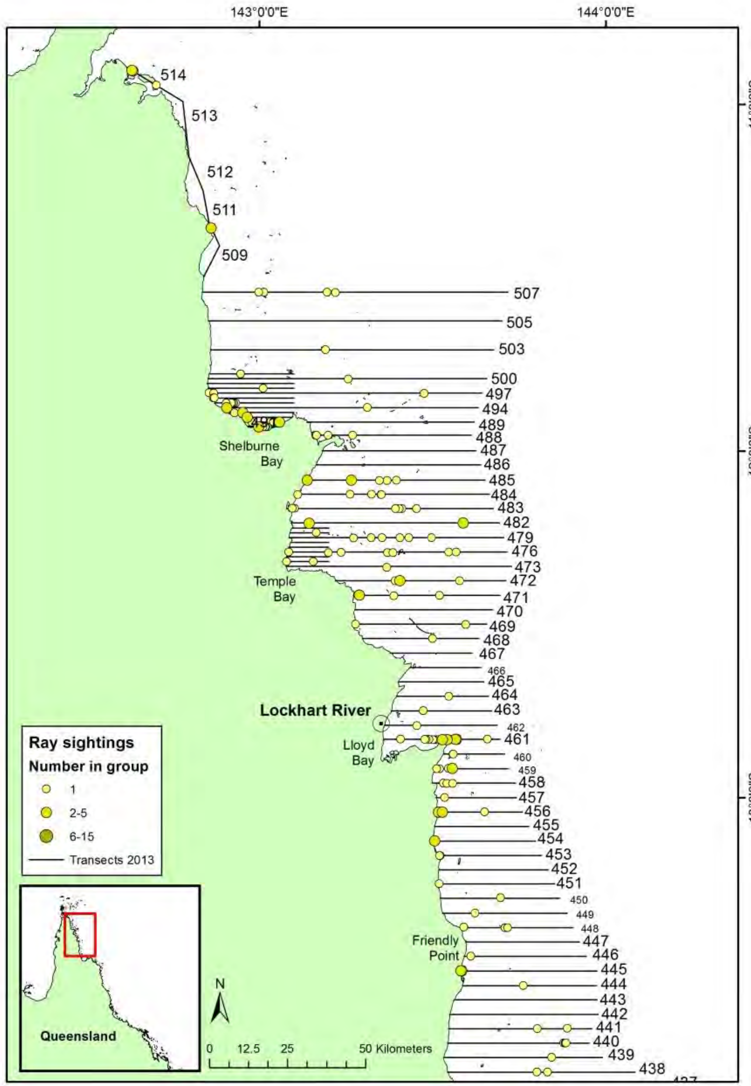


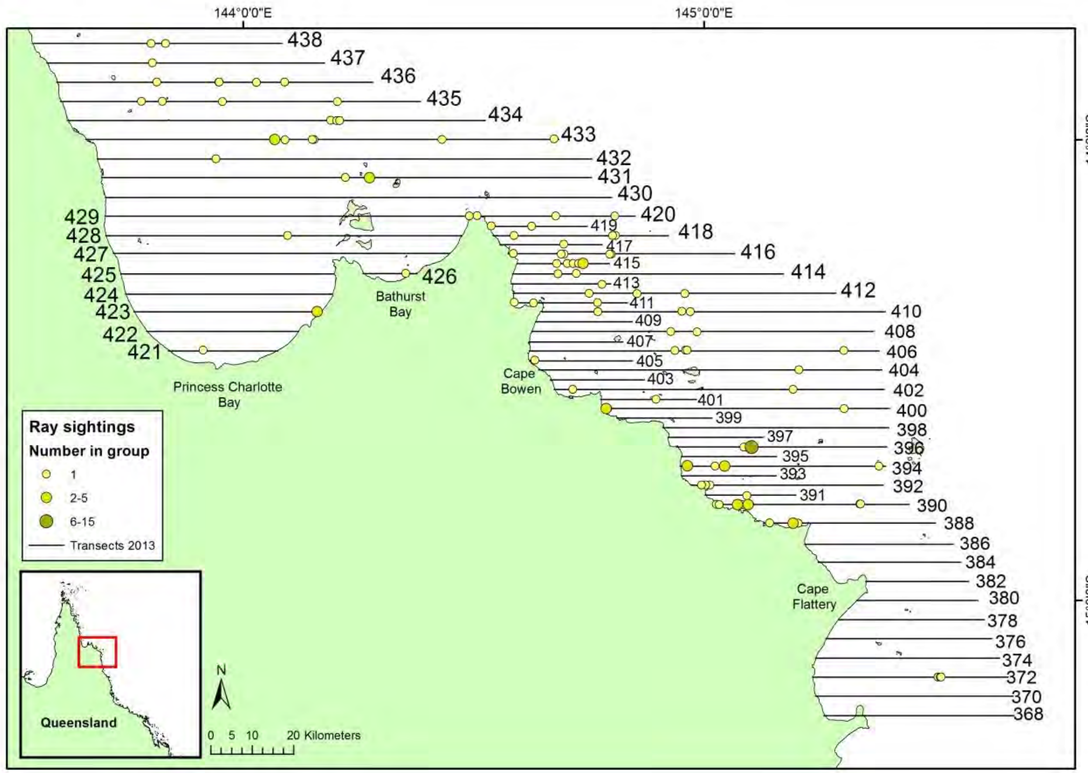
(e) GPS tracks of transects (three digit numbers) surveyed in the Northern Great Barrier Reef in November 2013 and the position and number of **sharks** sighted.



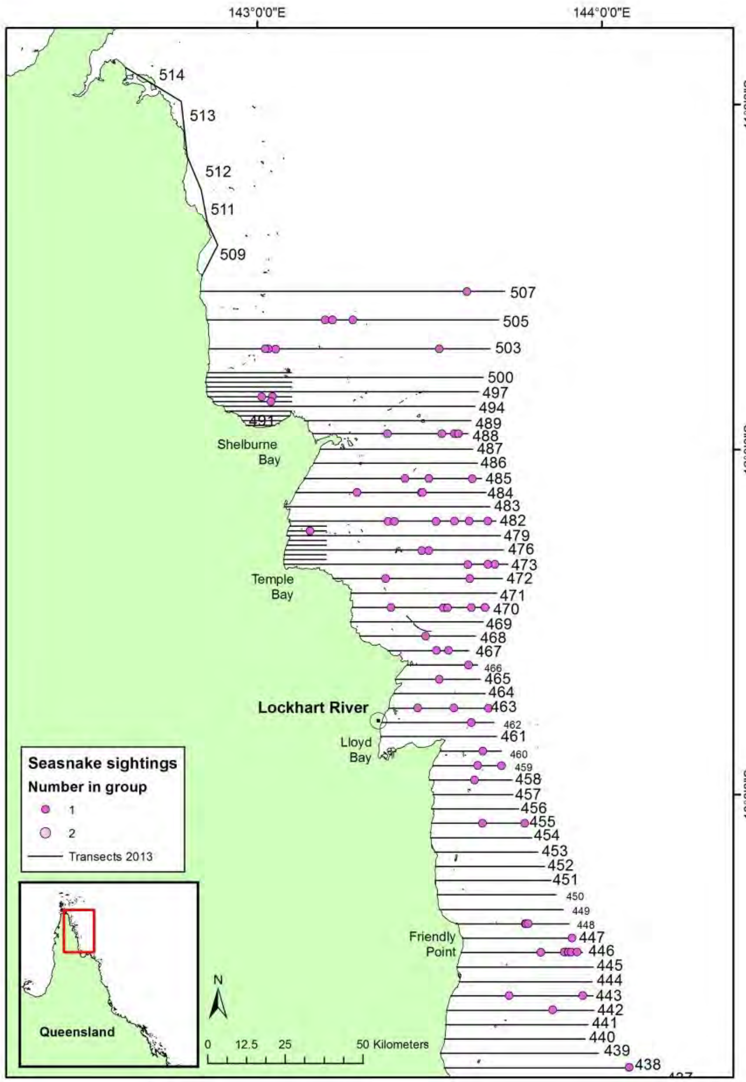


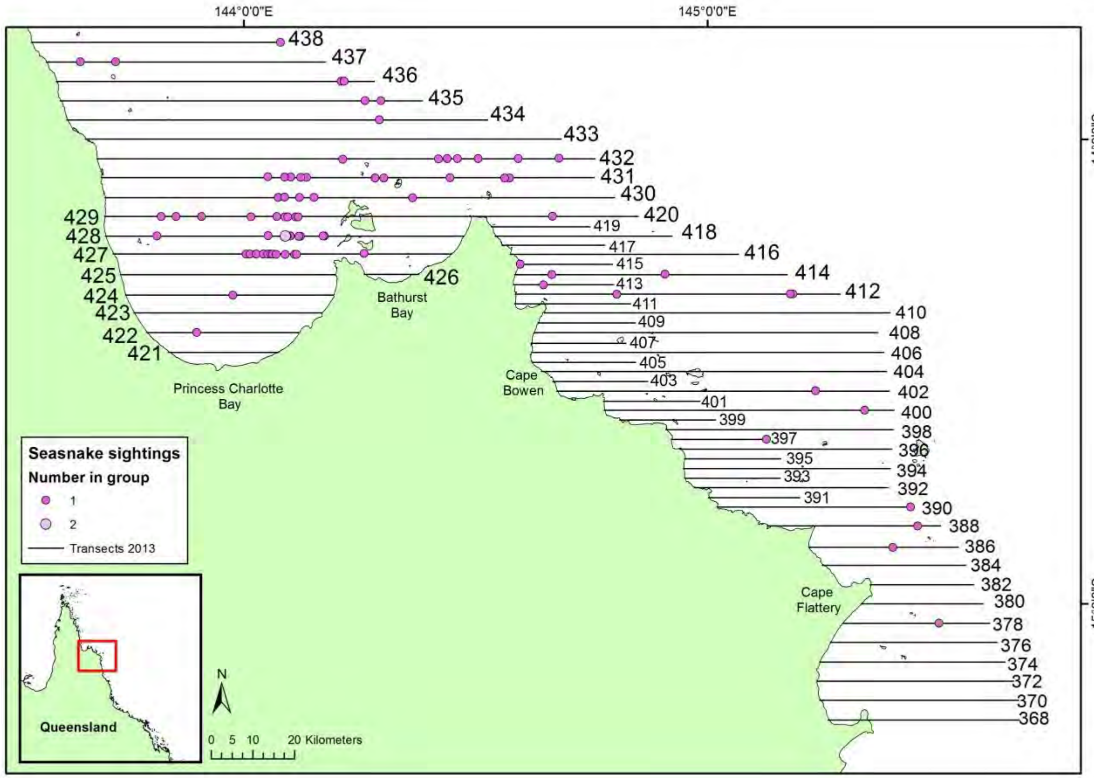
(f) GPS tracks of transects (three digit numbers) surveyed in the Northern Great Barrier Reef in November 2013 and the position and number of **rays** sighted.





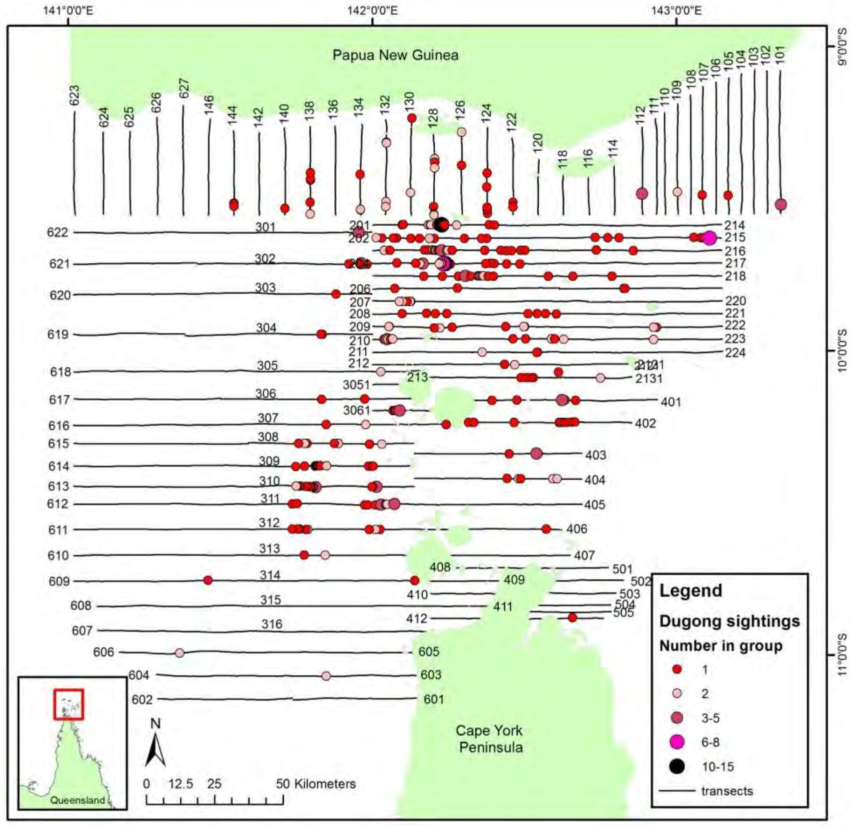
(g) GPS tracks of transects (three digit numbers) surveyed in the Northern Great Barrier Reef in November 2013 and the position and number of **seasnakes** sighted.



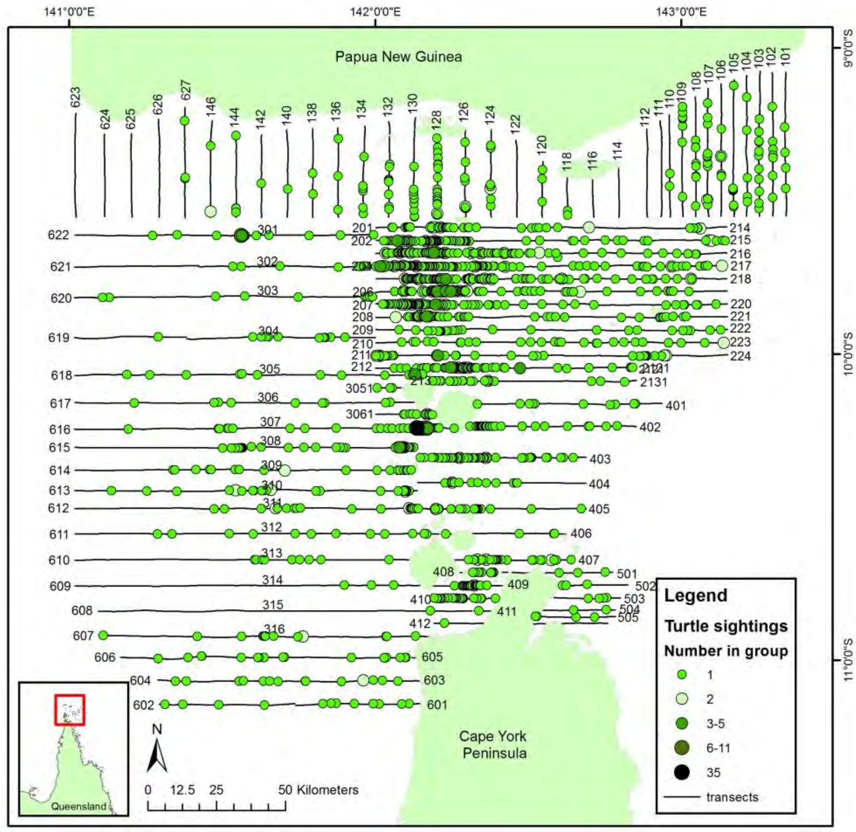


APPENDIX 5: Animal sightings in Torres Strait

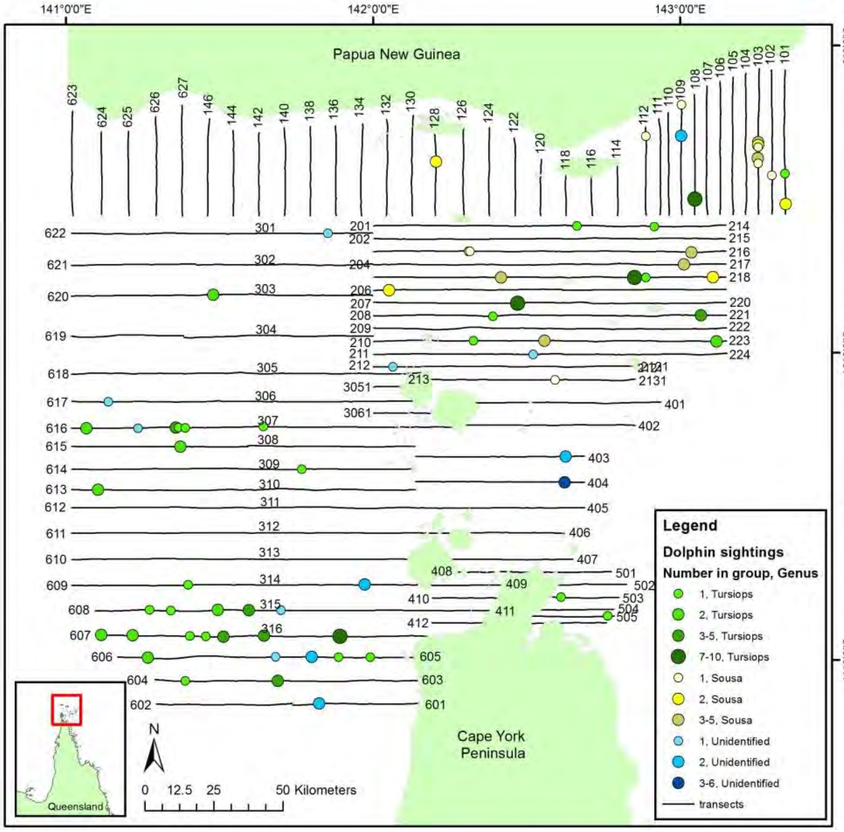
(a) GPS tracks of transects (three digit numbers) surveyed in the Torres Strait in November 2013 and the position and number of **dugongs** sighted.



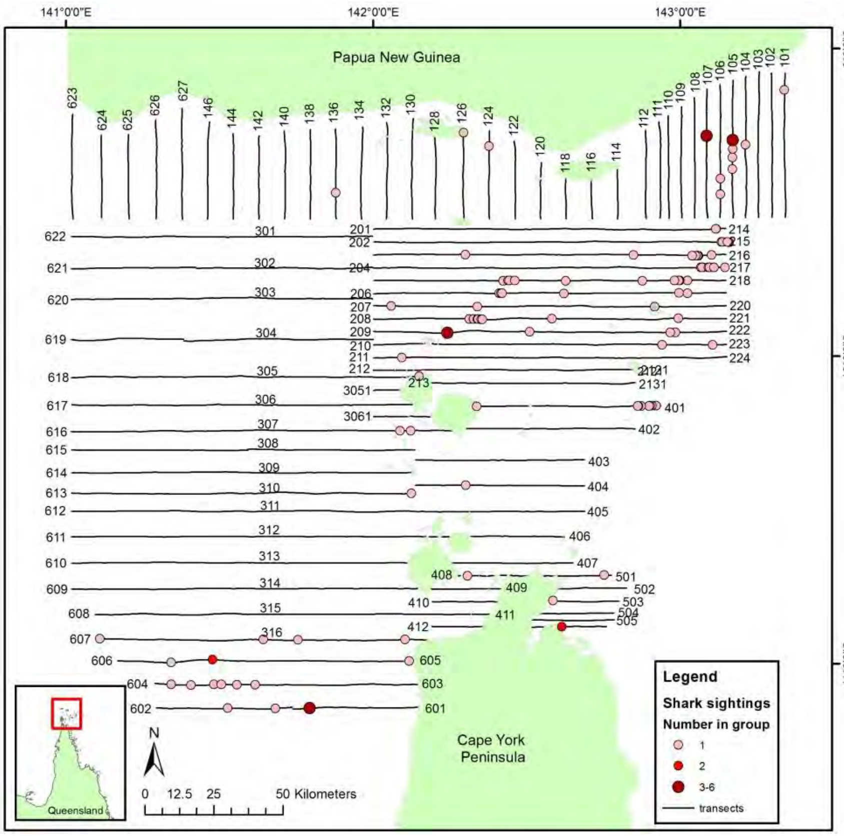
(b) GPS tracks of transects (three digit numbers) surveyed in the Torres Strait in November 2013 and the position and number of **turtles** sighted.



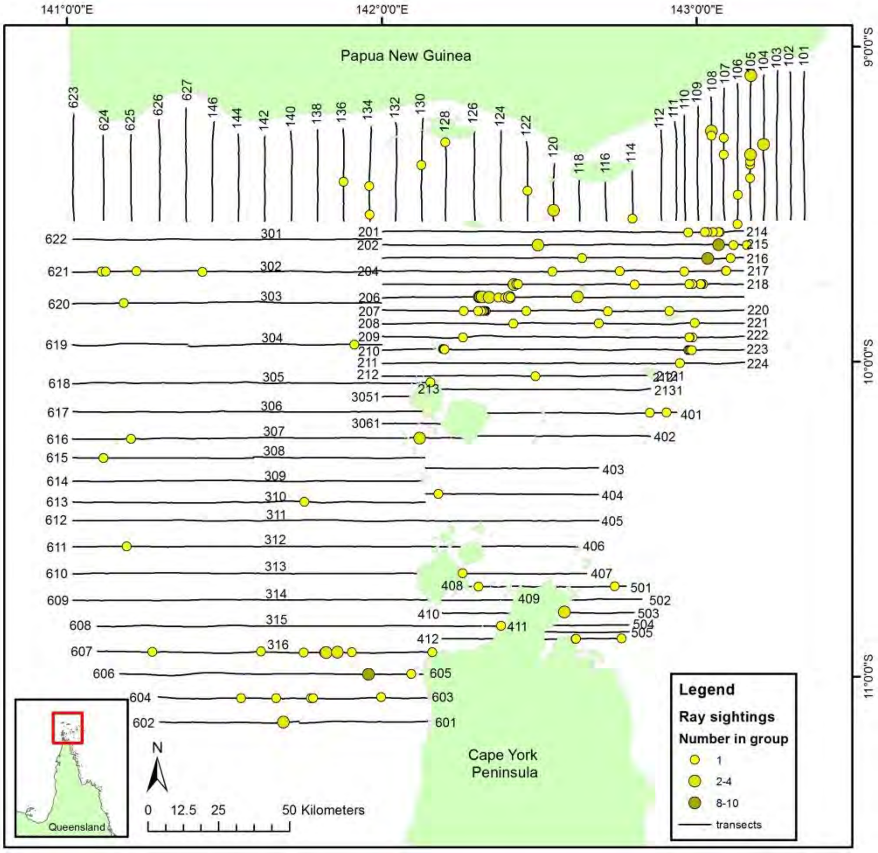
(c) GPS tracks of transects (three digit numbers) surveyed in the Torres Strait in November 2013 and the position and number of **dolphins** sighted.



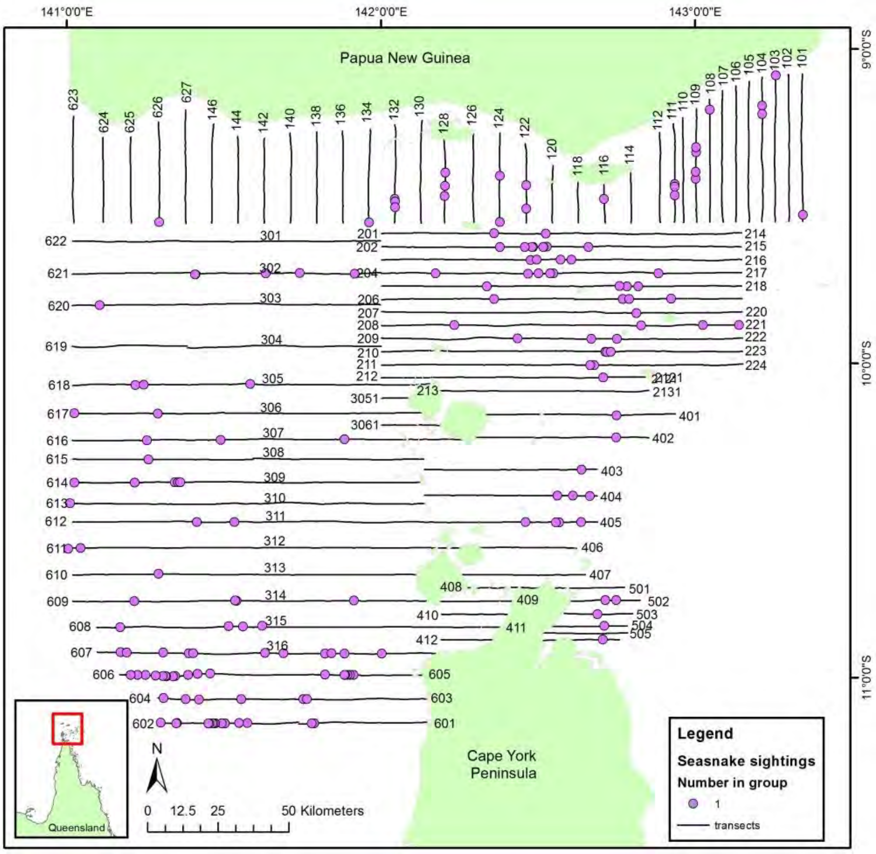
(d) GPS tracks of transects (three digit numbers) surveyed in the Torres Strait in November 2013 and the position and number of **sharks** sighted.



(e) GPS tracks of transects (three digit numbers) surveyed in the Torres Strait in November 2013 and the position and number of **rays** sighted.



(f) GPS tracks of transects (three digit numbers) surveyed in the Torres Strait in November 2013 and the position and number of **seasnakes** sighted.



APPENDIX 6: Results of log-linear models for a) the Northern Great Barrier Reef and b) Torres Strait.

a) Northern Great Barrier Reef				
	Estimate	**Std. Error**	**z value**	**Pr (>|z|)**
Intercept	0.585	0.046	12.745	<0.0001
Year 2006	-0.838	0.084	-10.027	<0.0001
Year 2013	-0.750	0.081	-9.245	<0.0001
Depth 5-<10	-0.700	0.076	-8.796	<0.0001
Depth 10-<15	-1.372	0.092	-14.899	<0.0001
Depth 15-<20	-3.306	0.223	-14.823	<0.0001
Depth ≥ 20	-3.711	0.132	-28.055	<0.0001
Year 2006 x Depth 5-<10	-0.456	0.163	-2.793	<0.01
Year 2013 x Depth 5-<10	-0.276	0.150	-1.837	0.06
Year 2006 x Depth 10-<15	0.665	0.145	4.595	<0.0001
Year 2013 x Depth 10-<15	-0.132	0.168	-0.786	0.43
Year 2006 x Depth 15-<20	1.889	0.267	7.072	<0.0001
Year 2013 x Depth 15-<20	1.260	0.288	4.381	<0.0001
Year 2006 x Depth ≥ 20	0.912	0.191	4.765	<0.0001
Year 2013 x Depth ≥ 20	-0.534	0.278	-1.920	0.05
b) Torres Strait				
	Estimate	**Std. Error**	**z value**	**Pr (>|z|)**
Intercept	-1.521	0.172	-8.872	<0.0001
Year 2006	0.585	0.214	2.731	<0.01
Year 2011	0.085	0.238	0.356	0.72
Year 2013	0.211	0.231	0.916	0.36
Depth 5-<10	0.101	0.206	0.492	0.62
Depth 10-<15	0.124	0.191	0.645	0.52
Depth ≥ 15	-1.298	0.227	-5.711	<0.0001
Year 2006 x Depth 5-<10	-0.133	0.259	-0.512	0.61
Year 2011 x Depth 5-<10	0.760	0.274	2.771	<0.01
Year 2013 x Depth 5-<10	0.380	0.271	1.400	0.16
Year 2006 x Depth 10-<15	-1.057	0.254	-4.158	<0.0001
Year 2011 x Depth 10-<15	-0.293	0.269	-1.088	0.28
Year 2013 x Depth 10-<15	0.317	0.254	1.245	0.21
Year 2006 x Depth ≥ 15	0.272	0.278	0.978	0.33
Year 2011 x Depth ≥ 15	-0.130	0.319	-0.407	0.68
Year 2013 x Depth ≥ 15	-0.086	0.308	-0.279	0.78

APPENDIX 7: Dugong aerial survey raw data

Raw data for sightings of dugongs for each transect in each block surveyed in November 2011. The raw data were used to estimate dugong population size (refer to Appendix Figures 4a and 5a for position of transects).

Transect	Average height/ transect	Transect length (km)	Transect area (km^2)	# dugongs/ transect
Northern Great Barrier Reef Block N1				
368	478	22.6	8.6	0
370	545	22.2	9.7	0
372	538	23.0	9.9	0
374	537	22.2	9.5	0
376	520	21.3	8.9	0
378	525	21.7	9.1	0
380	493	20.8	8.2	0
382	510	20.9	8.5	0
384	520	25.4	10.6	0
386	510	23.0	9.4	0
Northern Great Barrier Reef Block N2				
388	550	12.9	5.7	1
390	570	21.9	10.0	13
391	513	20.7	8.5	10
392	500	20.7	8.3	6
393	523	22.0	9.2	5
394	500	22.1	8.8	1
395	468	22.1	8.3	1
396	545	23.0	10.0	0
397	545	22.0	9.6	1
398	500	22.2	8.9	6
399*	505	19.7	8.0	20
400	520	22.4	9.3	9
401	540	22.2	9.6	2
Northern Great Barrier Reef Block N3				
402	503	22.8	9.2	52
403	527	21.8	9.2	1
404	505	33.3	13.4	15
405	510	23.9	9.8	4
406	537	22.4	9.6	0
407	513	22.0	9.0	0
408	510	22.2	9.0	2
409	527	22.6	9.5	0
410	530	22.4	9.5	2
411	544	26.7	11.6	2
412	537	23.7	10.2	1
413	537	23.2	10.0	6
414	543	22.4	9.7	2
415	530	21.6	9.2	1
416	510	23.2	9.5	0
417	528	23.8	10.1	0
418	520	24.1	10.0	2
419	540	22.9	9.9	1

420	500	25.3	10.1	0
Northern Great Barrier Reef Block N4				
368	490	21.5	8.4	0
370	493	23.4	9.2	0
372	525	22.5	9.5	0
374	517	20.5	8.5	0
376	530	17.4	7.4	0
378	525	12.3	5.2	0
380	500	7.3	2.9	0
382	480	2.9	1.1	0
384	520	7.5	3.1	0
386	550	11.4	5.0	0
388	505	27.0	10.9	0
390	530	23.5	10.0	1
392	517	23.5	9.7	2
394	503	25.7	10.3	5
396	523	25.7	10.8	5
398	495	30.4	12.1	2
400	492	44.8	17.6	0
402	505	54.3	21.9	1
404	533	42.9	18.3	2
406	522	59.3	24.8	10
408	505	57.6	23.3	5
410	533	58.4	24.9	1
412	523	51.9	21.7	3
414	538	41.0	17.6	0
416	537	29.7	12.8	0
418	513	16.8	6.9	0
420	500	12.7	5.1	0
Northern Great Barrier Reef Block N5				
421	510	25.3	10.3	2
422	527	35.5	15.0	0
423	526	43.8	18.4	5
424	524	48.5	20.3	0
425	515	50.1	20.6	0
426	510	12.4	5.1	6
427	514	78.8	32.4	5
428	602	83.4	40.1	5
429	508	86.5	35.2	2
430	512	118.5	48.5	4
431	515	114.8	47.2	0
432	528	116.0	49.0	3
433	515	110.8	45.7	3
434	521	97.9	40.8	9
435	513	84.3	34.6	12
436	516	74.1	30.6	10
437	526	65.0	27.4	6
438	510	58.5	23.9	3
439	508	49.6	20.1	1
440	510	44.1	18.0	2
441	506	44.6	18.1	2
442	528	46.3	19.6	0
443	508	44.7	18.1	1
444	525	41.7	17.5	2

		Northern Great Barrier Reef Block N6		
445	500	10.3	4.1	1
446	520	10.8	4.5	8
447	500	11.2	4.5	0
448	530	9.4	4.0	1
449	520	13.4	5.6	7
450	534	13.7	5.9	0
451	535	13.0	5.5	1
452	545	8.4	3.7	1
453	500	8.1	3.2	1
		Northern Great Barrier Reef Block N7		
445	516	32.6	13.4	0
446	533	27.3	11.6	2
447	518	24.5	10.1	0
448	530	25.6	10.8	0
449	505	25.3	10.2	0
450	503	23.7	9.6	0
451	520	23.4	9.7	0
452	543	25.8	11.2	0
453	504	24.3	9.8	0
		Northern Great Barrier Reef Block N8		
454	520	8.5	3.5	0
455	500	7.6	3.0	0
456	540	8.2	3.6	8
457	500	7.0	2.8	2
458	515	9.6	4.0	2
459	540	7.1	3.1	1
460	520	4.6	1.9	0
461	490	23.5	9.2	1
462	504	22.2	9.0	14
463	500	17.6	7.0	1
464	505	9.9	4.0	0
465	500	7.2	2.9	0
466	500	1.8	0.7	0
467	500	6.1	2.4	0
468	510	9.5	3.9	2
469	500	11.6	4.6	1
470	676	8.0	4.3	0
471	500	5.2	2.1	2
472	528	9.7	4.1	0
473	540	9.4	4.1	1
476	500	6.8	2.7	7
479	500	4.0	1.6	0
482	500	1.3	0.5	0
		Northern Great Barrier Reef Block N9		
454	495	23.5	9.3	0
455	505	21.7	8.8	0
456	503	19.2	7.7	0
457	500	18.1	7.2	0
458	500	16.4	6.5	0
459	495	15.8	6.2	0
460	500	14.7	5.9	0
461	520	13.1	5.5	0
462	490	13.2	5.2	0

463	505	13.8	5.6	0
464	520	19.0	7.9	0
465	503	19.7	7.9	0
466	500	20.4	8.2	0
467	503	19.4	7.8	0
468	503	27.2	10.9	0
469	528	30.3	12.8	0
470	505	35.5	14.3	0
471	500	40.8	16.3	0
472	516	43.6	18.0	0
473	536	48.0	20.6	0
476	505	49.4	19.9	1
479	508	51.1	20.8	2
482	529	52.5	22.2	0
Northern Great Barrier Reef Block N10				
483	500	12.6	5.0	1
484	520	12.7	5.3	0
485	500	8.2	3.3	2
486	552	7.2	3.2	0
487	500	7.8	3.1	1
488	525	8.4	3.5	0
489	500	5.4	2.2	0
Northern Great Barrier Reef Block N11				
490	515	8.5	3.5	0
491	500	12.2	4.9	1
492	517	16.0	6.6	3
493	508	21.0	8.5	3
494	513	21.6	8.9	1
495	500	25.0	10.0	3
496	513	26.4	10.8	1
497	500	26.9	10.8	0
498	498	27.0	10.8	0
499	527	27.4	11.5	0
500	526	27.0	11.4	0
501	508	26.9	10.9	0
Northern Great Barrier Reef Block N12				
503	510	15.1	6.1	0
505	505	11.6	4.7	0
507	510	11.4	4.7	1
Northern Great Barrier Reef Block N13				
483	510	52.2	21.3	0
484	520	47.7	19.8	0
485	526	48.0	20.2	0
486	510	44.7	18.2	0
487	526	40.6	17.1	0
488	523	40.8	17.0	0
489	511	47.2	19.3	0
494	505	58.2	23.5	0
497	507	59.4	24.1	0
500	518	60.7	25.1	0
503	506	74.3	30.1	0
505	504	80.9	32.6	0
507	511	85.2	34.8	0

Northern Great Barrier Reef Block N14				
473	540	13.4	5.8	2
474	530	13.5	5.7	2
475	550	13.2	5.8	4
476	500	12.9	5.2	2
477	510	12.4	5.1	0
478	510	12.0	4.9	0
479	500	12.4	5.0	0
480	500	12.2	4.9	0
481	525	11.6	4.9	0
482	507	11.8	4.8	0
Northern Great Barrier Reef Block N15				
509	490	11.2	4.4	0
510	513	7.9	3.2	0
511	555	10.5	4.7	0
512	517	11.6	4.8	0
513	530	17.9	7.6	0
514	550	20.9	9.2	0
Torres Strait Block 0				
136	506	32.4	13.1	0
138	498	32.2	12.8	6
140	506	31.6	12.8	1
142	503	29.8	12.0	0
144	503	30.7	12.3	3
146	497	35.0	13.9	0
Torres Strait Block 1A				
101	519	52.0	21.6	3
102	511	51.8	21.2	0
103	524	52.4	21.9	0
104	524	51.0	21.4	0
105	521	49.5	20.6	1
106	506	47.9	19.4	0
107	511	46.4	19.0	1
108	512	43.2	17.7	0
109	507	40.0	16.2	2
110	493	36.9	14.6	0
Torres Strait Block 1B				
111	502	34.6	13.9	0
112	514	31.7	13.0	3
114	533	18.0	7.7	0
116	517	13.8	5.7	0
118	523	14.5	6.1	0
120	527	20.1	8.5	0
122	501	27.9	11.2	2
124	522	31.7	13.2	5
126	494	31.7	12.5	3
128	507	29.5	11.9	10
130	519	36.1	15.0	3
132	530	34.6	14.7	7
134	506	33.1	13.4	4
Torres Strait Block 2A				
201	505	67.2	27.2	38
202	508	67.2	27.3	13

203	504	67.2	27.1	30
204	498	67.4	26.9	56
205	506	67.3	27.2	21
206	501	67.4	27.0	2
207	497	67.5	26.9	8
208	498	67.5	26.9	8
209	500	67.5	27.0	13
210	499	65.7	26.2	18
211	495	67.5	26.8	4
212	504	67.7	27.3	3
213	499	47.2	18.8	6
3051	510	9.6	3.9	0
3061	507	20.5	8.3	11
Torres Strait Block 2B				
214	512	58.7	24.0	0
215	515	58.6	24.1	14
216	506	58.5	23.7	2
217	512	58.6	24.0	0
218	510	58.6	23.9	2
219	506	58.5	23.7	4
220	511	58.5	23.9	0
221	506	58.6	23.7	0
222	516	58.4	24.1	3
223	507	58.6	23.7	4
224	512	58.5	24.0	0
2121	504	24.9	10.1	0
2131	493	25.7	10.1	3
Torres Strait Block 3				
301	501	45.7	18.3	3
302	501	63.1	25.3	5
303	512	63.0	25.8	1
304	509	67.7	27.6	2
305	516	84.7	34.9	2
306	500	68.8	27.5	2
307	518	83.2	34.4	4
308	516	59.6	24.6	10
309	514	58.5	24.0	23
310	516	59.8	24.7	24
311	508	59.7	24.3	19
312	566	67.9	30.7	11
313	528	57.5	24.3	3
314	546	61.2	26.7	1
315	503	65.2	26.2	0
316	521	65.3	27.2	0
Torres Strait Block 4				
401	517	66.5	27.5	8
402	518	60.7	25.2	9
403	508	60.2	24.5	5
404	505	60.2	24.3	8
405	506	60.4	24.4	0
406	503	43.8	17.6	1
407	510	43.3	17.7	0
Torres Strait Block 5				
408	514	26.2	10.8	0

409	533	25.7	11.0	0
410	540	23.7	10.2	0
411	523	21.2	8.9	0
412	523	18.3	7.6	0
501	510	25.3	10.3	0
502	513	24.6	10.1	0
503	524	25.5	10.7	0
504	514	26.3	10.8	0
505	507	29.6	12.0	0
506	503	26.8	10.8	1
		Torres Strait Block 6		
623	495	37.6	14.9	0
624	500	29.8	11.9	0
625	500	30.3	12.1	0
626	508	35.6	14.4	0
627	498	39.9	15.9	0
		Torres Strait Block 7		
616	516	53.0	21.9	0
617	507	52.9	21.4	0
618	513	40.0	16.4	0
619	509	40.2	16.4	0
620	503	44.8	18.0	0
621	515	44.5	18.3	0
622	517	62.0	25.6	0
		Torres Strait Block 8		
607	521	54.4	22.7	0
608	507	54.6	22.1	0
609	508	63.0	25.6	1
610	513	62.9	25.8	0
611	516	63.0	26.0	0
612	512	62.9	25.7	0
613	503	62.8	25.3	0
614	516	62.9	25.9	0
615	514	62.8	25.8	0
		Torres Strait Block 9		
601	495	44.8	17.7	0
602	493	48.5	19.1	0
603	508	45.8	18.6	2
604	542	47.7	20.7	0
605	506	52.9	21.4	0
606	531	52.9	22.5	2

*In addition, one herd was sighted with 49 dugongs.

APPENDIX 8: Details of correction factors

Details of correction factors used in the population estimates for dugongs on the data collected in November 2013. The estimate for the Availability Bias was used for the Marsh and Sinclair (1989a) method only.

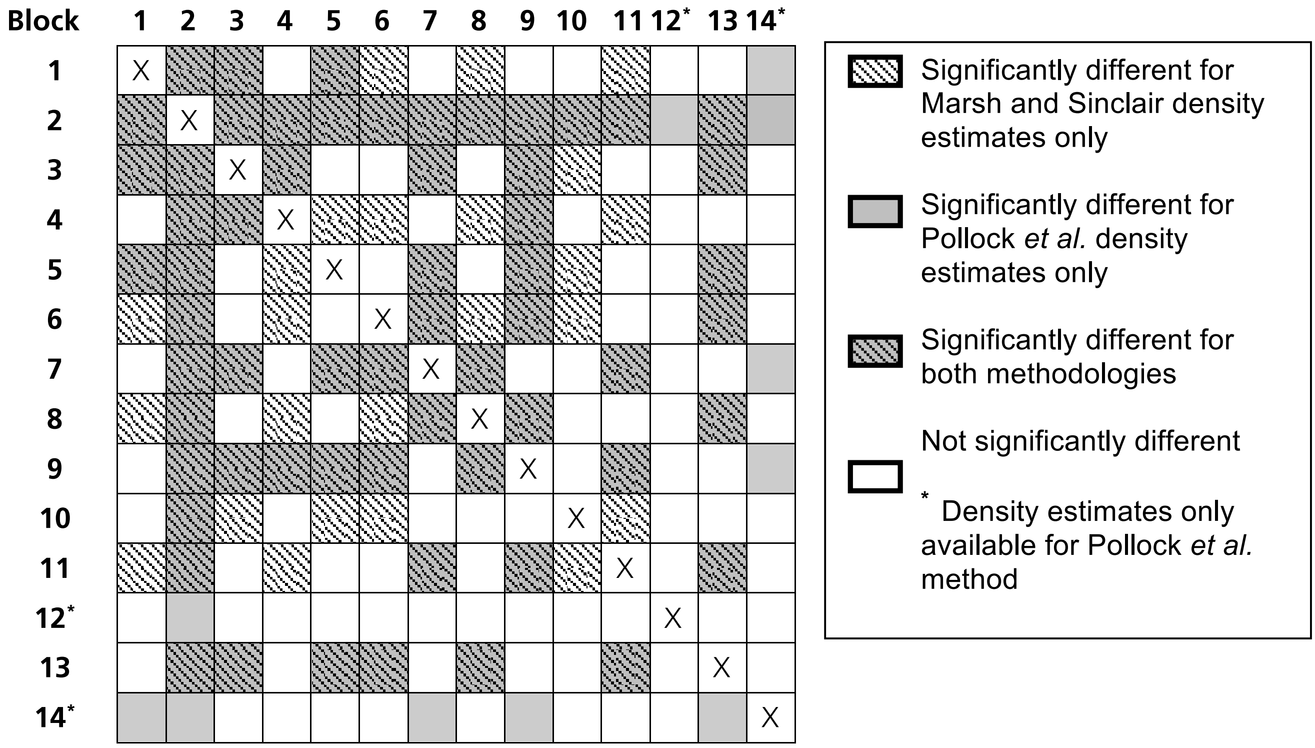
Block	Mean group size (C.V.)[1]	Perception correction factor (C.V.)[2]		Availability correction factor (C.V.)
		Port	Starboard	
Northern Great Barrier Reef				
N2	1.27 (0.07)	1.113 (0.019)	1.053 (0.008)	3.332 (0.112)
N3	1.65 (0.11)			
N4	1.32 (0.08)			
N5	1.2 (0.05)			
N6	1.25 (0.12)			
N8	1.5 (0.18)			
N11	1.09 (0.08)			
N14	1 (0)			
Torres Strait				
0	1.11 (0.1)	Team 1:		5.897 (0.102)
1B	1.42 (0.08)	1.009 (0.005)	1.048 (0.023)	
2A	1.54 (0.08)	Team 2:		
2B	1.6 (0.22)	1.010 (0.002)	1.003 (0.001)	
3	1.43 (0.07)	Team 3:		
4	1.29 (0.1)	1.113 (0.019)	1.053 (0.008)	

[1] excluding herds
[2] Torres Strait was surveyed by all three teams and therefore different perception correction factors applied to individual transects (see main text Table 2 for an overview of which transects were flown by which team).

APPENDIX 9: Results of unplanned comparisons of dugong densities in individual blocks

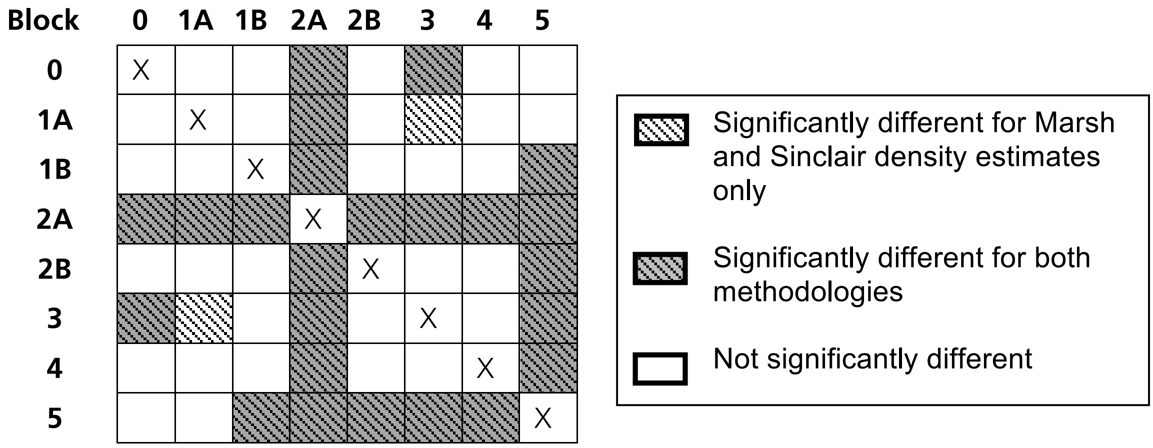
in (a) the Northern Great Barrier Reef and (b) Torres Strait estimated using the Marsh and Sinclair (1989) and Pollock *et al.* (2006) methodologies.

(a) Northern Great Barrier Reef



* Blocks 12 and 14 had to be excluded from the Marsh and Sinclair analysis since they were not sufficiently surveyed in the earlier years (before 2000). Note one in 20 of these comparisons is likely to be significant by chance alone.

(b) Torres Strait



Note: Block 1A was surveyed with double survey intensity from 2011 onwards. Since only transects were included in the analysis that were surveyed in every year, every second transect for Block 1A from 2011 onwards was excluded from the density analyses. This approach resulted in the loss of every dugong sighting in block 1A in 2013. Note one in 20 of these comparisons is likely to be significant by chance alone.